IUCAA

INTER-UNIVERSITY CENTRE FOR ASTRONOMY AND ASTROPHYSICS

(An Autonomous Institution of the University Grants Commission)

Annual Report

(April 1, 2008 - March 31, 2009)

Editor

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IUCAA

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HIGHLIGHTS OF 2008- 2009

This annual report covers the activities of IUCAA during its twenty-first year, April 2008 - March 2009. The endeavours of IUCAA span different fronts, as outlined in the pages of this Report. Here is a quick summary and highlights.

IUCAA has an academic strength of 17 core faculty members (academic), 12 post-doctoral fellows and 28 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 20-60. The publications of the IUCAA members, numbering to about 55 in the current year are listed in pages 84-86. IUCAA members also take part in pedagogical activities like lectures, seminars, popularisation of science, etc., the details of which are given in pages 92 - 94 and 123-126 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 61-78 of this report highlights their research contributions. The resulting publications, numbering to about 99 are listed in pages 87-91 of this report. A total of about 1012 person-days were spent by Visiting Associates at IUCAA during this year. In addition, IUCAA was acting as host to about 545 visitors through the year. During the current year the Visiting Associates were drawn from 66 universities and colleges from all over India. The visitors to IUCAA came from over 130 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, three students have successfully defended their theses and obtained Ph.D. degree from the University of Pune during the year 2008 -2009. Summary of their theses appears in pages 79- 83.

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 13 such events in IUCAA and 2 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. 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, more than 5000 people visited IUCAA.

These activities were ably supported by the scientific and technical, and administrative staff (25 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 127-135 of this Report.

Swara Ravindranath
Editor

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The Council and the Governing Board

The Council

(As on March 31, 2009)

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*),
Chairman, Department of Atomic Energy,
Mumbai.

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

Sanjeev Dhurandhar,
IUCAA, Pune.

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

Narendra Jadhav,
Vice-Chancellor,
University of Pune.

Vijay Khole,
Vice-Chancellor,
University of Mumbai.

G. Madhavan Nair,
Chairman,
Indian Space Research Organization,
Bangalore.

Rajaram Nityananda,
Centre Director,
National Centre for Radio Astrophysics,
Pune.

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

Amitava Raychaudhuri,
Director,
Harish-Chandra Research Institute,
Allahabad.

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

Ajay K. Sood,
Indian Institute of Science,
Bangalore.

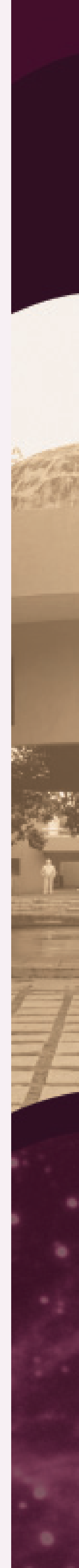
The following members have served on the Council for part of the year

Amarjyoti Choudhury,
Vice-Chancellor,
Gauhati University,
Guwahati.

Jishnu Dey,
Presidency College,
Kolkata.

J.N. Goswami,
Director,
Physical Research Laboratory,
Ahmedabad.

Arun Grover,
Tata Institute of Fundamental Research,
Mumbai.



Mushirul Hasan,
Vice-Chancellor,
Jamia Millia Islamia,
New Delhi.

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

Nagnath Kottapalle,
Vice-Chancellor,
Dr. Babasaheb Ambedkar Marathwada University,
Aurangabad.

Shyam Lal,
Vice-Chancellor,
Patna University.

O.K. Medhi,
Vice-Chancellor,
Gauhati University,
Guwahati.

K. Ramamurthy Naidu,
Banjara Hills, Hyderabad.

Mool Chand Sharma,
Vice-Chairman,
University Grants Commission,
New Delhi.

Raju Sharma,
Secretary,
University Grants Commission,
New Delhi.

The following members have been inducted in the Council during this year

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

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

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

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

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.

M. Sami,
Jamia Millia Islamia,
New Delhi.

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

Member Secretary

Naresh Dadhich,
Director, IUCAA, Pune.

The Governing Board

(As on March 31, 2009)

Chairperson

Anil Kakodkar

Members

Sanjeev Dhurandhar
S.S. Hasan
Narendra Jadhav
Vijay Khole
Rajaram Nityananda
Amitava Raychaudhuri
R.C. Sobti
Ajay K. Sood

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

K. Ramamurthy Naidu
Raju Sharma

The following member has been inducted on the Governing Board during the year

R.K. Chauhan

Member Secretary

Naresh Dadhich

Honorary Fellows

Geoffrey Burbidge,
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.

Jurgen Ehlers, [*Expired on May 20, 2008*]
Max-Planck Institute for Gravitational Physics,
Golm, Germany.

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 Institute of Washington, USA.

P.C. Vaidya,
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, 2009)

The Scientific Advisory Committee (SAC)

Abhay Ashtekar,
Center for Gravitation, Physics and Geometry,
The Pennsylvania State University, USA.

Naresh Dadhich (Convener),
IUCAA, Pune.

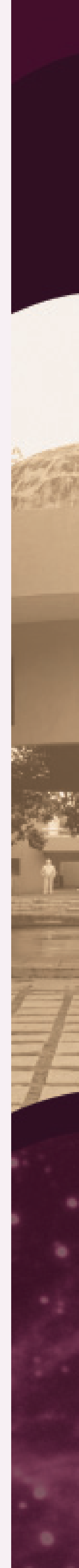
The following members have served on SAC till December 31, 2008

Rohini Godbole,
Centre for Theoretical Studies,
Indian Institute of Science,
Bangalore.

John Hearnshaw,
University of Canterbury,
Christchurch, New Zealand.

Umesh C. Joshi,
Physical Research Laboratory,
Ahmedabad.

Alain Omont,
Institut d’Astrophysique de Paris,
France.



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

T.P. Prabhu,
Indian Institute of Astrophysics,
Bangalore.

Ashoke Sen,
Harish-Chandra Research Institute,
Allahabad.

The following members have been inducted into SAC from January 1, 2009

P.C. Agrawal,
Tata Institute of Fundamental Research,
Mumbai.

Deepak Dhar,
Tata Institute of Fundamental Research,
Mumbai.

Andrew C. Fabian,
Institute of Astronomy,
University of Cambridge, UK.

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,
Astrophysics Institute, Potsdam,
Germany.

The Users' Committee

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

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

A.K. Kembhavi (Convener),
IUCAA, Pune.

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

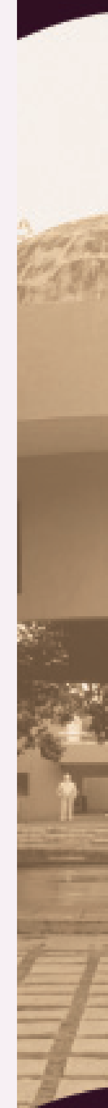
Naresh K. Dadhich (Chairperson)
T. Padmanabhan (Convener)
Joydeep Bagchi
Dipankar Bhattacharya
Gulab Chand Dewangan (from 01.05.2008)
Sanjeev V. Dhurandhar
Ranjan Gupta
Ajit K. Kembhavi
Ranjeev Misra
Maulik Parikh
A.N. Ramaprakash
Swara Ravindranath
Varun Sahni
Tarun Souradeep
R. Srianand
Kandaswamy Subramanian
Shyam N. Tandon

The Standing Committee for Administration

N.K. Dadhich (Chairperson)
A.K. Kembhavi
T. Padmanabhan
K.C. Nair (Member Secretary)

The Finance Committee

A. Kakodkar (Chairperson)
R.K. Chauhan
N.K. Dadhich
S.V. Dhurandhar
A. K. Dogra
R. Nityananda
A. Pimpale
K.C. Nair (Non-member Secretary)



Members of IUCAA
(as on March 31, 2009)

Academic

N.K. Dadhich (Director)
T. Padmanabhan (Dean, Core Academic Programmes)
Ajit K. Kembhavi (Dean, Visitor Academic Programmes)
Joydeep Bagchi
Dipankar Bhattacharya
Sanjeev V. Dhurandhar
Gulab C. Dewangan (from 01.05.2008)
Ranjan Gupta
Ranjeev Misra
Maulik Parikh
A.N. Ramaprakash
Swara Ravindranath
Varun Sahni
Tarun Souradeep
R. Srianand
Kandaswamy Subramanian
Shyam N. Tandon

Emeritus Professor

Jayant V. Narlikar

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
Vijay Mohan
N. Nageswaran
Arvind Paranjpye
Sarah Ponrathnam
Swapnil M. Prabhudesai
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
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 (from 26.09.2008)
Roudane Gannouji (from 29.10.2008)
Chiranjib Konar
Gauri Kulkarni (from 03.01.2009)
Siddharth Malu
Kuntal Misra
Pasquier Noterdaeme (from 12.01.2009)
Biswajit Pandey
Harsha Raichur (from 29.12.2008)

Sudhanshu Barway (till 14. 07. 2008)
Rajesh Gopal (till 22. 07. 2008)
Subharthi Ray (till 14.07.2008)

Research Scholars

Moumita Aich
Maryam Arabsalmani (from 30.07.2008)
Tanushree Basu (from 31.07.2008)
Bruce Cabral (from 23.01.2009)
Susmita Chakravorty
Saugata Chatterjee

Tuhin Ghosh
Gaurav Goswami
Charles Jose (from 04. 08. 2008)
Nisha Katyal (from 23.09.2008)
Sanved Kolekar(from 01.08.2008)
Dawood Kothawala
Sandeep Kumar
Sibasish Laha (from 30.07.2008)
Gaurang Mahajan
Dipanjan Mukherjee (from 16.07.2008)
Sowgat Muzahid
Hadi Rahmani (from 04.04.2008)
Aditya Rotti (from 04.08.2008)
Prashant Kumar Samantray
Saumyadip Samui
Sudipta Sarkar
Mudit Kumar Srivastava
Sharanya Sur

Abhishek Rawat (till 10.10.2008)
Arman Shafieloo (till 01.09.2008)
Indrajeet Singh (till 27.06.2008)
Archana Bora (till 20.03.2009)

Temporary/Project/Contractual Appointments

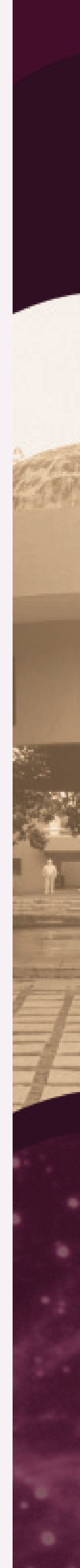
Tushar Agrawal
Neelam S. Bhujbal (from 19.03.2008)
Jeetendra S. Joshi (Observatory Support)
Manisha S. Kharade (ERNET Project)
Deoyani Nandrekar
Sharmad D. Navelkar (from 26.02.2009; VO Project)
Nilesh Pokharkar
Sujit Punnadi
Ashok Rupner
Sagar Shah
Sakya Sinha (from 22.12.2008)
Kirti Tonpe (from 12.03.2009)
Shrirang P. Zodage
Chinmay Deshpande (till 26.07.08)
Chaitanya Sathe (from 19.11.2008 till 16.01.2009)
Aarti Shinde (for various periods during
24.06.08 to 29.01.09)

Part-time Consultant

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

Long Term Visitor

Arvind Gupta (MVS)



Visiting Associates of IUCAA

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

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

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

N. Banerjee,
Department of Physics,
Jadavpur University, Kolkata.

S.K. Banerjee,
Amity School of Engineering, Noida.

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

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

Suresh Chandra,
School of Physical Sciences,
Swami Ramanand Teerth Marathwada University,
Nanded.

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

Tanuka Chattopadhyay,
Department of Mathematics,
Shibpur D.B. College, Howrah.

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

H.S. Das,
Department of Physics,
Kokrajhar Government College, Assam.

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.

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.

Sushant Ghosh,
Department of Mathematics,
BITS, Pilani.

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,
Newman College, Thodupuzha.

Deepak Jain,
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, Bangalore.

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

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

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

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

Nagendra Kumar,
Department of Mathematics,
K.G.K.(P. G.) College, Moradabad.

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

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,
Barasat Government College, Kolkata.

Biplab Raychaudhuri
Department of Physics
Surya Sen Mahavidyalaya, Siliguri.

Anirban Saha,
Department of Physics,
Sovarani Memorial College, Howrah.

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

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

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

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

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.

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

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.

R.S. Tikekar,
Department of Mathematics,
Sardar Patel University, Vallabh Vidyanagar.

Paniveni Udayashankar,
Department of Physics,
Sri Bhagwan Mahaveer Jain College of Engineering,
Bangalore.

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

Till July 31, 2008

Bindu A. Bambah,
School of Physics,
University of Hyderabad.

Deepak Chandra,
Department of Physics,
S.G.T.B. Khalsa College, Delhi.

Arnab Rai Choudhuri,
Department of Physics,
Indian Institute of Science, Bangalore.

M.K. Das,
Institute of Informatics and Communication,
University of Delhi.

Alok Kumar Durgapal,
Department of Physics,
Kumaun University, Nainital.

A.D. Gangal,
Department of Physics,
University of Pune.

Naveen Gaur,
Department of Physics,
Dyal Singh College, New Delhi.

A.C. Kumbharkhane,
School of Physical Sciences,
Swami Ramanand Teerth Marathwada University,
Nanded.

Daksh Lohiya,
Department of Physics and Astrophysics,
University of Delhi.

C. Mukku,
International Institute of Information Technology,
Hyderabad.

Anirudh Pradhan,
Department of Mathematics,
Hindu P.G. College, Zamania.

Lalan Prasad,
Department of Physics,
M.B. Government P.G. College, Haldwani.

Nagalakshmi Rao,
Department of Physics,
Government Science College, Bangalore.

Pankaj Kumar Shrivastava,
Department of Physics,
Government Model Science College, Rewa.

From August 1, 2008

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

Gour Bhattacharya
Department of Physics,
Presidency College, Kolkata.

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

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

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

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

The nineteenth batch of Visiting Associates, who were selected for a tenure of three years, beginning August 1, 2008.

Vasudha Bhatnagar

Gour Bhattacharya

Somenath Chakrabarty

Ajay S. Chaudhari

Manzoor A. Malik

Sanjay Baburao Sarwe

Appointments of the following Visiting Associates from the sixteenth batch were extended for three years : Suresh Chandra, Asis Kumar Chattopadhyay, Tanuka Chattopadhyay, Rabin Kumar Chhetri, Ujjal Debnath, Jishnu Dey, Mira Dey, Paramjit S. Goraya, Naseer Iqbal Bhat, Pushpa Khare, V.C. Kuriakose, Pradip Mukherjee, Sanjay K. Pandey, S.K. Pandey, Kishor Dnyandeo Patil, Ninan Sajeeth Philip, Shantanu Rastogi, Saibal Ray, Eeshankur Saikia, T. R. Seshadri, and Ramesh S. Tikekar

Organizational Structure of IUCAA's Academic Programmes

The Director
N.K. Dadhich

Dean, Core Academic Programmes
(T. Padmanabhan)

Head, Pedagogical Programmes
(K. Subramanian)

Head, Computing Facilities
(A.K. Kembhavi)

Head, Library
(V. Sahni)

Head, Publications
(T. Padmanabhan)

Head, Instrumentation Laboratory and IUCAA Girawali Observatory
(A. N. Ramaprakash)

Dean, Visitor Academic Programmes
(A.K. Kembhavi)

Head, Infrastructural Facilities
(A.K. Kembhavi)

Head, Meetings and Visitors
(N.K. Dadhich)

Head, Public Outreach Programmes
(R. Misra)

Head, Telescope and Observer Programmes
(R. Srianand)

Director's Report

As I sit to pen the last report, my mind goes back to February 10, 1988, when I was appointed Project Coordinator to prepare a Project Report for IUCAA. Professor Jayant Narlikar, who had taken up the challenge of setting up a world class institute, Professor Ajit Kembhavi and I quickly put together a document, which went through a process of review and approval, and IUCAA was formally inaugurated on December 29, 1988. I must say that the Project Report, the blue document displaying the eight-fold activities of IUCAA on the front page has served IUCAA well for 20 years and its projections had turned out amazingly close to what had actually happened. Now, it is time for IUCAA to take fresh guard and plan for next 20 years.

The main aim of IUCAA was to establish a world class common facility for propagation and growth of astronomy and astrophysics in universities. This meant bringing the academically charged environment including world class facilities in terms of computation, observation and instrumentation, which are internationally competitive at the doorstep of university faculty and students. It was to transmit excitement of A & A research to young students, who were otherwise had no exposer to it in their regular curriculum. In terms of observing facilities, IUCAA offers best of the facilities to university scientists. They include, apart from the national facilities like GMRT and ASTROSAT, in the development of the latter, IUCAA has been substantially contributing, a very fine 2 metre optical telescope at IGO (IUCAA Girawali Telescope), which is one of the largest in the country, and a 6% share, translating to 15 nights in observation time in an year, on a 10 metre class, the largest in the existing telescopes, SALT (Southern African Large Telescope). Currently, IUCAA is seriously involved in a national project of participation in one of the international collaborations in the proposed 30 metre class, GSMT (Giant Segmented Mirror Telescope) project. It is indeed very exciting and challenging times ahead for the astronomy community.

I should also mention here that in the last SAC meeting in July 2008, it was noted with much admiration and satisfaction that there were as many as 15 university faculty and students who were involved in serious observations at various national and international facilities and they came from interior places like Raipur, Gonda and Nanded. Nothing could be more gratifying for some of us who had envisioned observational culture taking roots in universities. Having said this, let me also echo Jayant's sentiment in his last report in 2003 that he was quite happy with the recognition and standing IUCAA had attained as one of the leading astronomy centers, but much needed to be done in enhancing interaction with universities and their participation in challenging programmes. I must confess that we have a long way to go on this road. I had proposed that an IUCAA faculty member should visit a university for 2 weeks every year and give a course of lectures. This would build stronger interaction with students as well as hopefully bringing about research collaborations. This is a long term issue and we have to devise new innovative and imaginative methods for promoting and enhancing interaction.

For university interaction, Associateship Programme is one of the key programmes which had been quite successful. In my first report, I had said that now was the time for consolidation in terms of taking up interesting and substantive problems both in theory and observation. IUCAA provides a wide canvass of expertise spanning the entire astrophysical spectrum ranging from fundamental studies in gravity to observation and instrumentation. If one is not opening out one's horizon to this rich resource and keeps confined to what one had been doing over the years, it would be a great pity. IUCAA has created and provided the best of the facilities in mind and machine, it would, therefore, be not unreasonable if it asks for the best of science to come out. May I once again urge my Associate colleagues to make full use of this wonderful resource in doing good and world class astronomy.

IUCAA's philosophy and guiding principle had been to take up a challenge and then work hard to live up to it. Setting up IUCAA was a challenge and we have wonderfully lived up to it. Now, IUCAA is on a threshold of taking up challenge of similar proportion of building up major instrumentation and observation programmes with much stronger university participation. This is a great challenge and opportunity, and I am confident that my colleagues in IUCAA as well as in universities would measure up to it. It would, however, need devising some new formats and structures for effective and efficient functioning in the IUCAA tradition and style.

It may not be out of place to say a word or two about IUCAA's system of governance. Jayant had said in his last report that he spent only 25% of his time on administration, which surprised one of the institute directors, and he called me to ask whether it was really so. I told him that he was a great manager of his time, but even though I was not at all organised yet I didn't have to spend even that bit. The reason is, thanks to Jayant's wisdom and foresight that there is a well defined system of shared responsibility with freedom and trust. It is an excellent example of participative governance in which everyone feels involved leaving the Director free to sign some a dozen papers a day. That I do hardly ever reading a word, which takes no time at all. I should, however, point out that many of my colleagues have to devote much more time and thought on administrative matters working on various committees. No decision of any substance is taken by an individual, may it be the Director. Apart from the norm, it was a matter of ideology for me and hence, I refused to use the Directorial discretion. I had inherited a well geared governance setup and I had attempted to make it a bit more transparent. The abiding motto is, "Trust breeds Trust" and IUCAA has been thriving on it.

I have been very fortunate to enjoy full and enthusiastic support from all my colleagues academic as well as administrative. IUCAA is blessed with a team of support staff, which has grown with it and it is their commitment and dedication that signifies the smooth and effortless functioning. No words would be adequate to appreciate in full measure how much IUCAA's success pegs on their sense of belonging and character. Notwithstanding the inadequacy of phrase for expression of what I feel, I feel highly indebted and grateful to all my colleagues who have taken upon themselves much more than their due.

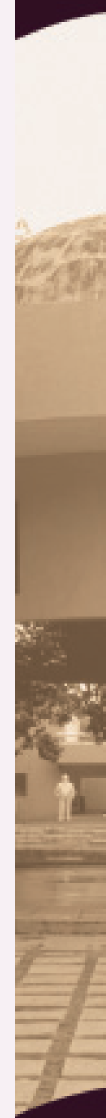
As Governing Board Chairs, I was very fortunate to have first Professor N. Mukunda, who had been a very good friend for a long time, and then Dr. Anil Kakodkar. Their wise counsel, guidance and committed support to various programmes have been very crucial, particularly in first, completion of 2 metre telescope at Girawali and then joining the SALT Consortium. The speed with which the SALT agreement could be negotiated was due to Dr. Kakodkar's enthusiastic support and the confidence he posed in IUCAA's faculty and programmes. I sincerely hope that he has another term as GB Chair so that IUCAA could benefit of his continued guidance and support for the new major initiatives it is embarking upon.

I am very grateful to the two Presidents of IUCAA Council and Chairmen of UGC, Professors Arun Nigavekar and Sukhdeo Thorat, and all the UGC officials for their understanding and appreciation of IUCAA's work and its specific needs. I am happy to say that IUCAA has enjoyed full support and cooperation from all quarters in UGC for timely release of funds for various projects. Particularly their support for the completion of 2 metre telescope project (Professor Nigavekar) and joining the SALT Consortium (Professor Thorat) was very critical and I shall always remain indebted to them. In return, I can only say that a young student from the remote place, Gonda now has the access to observe from world's largest telescope. This was precisely the reason for which IUCAA was created. With due humility, I would like to say that we have done that.

I have enjoyed a great camaraderie not only with my colleagues in IUCAA and universities but also in the larger academic community as well as in UGC and other Government offices, I wish to say an affectionate Thank You to them all.

Finally, I hope that IUCAA has progressed somewhat from the state I took over, and I am sure my successor would take it to greater heights and I wish him as well as the entire IUCAA family all the best. Thank You.

Naresh Dadhich



Congratulations to ...

Sanjeev Dhurandhar, on being elected ***President of the Indian Association for General Relativity and Gravitation (IAGRG)*** for a period of two years from March 14, 2008.

Arvind Gupta, on being selected for the ***One India One People Award*** by Foures Engineering (India) Limited, Mumbai.

Ajit Kembhavi, on being elected ***Fellow of the Indian Academy of Sciences***.

Kuntal Misra, ***COSPAR fellowship 2009*** (High resolution XMM-RGS spectroscopy of bright supernova remnant N312D with Randall Smith at CfA).

J. V. Narlikar, on receiving the ***G.R. Paranjape Award,*** awarded by the Maharashtra Sahitya Parishad, Pune, September 27.

J.V. Narlikar, on receving the ***Doctor of Literature (Honoris Causa),*** from the Jadavpur University, Kolkata, December 24.

T. Padmanabhan, on receiving ***the First Prize in the Gravity Research Foundation, (USA) essay contest 2008*** for his essay titled *Gravity: The Inside Story.*

T. Padmanabhan, on receiving the ***J.C. Bose Fellowship*** awarded by the Department of Science and Technology, Government of India.

T. Padmanabhan, on being elected the ***Vice Chairman of C19 Commission on Astrophysics*** of the International Union of Pure and Applied Physics (IUPAP) for the period 2008 – 2011.

P. N. Pandita, on being elected a ***Fellow*** of the ***Indian National Science Academy***.

S.K. Pandey, who has been a Visiting Associate of IUCAA right from the first batch in 1989, on being appointed as **Vice-Chancellor** of Pt. Ravishankar Shukla University, Raipur.

Maulik Parikh, on being selected for the ***Scopus Young Scientist Award in Physics*** for the year 2008 by Elsevier India (Science and Technology).

R. Srianand, on receiving the ***Shanti Swarup Bhatnagar Prize for the year 2008*** awarded by the Council of Scientific and Industrial Research, Government of India.

R. Srianand, on being conferred with the ***Hari Om Ashram Prerit Dr. Vikram Sarabhai Research Award (2007)*** by Physical Research Laboratory, Ahmedabad.

Mudit K. Srivastava and A. N. Ramaprakash, on being awarded the ***Best Poster Award in Instrumentation Discipline,*** at the 27th Annual Meeting of the Astronomical Society of India, held at the IIA, Bangalore during February 18 - 20, 2009.

Welcome and Farewell

Welcome to...

Kinjal Banerjee, who has joined as a post-doctoral fellow. His areas of research are Loop Quantum Gravity and Cosmology, and the Application of Loop Quantization Techniques.

Gulab Chand Dewangan, who has joined as a Faculty Member. His areas of research are X-ray Astronomy, AGNs, ULXs, X-ray Binaries, and Multi-wavelength Astronomy.

Radouane Gannouji, who has joined as a post-doctoral fellow. His areas of research are Dark Energy Models, Modification of Gravity, and Growth of Linear Perturbations.

Gauri V. Kulkarni, who has joined as a post-doctoral fellow (Project). Her areas of research are Statistics of the Large Scale Structure, and Cosmic Microwave Background.

Pasquier Noterdaeme, who has joined as a post-doctoral fellow. His areas of research are Quasar Absorption Lines, Interstellar Medium at High Redshift, and Molecules and Dust.

Harsha Raichur, who has joined as a post-doctoral fellow. Her areas of research are X-ray Binary Pulsars, and Timing Analysis of X-ray Astronomical Data.

Maryam Arabsalmani, Tanushree Basu, Hadi Rahmani Bayegi, Bruce Cabral, Charles Jose, Nisha Katyal, Sanved Vinod Kolekar, Sibasish Laha, Dipanjan Mukherjee, and Aditya Rotti who have joined as Research Scholars.

..Farewell to

Sudhanshu Barway, who has joined as a Virtual Observatory Scientist at the South African Astronomical Observatory, Cape Town.

Archana Bora, who has completed her tenure as a research scholar (Project) at IUCAA and joined at her parent institute, Gauhati University, Guwahati.

Rajesh Gopal, who has completed the tenure at IUCAA.

Subharthi Ray, who has joined as an Associate Professor at the Department of Mathematical Sciences, University of Kwazulu Natal, Durban, South Africa.

Abhishek Rawat, who has joined as a Research Geophysicist with MindSET Seismic (Pvt.) Ltd., Panchkula, India.

Arman Shafieloo, who has accepted a post-doctoral position at Oxford University, U.K.

Welcome to...

Professor E.P.J. van den Heuvel, Astronomical Institute, University of Amsterdam, Netherlands, who has accepted our invitation to be an Honorary Fellow of IUCAA from February 2, 2009. A very warm welcome to Professor Heuvel into the extended IUCAA family.

Professor Ved Prakash, who took over as Vice-Chairman, University Grants Commission, from February 28, 2009.

... Farewell to

Professor Mool Chand Sharma, whose term as Vice-Chairman, University Grants Commission came to an end.

Calendar of Events

2008

April 14 - May 23
School Students' Summer Programme
at IUCAA

May 9
IUCAA-NCRA Graduate School
Second semester ends

May 12 - June 13
Introductory Summer School on Astronomy and Astrophysics (for college/university students)
at IUCAA

May 12 - June 27
Vacation Students' Programme
at IUCAA

July 21 - August 31
ICTS-IUCAA Programme on Cosmology with CMB and LSS
(Conducted jointly by International Centre for Theoretical Sciences, Mumbai, and IUCAA)
at IUCAA

July 22 - 23
Meeting of IGO Users
at IUCAA

August 4
IUCAA-NCRA Graduate School
First semester begins

September 17 - 19
Workshop on Open Source Standards and Software in Libraries: Spotlight on NewGenLib
at IUCAA

September 23 - 27
Technology Workshop on
Performance Enhancement on Emerging Parallel Processing Platforms (PEEP - 2008)
(Conducted jointly by IUCAA and C-DAC, Pune)
at IUCAA

October 13 - 15
Workshop on X-ray Timing with ASTROSAT: Science, Techniques and Tools
at IUCAA

November 3 - 4
Workshop on Science with SALT
at IUCAA

November 7 - 8
Workshop on Light Scattering: Its Applications in Astrophysics and Other Fields
at Gujarat Arts and Science College, Ahmedabad

December 5
IUCAA-NCRA Graduate School
First semester ends

December 15 - 23
IUCAA – NCRA Radio Astronomy Winter School (for college / university students)
at IUCAA /NCRA

December 29
Foundation Day

2009

January 5
IUCAA-NCRA Graduate School
Second semester begins

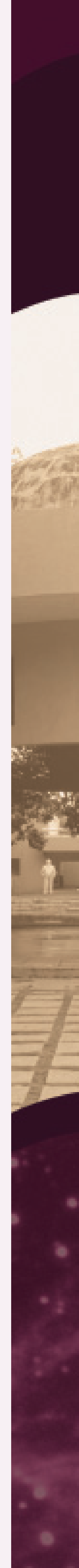
January 9 - 10
Launching of IYA 2009
at IUCAA.

January 19 - 23
Workshop on Machine Learning Methods in Astronomy
at Mar Athanasios College for Advanced Studies (macfast), Thiruvalla

February 2 - March 20
X-ray Astronomy School
at IUCAA

February 23 - 25
Workshop on Broadband X-ray Spectroscopy with ASTROSAT
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

The research described below is grouped area-wise. The name of the concerned IUCAA member appears in boldface.

Quantum Theory and Gravity

Quantization of gravitational entropy

It was conjectured by Bekenstein long back that, in a quantum theory, the black hole *area* would be represented by a quantum operator with a discrete spectrum of eigenvalues. Bekenstein showed that the area of a classical black hole behaves like an adiabatic invariant, and so, according to Ehrenfest's theorem, the corresponding quantum operator must have a discrete spectrum. It was also known that, when a quantum particle is captured by a (non extremal) black hole, its area increases by a minimum non-zero value, which is independent of the black hole parameters. This argument also suggests an equidistant spacing of area levels, with a well-defined notion of a *quantum of area*. The fundamental constants G, c and $\hbar$ combine to give a quantity with the dimensions of area, $A_P = (G\hbar/c^3) = 10^{-66}$ cm^2, which is quite suggestive and sets the scale in area quantization.

In Einstein's gravity, entropy of the horizon is proportional to its area. Hence, one could equivalently claim that it is the gravitational entropy which has an equidistant spectrum with a well-defined notion of *quantum of entropy*. But, when one considers some natural higher derivative correction terms to the original Einstein-Hilbert action, no such trivial relationship holds between horizon area and entropy. One such higher derivative theory is Lanczos-Lovelock (LL) gravity, of which the lowest order correction appears as a Gauss-Bonnet (GB) term in $D(> 4)$ dimensions. These Lagrangians have the unique feature that the field equations obtained from them are quasi linear, as a result of which, the initial value problem remains well-defined. More importantly, several features related to horizon thermodynamics, which were first discovered in the context of Einstein's theory, continues to be valid in LL gravity models. For these spacetimes, the notion of entropy can be defined using Wald's formalism, where entropy is associated with the Noether charge of diffeomorphism invariance symmetry of the theory. This Noether charge entropy is no longer proportional to horizon area. The question then arises as to whether it is the quantum of area or quantum of entropy (if at all either), which arises in a natural manner in these models. In a recent paper, **Dawood Kothawala**, **T. Padmanabhan**, and **Sudipta Sarkar** have made an attempt to answer this question, based on a very general argument, which suggests that it is the entropy, and not area, which is quantized with equidistant spectrum in the case of LL gravity. Their work provides an explicit demonstration of this in the context of GB gravity using the known asymptotic form of the quasi-normal mode frequencies of a spherically symmetric GB black hole.

Thermodynamic structure of gravitational field equations in static spacetimes

It is a well-established fact that Einstein field equations, near a horizon, can be written as a thermodynamic identity; moreover, the result also holds for spherically symmetric horizons in LL gravity. This fact lends support to the point of view that gravity is a long wavelength, emergent phenomenon, and gravitational dynamics, at the macroscopic level is, therefore, governed by relations which bear resemblance to the equations of thermodynamics. Since we do have operationally well-defined notions such as entropy and temperature associated with a wide class of horizons in general relativity, it is natural to expect that the *near horizon* behaviour of the field equations of gravity might actually be a statement of local thermodynamic equilibrium. Earlier demonstrations of the thermodynamic structure of gravitational field equations have involved certain assumptions like, for example, that of spherical symmetry, which is somewhat restrictive. Recently, **Dawood Kothawala**, and **T. Padmanabhan** have given a general proof, based on the near-horizon symmetries of the LL field equations, that near *any static horizon*, the field equations can be written as $T\mathrm{d}S - \mathrm{d}E = P_{\perp}\mathrm{d}V$, where the variations correspond to normal displacement of the horizon. This not only shows that the thermodynamic structure of gravitational field equations is quite generic, but also connects the origin of this result with the existence of classical symmetries of gravitational field equations near a horizon.

At a deeper level, these results suggest that it is necessary to abandon the usual picture of treating the metric as the fundamental dynamical degrees of freedom of the theory and treat it as providing a coarse grained description of the spacetime at macroscopic scales, somewhat like the density of a solid — which has no meaning at atomic scales. The unknown, microscopic degrees of freedom of spacetime (which should be analogous to the atoms in the case of solids), should normally play a role only when spacetime is probed at Planck scales (which would be analogous to the lattice spacing of a solid). So we normally expect the microscopic structure of spacetime to manifest itself only at Planck scales or near singularities of the classical theory. However, in a manner which is not fully understood, the horizons — which block information from certain classes of observers — link certain aspects of microscopic physics with the bulk dynamics, just as thermodynamics can provide a link between statistical mechanics and (zero temperature) dynamics of a solid. The reason is probably related to the fact that horizons lead to infinite redshift, which probes *virtual* high energy processes; it is, however, difficult to establish this claim in mathematical terms. This aspect, as to why horizons act as window to microphysics of spacetime, is worth investigating further.

The thermodynamics of spacetime

Maulik Parikh and a student have shown that all diffeomorphism-invariant theories of gravity (Einstein gravity, Lovelock theories, f(R), etc) appear to have a deep connection to thermodynamics. The classical gravitational equations of motion for all such theories follow from the Clausius relation, dQ = TdS, applied locally at the light cones of any point in spacetime. Here S is the Wald entropy, which generalizes the Bekenstein-Hawking entropy. Thus, in some mysterious sense, classical gravity appears to be the thermodynamics of spacetime.

Energetics of a rotating black hole in five dimensions

There has been a good deal of interest in black holes in higher dimensions. In particular, a black hole in 5 dimensions is studied. The analogue of static Schwarzschild black hole is straightforward and is on expected lines, while rotation brings in new features that there are now two rotations instead of one. The most interesting property of rotating black hole is existence of ergoregion, where a timelike particle can attain negative energy relative to infinity and thereby giving rise to possibility of energy extraction by Penrose process. Since now there are two rotations, it is pertinent to study the shape and geometry of ergoregion and horizon for their role in energy extraction.

Another unexpected surprise which comes about is that it is not possible to put electric charge on a rotating black hole in 5 dimensions. There has been intense activity in this direction but without success and what has been achieved is that it is possible to include electric charge with inclusion of supergravity and Chern-Simon interaction. It raises an interesting question, does inclusion of charge on rotating black hole in higher dimensions require supergravity; i.e., is supergravity necessary? If yes, the two must have some deep and intimate connection. This is indeed a very profound question, which black holes in higher dimension seem to indicate or suggest.

Naresh Dadhich and a VSP student, Kartik Prabhu have studied the shape of ergoregion, the region bounded between event horizon and static limit for various values of rotation and charge parameters. One of the interesting features that shows up is that even at the axis of one of the rotations, horizon and static limit do not coincide as is the case in 4 dimension. This is because now the other rotation works to split them apart at the axis. That is, even an axial fall could extract energy from black hole. This is very interesting. The ergoregion at the axis increases with increase of the other rotation parameter, while at the equator it increases with charge. The ergoregion and thereby the energetics of higher dimensional rotating black hole is, therefore, much richer and exciting.

Gravitational Waves

The transformation in science is driven by new kinds of data. Radio astronomy revealed the non-thermal emissions of comparatively low frequency electromagnetic waves than visible light and led to the discovery of new astrophysical phenomena in the universe, which were not even dreamed of. The astronomy covers a vast range of phenomena from pulsars, neutron stars and their habitats to magnetised plasmas and relativistic particles and the cosmic microwave background. It has vastly changed our perception of the universe and promises many more advances in the future years to come. Another dramatic transformation is in the offing - the direct detection of gravitational waves (GW). GW are produced by bulk motions of matter and are analogous to sound waves. They come with two polarisations producing a stereophonic symphony of the universe. This new science will provide the much needed sound track to the electromagnetic picture of the universe, which though rich in detail, has upto been silent.

The transformation to new science of GW is being brought about by the great strides that have been taken by technology in the past several decades. Gravitational wave detectors are like super sensitive microphones that measure the tiny motions of test masses caused by spacetime vibrations. Although, the GW energy in terms of power and energy density is comparable to that of electromagnetic waves, their extremely weak coupling to matter produce only tiny distortions of spacetime causing miniscule motions of the test masses. Laser interferometric detectors of GW precisely sense the relative motion of test masses. The ground-based detectors such as the LIGO (US), VIRGO (France-Italy), GEO (Germany-UK) and TAMA (Japan) are geared to operate in the range of few tens of Hz to kHz range. There are also plans of future ground-based detectors in Australia (AIGO) and India (INDIGO). About a year ago, the initial LIGO detector surpassed its goal sensitivity, solidly establishing the credibility of the Ligo Science team. The other groups also have made notable advances. 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 in the next decade with an intermediate stage of the enhanced LIGO, which is expected to be in operation in a few years time and which may have a small chance of detection. The best sources for these detectors are coalescences of compact binaries - neutron stars/black holes. Although these are rather rare events, increasing the sensitivity of the detectors will increase the volume of universe that can be probed, giving a reasonable chance of detection. Here at IUCAA the extraction of GW in-spiral signals has been the main focus of research for several years.

The Laser Interferometric Space Antenna (LISA) is a proposed space mission to observe low frequency GW in the range 0.1 mHz to 0.1 Hz. Since astrophysical systems are generally large and in spite of high velocities do not change their quadrupole moment too quickly, the universe is richly populated with sources in this frequency band. Also the masses that produce GW in this frequency band are generally large and thus produce stronger GW than those in ground-based detectors, leading to high signal-to-noise ratios (SNR). The signals for LISA arise from a large variety of phenomena, merging massive and supermassive black-holes, vibrating black holes (quasi-normal modes), stellar mass objects falling into massive and supermassive black holes, GWs of cosmological origin, etc. The high SNRs of these signals imply detailed and accurate information, which can test general relativity and its ramifications to unprecedented accuracies. Astrophysics of various objects like compact binaries, stellar remnants can be studied and LISA observations can provide useful clues to events in the early universe.

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

It is well known that the all sky all frequency search for pulsars or rotating neutron stars is extremely computionally intensive. The signal is very weak with its typical amplitude about three orders of magnitude below the raw detector noise and therefore, requires long integration times of the order of a few months or even a year to build sufficient signal to noise ratio. This means that even if one assumes the simple case of a monochromatic source, the signal in the detector is frequency and amplitude modulated depending on the direction of the source. Thus, if the source direction is unknown one must search over all the directions in the sky. Typically, one must search over 10^{13} directions corresponding to arcsecond resolution. The all sky all frequency search, thus, requires at the minimum 10^{24} computer operations. Even with a teraflop machine this would require 10^5 years! And this does not take into account the intrinsic spindown of the pulsar, which would amount to searching over additional parameters and therefore, increase the computational cost further by several orders of magnitude.

Several methods, essentially of the hierarchical kind have been developed over the past two decades. They reduce the computational cost to some extent. However, this is not sufficient for processing the data in real time with the currently available computing resources. **S. V. Dhurandhar**, and B. Krishnan from AEI, Potsdam, Germany are exploring a completely novel approach based on exploiting the symmetries in the problem. The sky (space of directions) has rotational symmetry and the frequency has translational symmetry and therefore, there is a group theoretic structure in the problem. The general idea is to use these symmetries to reduce the computational cost. The procedure sought is analogous to the procedure followed in the fast Fourier transform, for instance, in the Cooley-Tukey algorithm. The first step is to obtain the representation of the group involved, essentially the rotation group. If possible, obtain several representations of the group and choose among them the one most useful for the problem. The next step would be to examine the Lie algebra and from this obtain recurrence relations, which then should lead to a fast algorithm. This is the general roadmap that **Dhurandhar** and Krishnan have laid out. This work is being undertaken within the Ligo Science Collaboration. One way would be to build upon a former approach of Schutz called *Stepping around the sky*, which directly maps a modulation of one direction to a modulation of another via a kernel function. Below the precise problem is briefly described.

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 - monochromatic of constant frequency, say f_0. The detector, however, takes part in an accelerated motion - in general, a superposition of simple harmonic motions of varying amplitudes and phases. In some approximatio, this motion can also be considered as superposition of circular motions - cycles and epicycles. 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. If the direction to the source and the frequency is unknown, all directions in the sky must be scanned as also the frequency. From astrophysical considerations usually the maximum frequency $f_{\max}$ is taken to be 1 kHz. The brute force method consists of trying out each direction by first demodulating the signal and taking its Fourier transform. If the signal is a sinusoid, its Fourier transform will show a peak and stand above the noise. On the other hand, the stepping method gives a direct way for obtaining the Fourier transform in the barycentric frame of the demodulated signals connecting two different directions. The novel idea of **Dhurandhar** and Krishnan is to use the group theoretic structure to reduce the number of operations in the data processing.

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

In recent years, a number of ground based detectors are taking quality science data and are collaborating together. The time is, therefore, ripe to consider the analysis of network data for the detection of inspiraling binaries. The advantages of multidetector search for the binary inspiral is that, not only does it improve the confidence of detection, but it also provides information about the direction and polarization state of the source. Inspiraling binaries are one of the most promising candidates for first detection of GW. They are astrophysically important, because they will not only carry detailed information about the binary system, but also general relativistic deviations from Newtonian gravity in their orbit and these can be experimentally measured.

There are two strategies which are employed in searching for inspiraling binary sources with a network of detectors: the coherent and the coincident. The coherent strategy combines data from different detectors phase coherently, appropriately correcting for time-delays and polarization phases and obtaining a single statistic, for the full network, that is optimized in the maximum likelihood sense. The statistic in effect brings all the detectors to one location and one orientation. The important point is that it treats the network as a single detector. On the other hand, the coincident strategy considers each detector in isolation.

The coherent search strategy uses the maximum likelihood method, where a *single* likelihood ratio for the entire network is constructed - that is the network is treated as a single detector - this is similar to aperture synthesis carried out, for example, by radio astronomers. The likelihood method combines the data from a network of detectors in a *phase coherent* manner to yield a single statistic which is optimal in the maximum likelihood sense. This statistic is then compared with the threshold determined by the false alarm rate that one is prepared to tolerate. If the statistic crosses the threshold, then a detection is announced. Note that a *single* likelihood ratio is computed and a *single* threshold applied in this type of search.

On the other hand, the coincidence approach involves separately filtering the signal in each detector, applying two separate thresholds corresponding to each detector and preparing two event lists determined by the crossings. Then the event lists are matched. If the estimated parameters for the events lie in a reasonable neighbourhood in the parameter space of signals, a coincident detection is registered - that is, the parameters of the events must lie within a certain 'window' of the parameter space in order that a detection is registered.

The aim was to decide as to which strategy performs better. First, the simple case of aligned detectors located in the same place was considered by the Indo-Japanese team consisting of H. Mukhopadhyay, H. Tagoshi, **Dhurandhar** and N. Kanda. This work is part of the Indo-Japanese project funded by DST (India) and (JSPS) Japan. The situation of two coaligned detectors located at the same place with correlated noise was first considered and improved in a later paper. This analysis is applicable to the case of existing detector pairs H1-H2 and planned future Japanese detector LCGT. The strategies are effectively compared by plotting the detection efficiencies of the two strategies at the same false alarm rate, namely, the *Receiver operating characteristics* (ROC) curves. From this it was inferred that for the viable false alarm regime the coherent strategy performed much better than the coincident strategy.

The same team is now considering the general case of two widely separated detectors with different orientations. The coherent statistic for nonaligned detectors is completely different from that of the aligned case. Earlier results of aligned detectors cannot be extrapolated to incorporate the more general case. The performance of the two strategies for the generalized case is compared by plotting the relevant ROC curves, which are obtained analytically as well as via simulation. It is found that when the detectors are not aligned, the performance of the simple coincidence strategy is very poor because of poor sky coverage. Therefore, an improved coincidence strategy is formulated, called *enhanced coincidence*. In this strategy, the first screening step is to obtain candidate event lists by setting a low threshold. The event lists are then compared for consistency in the estimated signal parameters. Then in the final step, the two statistics from individual detectors are added in quadrature and a single threshold is set on the resulting statistic. This strategy, only for the case of two detectors, results in a statistic identical in form to that of the coherent strategy. However, this is only a superficial similarity and the strategy itself is different from the standard coherent strategy. This form of coincidence strategy performs far better in the non-aligned case and is almost as good in performance as the coherent strategy. This work is in progress and the necessary simulations are being carried out to arrive at a conclusion. The work could also be extended to include more baselines. In particular the results of such an analysis will be applied to the planned Japanese large scale detector LCGT.

(iii) General relativistic analysis of LISA dynamics and optics.

LISA - Laser Interferometric Space Antenna - is a proposed mission of the ESA and NASA, which will use coherent laser beams exchanged between three identical spacecraft forming a giant (almost) equilateral triangle of side 5×10^6 kilometres for observing low frequency cosmic GW. This will complement the ground-based detectors, which are geared to operate at higher frequencies ranging from few tens of Hz to kHz. For the successful operation of LISA, it is crucial that the formation of spacecraft be stable - that is, the spacecraft should maintain as much as possible, constant distances between them. However, the spacecraft are freely floating in the ambient gravitational field of the Sun, planets and other celestial bodies (moon for instance) and it is a astrometry problem to seek spacecraft orbits, which maintain the equilateral triangular formation as nearly as is possible - that is, optimal orbits for the spacecraft should be found. There are several criteria which the spacecraft formation should satisfy for LISA's successful operation - constraints on variation in armlengths, the angle between arms, etc. Here we focus on the variation in armlengths, the so-called '*flexing*' of the arms for the reasons detailed below. Optimisation of LISA orbits will be also useful in simplifying the hardware that will be required in the design of LISA.

Minimising the flexing of the arms is important for suppressing the laser frequency noise. In ground-based detectors, the near exact symmetry between the arms suppresses this noise as it is common to both arms. But in LISA, such high symmetry is not possible, and moreover, the armlengths change with time. Suppression of this noise is crucial, since the raw laser noise is orders of magnitude larger than other noises in the interferometer. In LISA, six data streams arise from the exchange of laser beams between the three spacecraft. The cancellation of the noise is achieved by the technique called *time-delay interferometry* (TDI), where the six data streams are combined with appropriate time-delays. This is possible because of the redundancy present in the data. TDI was put on a sound mathematical footing by **Dhurandhar** and collaborators by establishing that the data combinations had an algebraic structure. The time delayed data is represented by polynomials of time-delay operators acting on the data, each time-delay operator playing the part of an 'indeterminate' of a polynomial ring. The data combinations are then represented by polynomial vectors, which form a free module over the polynomial ring of time-delay operators. Out of these, the data combinations cancelling laser frequency noise form a submodule of this free module, well-known in mathematics, as the *first module of syzygies*. The generators of the submodule were found assuming constant armlengths, where one then deals with the simpler case of a commutative ring of time-delay operators. But for realistic spacecraft orbits, the armlengths vary with time, and then the TDI methods involve non-commutative operators leading to the imperfect cancellation of laser frequency noise or residual noise. The residual noise in turn depends on the rate of change of armlengths - the flexing of arms; thus searching for orbits, which reduce the flexing and also reduces the residual laser frequency noise.

Dhurandhar, R. Nayak, and J-Y Vinet have included the gravitational field of the Earth in addition to that of the Sun's in the optimisation problem. The orbits in the Sun's field are taken upto second order in eccentricity. The Earth is chosen over Jupiter, because the Earth perturbs the Keplerian orbit in resonance, resulting in unbounded growing of the perturbations and also Jupiter's tidal field, which affects the flexing which is less than 10% of the Earth's and hence, not a dominant one. Although it is recognised that the problem is inherently non-linear - it is a three body problem - the linear perturbative approach is a useful approximation for short mission periods.

The LISA spacecraft execute a rotational motion and also the background spacetime is curved, all of which affect the optical links and the time-delays. Thus, the Sagnac effect, Einstein effect, Shapiro delay, etc. are important and must be incorporated into the analysis if the laser frequency noise is to be effectively cancelled. All these effects are taken into consideration, in the full framework of general relativity. The base orbits are taken to be Keplerian in the gravitational field of the Sun only, assuming the Sun to be a point mass. On these, base orbits is superposed the perturbative effect of the Earth's gravitational field. The optical links are computed by numerically integrating the null geodesics from one spacecraft to another in the gravitational field of the Sun. Finally, the residual laser frequency noise spectrum for some important TDI observables, namely, the Sagnac, the Michelson and the Symmetric Sagnac in their modified first generation form is obtained. It is found that the residual laser frequency noise, in general, tends not to be very high as compared to secondary noises. If this level of noise is found to be acceptable, then there may be no need to use second generation TDI observables, which in general involve higher degree polynomials in time-delay operators and thus, require more interpolations which in turn result in larger errors in the data analysis. This is the main result of the investigation.

The results for the TDI Sagnac observable are shown in Figure 1. The straight lines are the power spectral densities (PSD) of the residual noise at three different epochs during the LISA mission period. The curve above them denotes the sum of the secondary noise PSDs, such as the optical and the acceleration noise. It is clearly seen that the residual noise PSD is below the secondary noise PSD for the Sagnac observable.

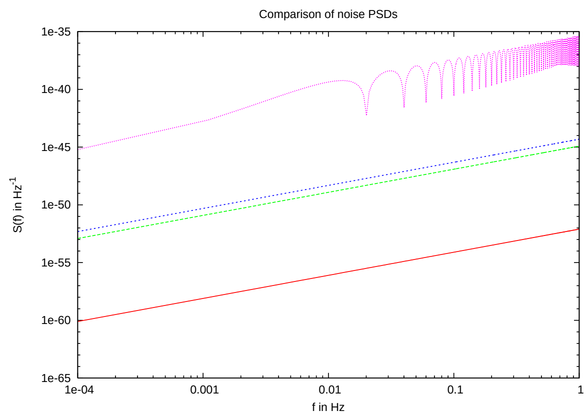


Figure 1: The 'top' curve shows the power spectral density (PSD) of the secondary noises, the optical noise and acceleration noise. The straight lines are PSDs of the residual laser frequency noise at three epochs chosen an year apart. It is seen from the figure that the residual noise is adequately suppressed.

For minimising the flexing, the first step is to obtain the general solution. This solution contains 18 arbitrary constants, corresponding to 3 positions and 3 velocities for each of the three spacecraft. Optimising the 18 parameter solution is a daunting problem. However, from physical considerations, a solution is proposed, which is called the *'projectile'* solution and which considerably reduces the flexing of the arms - the rate of change of all armlengths is less than 5.5 metres/sec in a three year mission period. The effects of eccentricity are also included in these computations and it is found that for certain initial conditions it has minimal effect on the flexing of the arms.

Dhurandhar has extended the algebraic approach to TDI, of stationary LISA in flat spacetime, to the realistic case in which LISA's arms flex. In the general case, the up-down links are unequal, and because of the flexing of the arms, there is now a non-commutative ring in six indeterminates. It is shown that the algebraic structure is still a module over this non-commutative polynomial ring. Further, for the LISA model, which has been optimised to reduce flexing, symmetries have been found, which could be used to simplify the algebra. The symmetries can be used to construct a smaller ring. This is done as follows: an ideal is constructed whose generators are vanishing and approximately vanishing commutators. These commutators capture the symmetries inherent in the problem. Then the non-commutative ring in six variables is quotiented by this ideal, resulting in a much smaller and simpler ring. The TDI now need to be constructed over this simplified quotiented ring, which is now a much cleaner problem. One expects that these computations will be useful in the development of LISA simulators, the LISACode for instance.

Cosmology and Structure Formation

Braneworld dynamics

Varun Sahni, *Yuri Shtanov*, **Arman Shafieloo** and *Alexey Toporensky* have developed a new higher dimensional 'braneworld' model. Extra-dimensional 'braneworld' models have attracted considerable attention in recent years. This is partly due to the fact that superstring/M-theory can only be consistently formulated in a universe, which has more than four spacetime dimensions. A distinctive feature of this theory is that it allows some of the extra dimensions to be large and even infinite, thereby, accommodating the braneworld scenario.

It is now well known that braneworld cosmologies can display quite distinctive behaviour, which departs from that in general relativity either during early or late times. The latter arises because of the infrared modification of gravity on large scales. From the observational perspective, an abundance of recent cosmological observations points to a universe which is currently accelerating. Although, the source of cosmic acceleration remains unknown, most observations are well described by a small cosmological constant $\Lambda/8\pi G \simeq 10^{-47}\,\mathrm{GeV}^4$. Such a small value for the Λ-term is difficult to explain within the context of standard field theory, which typically predicts a value for Λ, which is several orders of magnitude larger than what is indicated by observations.

In this setting, it is natural to ask whether cosmic acceleration could arise via an infrared modification of gravity at large distances. **Sahni**, *Shtanov*, **Shafieloo** and *Toporensky* investigate the cosmological properties of an 'induced gravity' brane scenario in the absence of mirror symmetry with respect to the brane. (In other words, the fundamental constants describing the five dimensional 'bulk' spacetime can be different on adjacent sides of the brane. The dilaton stabilised in different vacuum states on adjacent sides of the brane could lead to such a scenario, which is also preferred from the string landscape point of view.) They find that brane evolution can proceed along one of the four distinct branches. (By contrast, when mirror symmetry is imposed, only two branches exist, one of which represents the self-accelerating brane, while the other is the so-called normal branch.) This braneworld allows many interesting possibilities including phantom acceleration ($w < -1$), self-acceleration, transient acceleration, quiescent singularities, and cosmic mimicry. (The present family of braneworld models contains the famous DGP scenario as a subclass.) Significantly, the absence of mirror symmetry also provides an interesting way of inducing a sufficiently small cosmological constant on the brane. One of the central results of this study is that a small (positive) Λ-term can be induced by a small asymmetry in the values of bulk fundamental constants on the two sides of the brane. Thus, the discovery of cosmic acceleration has a unique explanation within this theoretical scenario.

They also found that the current acceleration of the universe in the braneworld context need not be eternal. In other words, for a specific relationship between the fundamental parameters in the braneworld action, the acceleration of the universe is a *transient* phenomenon, and the universe reverts back to matter-dominated expansion in the future. This is demonstrated in Figure 2, which shows the behaviour of the deceleration parameter $q(z)$ on the brane.

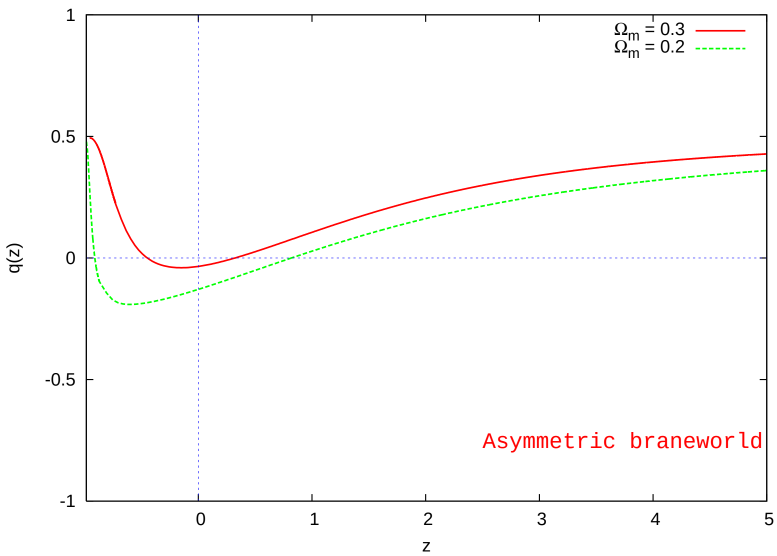


Figure 2: The deceleration parameter versus redshift is plotted for a braneworld in the absence of Z_2 symmetry for two values of the density parameter. As revealed in this figure, in a transiently accelerating universe, cosmic acceleration is sandwiched between two matter-dominated regimes. A transiently accelerating braneworld clearly does not possess the Big Rip of phantom cosmology, nor even the event horizon of De Sitter space!

Two new diagnostics of dark energy

(i) The *Om* diagnostic

Varun Sahni, **Arman Shafieloo** and *Alexei Starobinsky* have proposed two new diagnostics of Dark Energy (DE) which could help in distinguishing a cosmological constant from dynamically evolving models of dark energy.

The nature of DE is one of the most intriguing questions facing physics. The fact that DE provides the main contribution to the energy budget of the universe today while remaining subdominant during previous epochs, provides a challenge to model builders attempting to understand the nature of this seemingly all-pervasive ether-like substance.

Theoretical models for DE include the famous cosmological constant, Λ, suggested by Einstein in 1917 and shown to be related to the vacuum energy $\langle T_{ik} \rangle_{\rm vac} \propto \Lambda g_{ik}$ by Zeldovich and others, several decades later. However, within the context of cosmology, an explanation of DE in terms of Λ faces one drawback, namely, in order for the universe to accelerate today, the ratio of the energy density in the cosmological constant to that in radiation must have been very small at early times. In the absence of a compelling model for Λ, there is ample room for alternatives including models in which both the DE density and its equation of state (EOS) evolve with time. Alternatives to the cosmological constant include scalar field models called quintessence, which have $w > -1$, as well as more exotic 'phantom' models with $w < -1$. Clearly the need of the hour, then, is a diagnostic, which is able to differentiate LCDM from 'something else' with as few priors as possible being set on other cosmological parameters, such as the matter density, etc.

They have developed a new diagnostic, *Om*, which is determined directly from observations and provides a *null test* of the cosmological constant hypothesis based solely on observational data. *Om* is able to distinguish dynamical DE from the cosmological constant in a robust manner, *both with and without reference* to the value of the matter density, which can be a significant source of uncertainty for cosmological reconstruction.

The *Om* diagnostic is constructed from the ex-

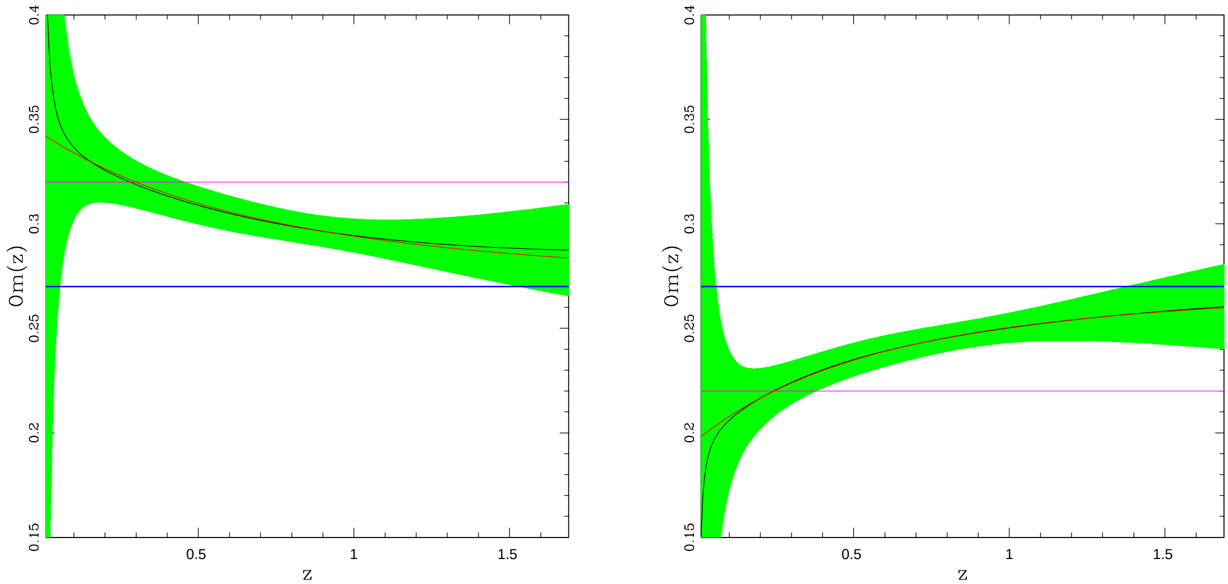


Figure 3: The *left panel* shows the $Om(z)$ diagnostic reconstructed for a fiducial *quintessence* model with $w = -0.9$ and $\Omega_{0\mathrm{m}} = 0.27$ (black line, green shaded region shows 1σ CL, the red line is the exact analytical result for Om). The horizontal blue line shows the value of Om for a ΛCDM model with the same value of $\Omega_{0\mathrm{m}}$ as quintessence. Note that any horizontal line in this figure represents ΛCDM with a *different value of* $\Omega_{0\mathrm{m}}$. For instance, ΛCDM with $\Omega_{0\mathrm{m}} = 0.32$ is shown by the horizontal magenta line. As this figure shows, the negative curvature of quintessence allows us to distinguish this model from (zero-curvature) ΛCDM independently of the current value of the matter density. The *right panel* shows the $Om(z)$ diagnostic reconstructed for a fiducial *phantom* model with $w = -1.1$ and $\Omega_{0\mathrm{m}} = 0.27$ (black line, green shaded region shows 1σ CL). The positive curvature of phantom allows us to distinguish this model from (zero-curvature) ΛCDM independently of the current value of the matter density. For instance, phantom can easily be distinguished from ΛCDM both with the correct $\Omega_{0\mathrm{m}} = 0.27$ (horizontal blue) as well as incorrect $\Omega_{0\mathrm{m}} = 0.22$ (horizontal magenta).

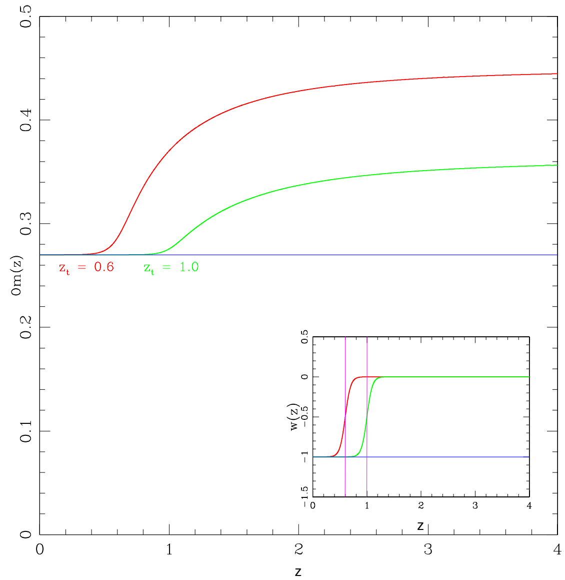


Figure 4: The Om diagnostic is shown for two tracker models which mimick LCDM at low redshift ($z < z_t$) and dark matter at high redshift ($z > z_t$). The horizontal blue line shows LCDM. The inset shows the EOS for the tracker's as a function of redshift.

pansion history $H \equiv \dot{a}/a$ as follows ($a(t)$ is the expansion factor of a Friedmann-Robertson-Walker (FRW) cosmology):

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

It is easy to show that, for dark energy models with a constant equation of state, $Om(z) = \Omega_{0m}$ for the cosmological constant, whereas $Om(z) > \Omega_{0m}$ in quintessence while $Om(z) < \Omega_{0m}$ in phantom. In other words, the Om diagnostic provides us with a *null test* of the cosmological constant since $Om(z) - \Omega_{0m} = 0$ only for the Λ-term This is a simple consequence of the fact that $h^2(x)$ plotted against x^3 results in a straight line for LCDM, whose slope is given by Ω_{0m}, whereas for other DE models the line describing $Om(z)$ is curved.

In practice, the construction of Om requires a knowledge of the Hubble parameter, $h(z)$, which can be determined using a number of model independent approaches, several of which have been developed by **Sahni** and *Starobinsky*. In Figure 3, we have shown the Om diagnostic reconstructed from SNAP-quality data. One clearly sees that for quintessence as well as phantom, the line describing $Om(z)$ is curved, which helps distinguish these models from LCDM even if the value of the matter density is not accurately known.

Interestingly, a comparison of Om at two different redshifts can lead to insights about the nature of DE even if the value of Ω_{0m} is not accurately known. Thus, the two-point difference diagnostic $Om(z_1, z_2) \equiv Om(z_1) - Om(z_2)$ can serve as a *null* test of the cosmological constant hypothesis, since $Om(z_1, z_2) = 0$ only for the cosmological constant; $Om(z_1, z_2) > 0$ for quintessence, while $Om(z_1, z_2) < 0$ for phantom ($z_1 < z_2$). Thus, the value of Om determined at two redshifts can help distinguish between DE models without reference either to the matter density or H_0 !

The Om diagnostic is in many respects the logical companion to the statefinder $r = \dddot{a}\, / aH^3$ developed earlier by **Sahni** and collaborators. We remind the reader that $r = 1$ for the cosmological constant while $r \neq 1$ for evolving dark energy models. Hence $r(z_1) - r(z_2)$ provides a *null test* for the cosmological constant. Similarly, the unevolving nature of $Om(z)$ in LCDM furnishes $Om(z_1) - Om(z_2)$ as a *null test* for the cosmological constant. Like the statefinder, Om depends only upon the expansion history of our universe. However, while the statefinder r involves the third derivative of the expansion factor $a(t)$, Om depends upon its *first* derivative only. Therefore, Om is much easier to reconstruct from observations

An important example of dark energy is provided by tracker models, which give rise to cosmic acceleration at late times while earlier, during the radiation and matter dominated epochs, the density in the tracker remains proportional to the background matter density. This last property leads to $\rho_{\rm track}/\rho_{\rm B} \simeq$ *constant* $\ll 1$ at $z > z_t$, where $\rho_{\rm B}$ is the background density of matter or radiation and z_t is the redshift when tracking ends. (Tracker behaviour can also arise in modified gravity theories such as braneworld models and scalar-tensor cosmology.) As shown in Figure 4, the Om diagnostic applied to data at low and high redshift, can help distinguish between tracker dark energy and the cosmological constant.

(ii) **The acceleration probe**

Varun Sahni, **Arman Shafieloo** and *Alexei Starobinsky* have constructed another diagnostic which could be helpful for determining the onset of cosmic acceleration in dark energy models. This is the *acceleration probe*

$$\bar{q} = \frac{1}{t_1 - t_2} \int_{t_2}^{t_1} q(t)dt \ . \tag{2}$$

which can also be written in the following simple form

$$1 + \bar{q} = \frac{1}{t_1 - t_2} \left(\frac{1}{H_1} - \frac{1}{H_2} \right) \tag{3}$$

which expresses the mean deceleration parameter in terms of the look-back time and the value of the Hubble parameter at two distinct redshifts.

In Figure 5, we have shown $\bar{q}$ obtained using Union supernovae and the CPL ansatz. The behaviour of $\bar{q}$ suggests $0.4 \leq z_a \leq 0.8$ for the redshift at which the universe began to accelerate. This result is independent of the value of the matter density. Close to the acceleration redshift, $\bar{q} \simeq 0$, and one obtains a very simple relationship linking the look-back time with the Hubble parameter

$$\Delta t = \frac{1}{H_1} - \frac{1}{H_2} \ , \tag{4}$$

where H_1 and H_2 lie on 'either side' of the acceleration redshift z_a when $q(z_a) = 0$. Since both the look-back time and the Hubble parameter can be reconstructed quite accurately, it follows that one might be able to obtain the redshift of the acceleration epoch in a model independent manner using (4).

Cosmic Microwave Background Radiation

Rapid pace of progress of cosmology in recent time owes significantly to sustained improvement in the Cosmic Microwave Background (CMB) anisotropy and polarization measurements. This trend is expected to continue unabated in the coming decade, opening up further the emerging avenues of fruitful research on subtler cosmic signatures.

As regularly reported in previous annual reports, **Tarun Souradeep** and his collaborators have a successful research programme related to the CMB anisotropy and polarization. The Wilkinson Microwave Anisotropy Probe had three data releases, most recently the five year data, in March 2008. These have made a deep impact on cosmology and related subjects. In the past year, **Souradeep** and collaborators continued their work on the WMAP data within the broad programme of research to extract subtle signatures of early universe from the CMB measurements. In this quest, they have also developed and improved analysis methods that alleviate observations artifacts that could mask, or mimic, these effects. The Planck Surveyor mission of ESA – arguably, the most ambitious of CMB experiments yet, has now been launched. Current research at IUCAA has also focused on harnessing the high quality data expected from Planck. The past year has also seen increased involvement in experimental efforts in CMB and related areas.

Angular power spectrum of CMB polarization from WMAP

As reported in previous annual reports, **Tarun Souradeep**, Rajib Saha and Pankaj 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. In previous years, the method has been used to obtain the angular power spectrum of CMB temperature fluctuations alone. The CMB polarization power spectra faced was thought to present challenges due to the sensitivity (noise level) of WMAP detectors and the expected levels of polarized foreground emission. During the last year, the group, now including Simon Prunet, Jacques Delabrouille, has successfully estimated the CMB polarization spectra (EE &

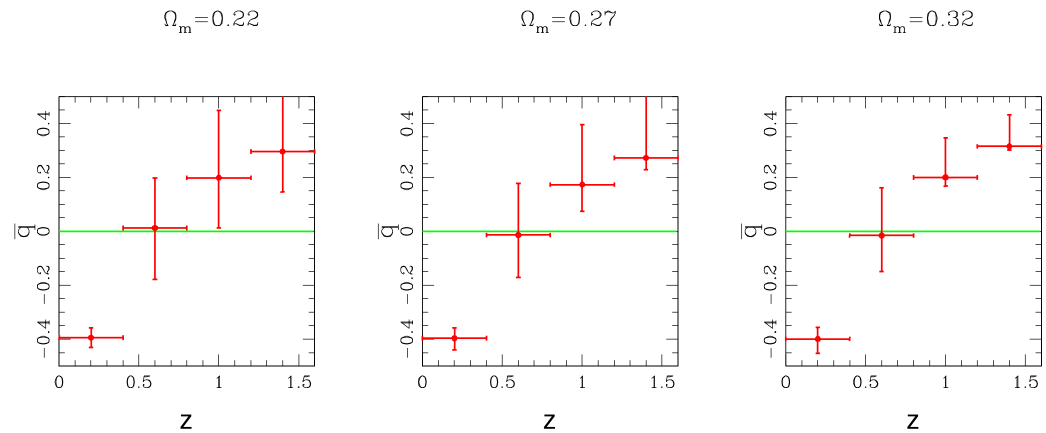


Figure 5: The diagnostic $\bar{q}$ is plotted in 4 bins using the recent Union supernovae data. The CPL ansatz has been used for three different values of the matter density. Error-bars in y-axis show $1-\sigma$ CL. Note that the value of the acceleration redshift $0.4 \leq z_a \leq 0.8$ appears to be robust.

TE) from WMAP 5 year data providing the first independent estimation and confirmation of same from the WMAP team. This result has been submitted for publication.

As reported in the previous year, with Simon Prunet, the group has published an in-depth study to identify the subtle biases in the estimated power spectrum using this method. In particular, the bias arising due to chance correlation of foreground and noise creates a non-negligible bias to the CMB polarization spectra from WMAP, that needed to be corrected in the recent results. **Tuhin Ghosh** and **Souradeep** have developed an improved method employing a clever strategy to remove this source of bias. This also alleviates the bias arising due to noise and unresolved residual point source contamination. Preliminary results allows a more robust estimation of the CMB polarization power spectra from the WMAP data. They are also including this improved method in the ongoing, comprehensive feasibility study for the recently launched Planck Surveyor mission.

Foregrounds emission in CMB anisotropy measurements

In the past year, **Tuhin Ghosh**, Rajib Saha, Pankaj Jain and **Tarun Souradeep** have refined and published the first, completely model independent estimate of the foreground contamination to the CMB maps from the diffuse galactic emission. This completes a comprehensive programme that estimates both the CMB power spectrum (reported in the previous section) and the foreground power spectrum simultaneously in a model independent approach. They have shown that relative to their model independent estimates, the model based MEM (Maximum entropy method) maps from the WMAP team overestimates the foreground power close to galactic plane and underestimates it at high latitudes. Including the low frequency Haslam map, the model independent method also allowed the estimation of the variation of the spectral index of synchrotron emission over the sky from WMAP.

Ghosh has also been engaged in a very active and interesting collaboration with A. Banday initiated during a three month visit to MPA, Garching, in the summer of 2008 under a Marie Curie

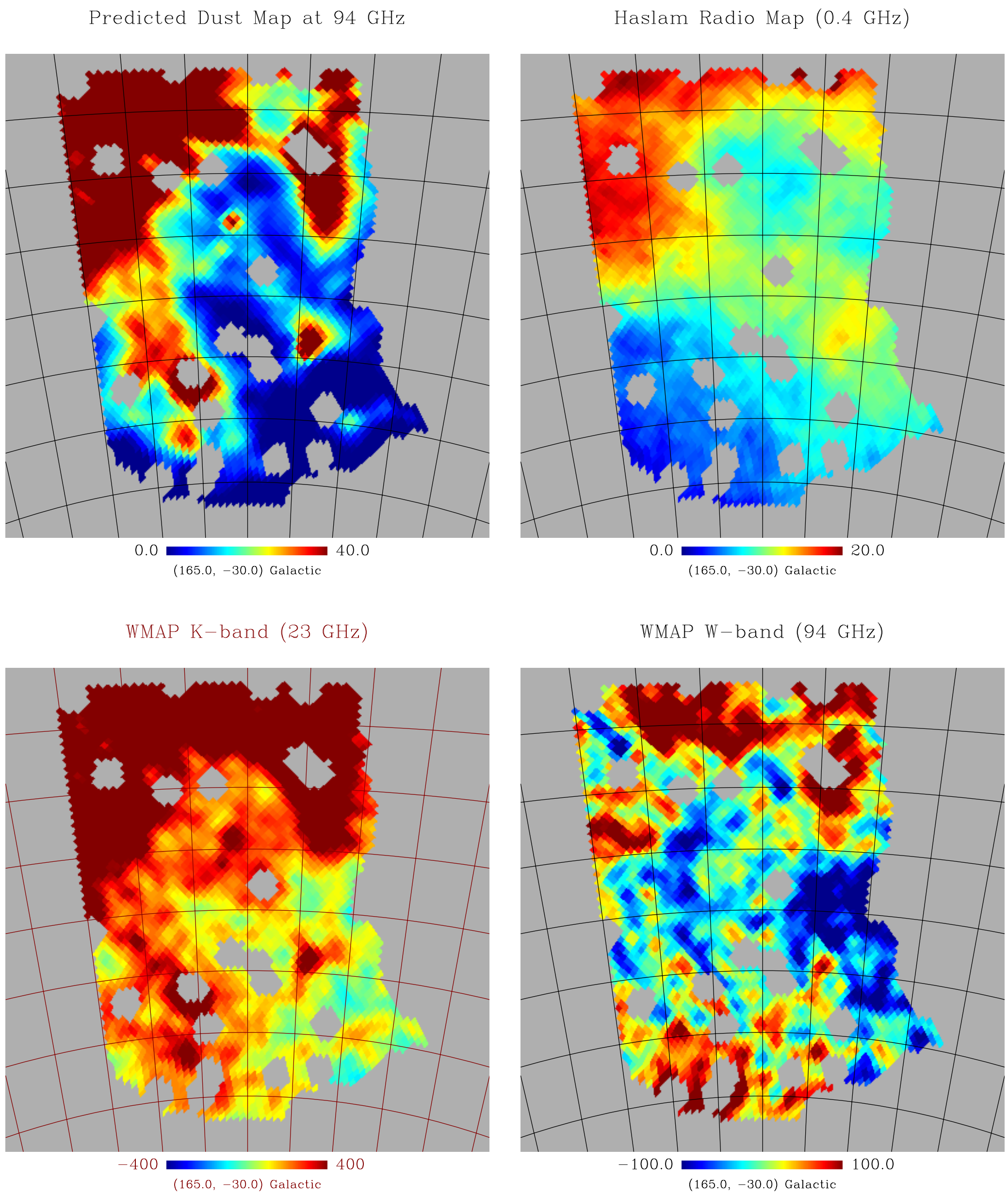


Figure 6: **Hints of spinning dust contamination in CMB measurements**.
Multi-frequency maps of a $5^\circ \times 5^\circ$ region of sky that suggests significant spinning dust emission. The top left panel is the total dust emission predicted at 94 GHz by extrapolation from SFD dust maps at 3000 GHz. The lower two panels correspond to WMAP 5 yr measurement at the K-band (23 GHz), W-band (94 GHz). The dominant feature (red region at the top) of the dust map correlates with the lower frequency K-band map than with the W-band. Since thermal dust emission (due to vibrational modes of dust grains) is expected to increase with frequency, this rules out that possibility. The top right panel is taken from the Haslam map (0.4 GHz). Further, the feature is absent in the Haslam map, which rules out hard synchrotron emission. Hence, a very plausible explanation is emission from spinning of dust grains that can be expected to become important around 10-30 GHz.

fellowship. The collaboration has carried out a comprehensive study of the different components of the foreground emission at CMB frequencies using WMAP data, in conjunction with available external templates, such as, the Haslam map of synchrotron emission, FDS dust maps and H_α maps. An important goal of this study is establish the contribution to foreground emission from spinning dust (see Figure 6). Preliminary results confirm the existence of spinning dust contamination in certain regions of the sky. Using the available H_α maps, the team is investigating if these regions correspond to stellar residuals in the galaxy. The estimated free-free emission component has also provided an independent estimate of the electron temperature in the galaxy that is found to be significantly higher than that deduced by the WMAP team.

Statistical isotropy of the CMB sky

As reported in the previous annual reports, bipolar spherical harmonic analysis has been proposed and established by the group in IUCAA as a robust measure of violation of statistical isotropy in the CMB anisotropy map. These include the bipolar spectrum, reduced bipolar coefficients and the bipolar map of correlation patterns published by **Tarun Souradeep** and Amir Hajian in previous years.

In the past year, IUCAA associate Sanjay Jhingan and his student Nidhi Joshi have been working with **Souradeep** to relate different levels of breakdown of statistical isotropy of the CMB sky to the bipolar coefficients and the bipolar map. On another front, **Tuhin Ghosh**, **Souradeep** and Hajian have recast the bipolar harmonic analysis in terms of needlet representation, allowing a better defined exploration of statistical isotropy at different angular scales.

The CMB anisotropy and polarization power measured at all angular scales arise from free-streaming of anisotropy power at very low multipole (essentially the monopole, dipole and quadrupole) at the epoch of last scattering. **Moumita Aich** and **Souradeep** have extended the CMB formalism to incorporate violation of statistical isotropy in the photon distribution function at the last scattering surface. They have shown that the statistical anisotropy of baryon-photon plasma at low multipole would free-stream to high multipole in a manner similar to the statistically isotropic part. This provide a unifying formalism to study known physical origin of statistical isotropy (such as, from magnetic fields in the baryon-photon plasma) and also allow a study of the new physical effects.

Early universe from CMB

The observables of the perturbed universe, CMB anisotropy and large structures, depend on a set of cosmological parameters, as well as, the assumed nature of primordial perturbations. In particular, the shape of the primordial power spectrum is, at best, a well motivated assumption.

As reported in previous annual reports, the accurate measurements of the angular power spectrum over a wide range of multipoles from the WMAP have allowed **Arman Shafieloo** and **Tarun Souradeep** to deconvolve the primordial power spectrum from the angular power spectrum of CMB anisotropy measured by WMAP. The robust features in the published primordial spectrum derived from WMAP first year and three year data, reported in previous annual reports, have been recently reconfirmed by a group in Imperial College using a similar deconvolution technique, but including recent CMB polarization data.

It is known that the assumed functional form of the primordial power spectrum can affect the best fit parameters and their relative confidence limits in cosmological parameter estimation. In a recent paper submitted for publication, they have demonstrated that a specific assumed form actually drives the best fit parameters into distinct basins of likelihood in the space of cosmological parameters, where the likelihood resists improvement via modifications to the primordial power spectrum (see Figure 7). The regions where considerably better likelihoods are obtained allowing free form primordial power spectrum lie outside these basins. Hence, the apparently 'robust' determination of cosmological parameters under an assumed form of $P(k)$ may be misleading and could well

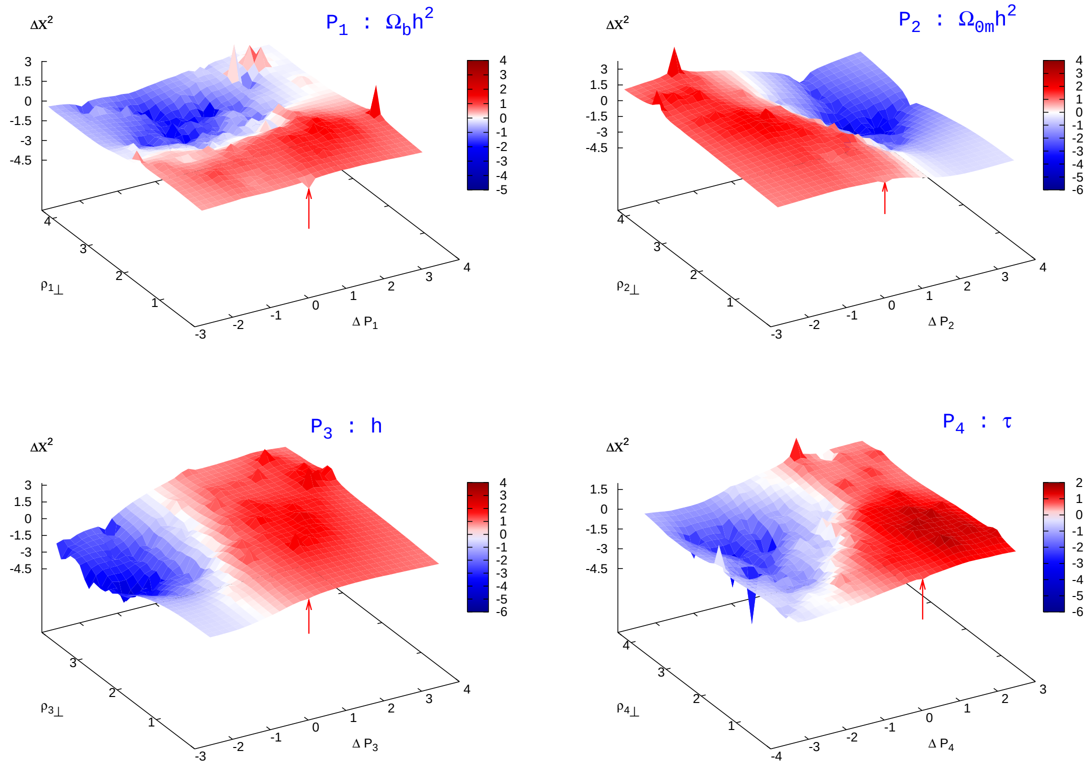


Figure 7: **Basins in cosmological parameter space around best-fit model under the power law primordial power spectrum assumption.**
A $2D$ surface representation of the optimized $\Delta\chi^2$ around the best-fit point assuming a power law form of the primordial power spectrum for the four parameters. For each parameter, i, ΔP_i measures separation along the parameter, and $\rho_{i_\perp}$ measures the separation in the three other parameters in units of their standrad deviation at the best-fit point. Regions in the parameter space with $\Delta\chi^2 > 0$ are shown by red colour and are separated by a white band (representing $\Delta\chi^2 \approx 0$) from the regions with $\Delta\chi^2 < 0$ shown by blue colour. Red plateaus represent the regions where allowing the free form primordial spectrum does not improve the likelihood. Red arrows show the position of best fit point assuming power law form of the primordial power spectrum.

largely reflect the inherent correlations in the power at different k implied by the assumed form of the primordial power spectrum. In the absence of a preferred model of inflation, this raises a concern that current cosmological parameters estimates are strongly prejudiced by the assumed form of primordial power spectrum. The results strongly motivate approaches toward simultaneous estimation of the cosmological parameters and the shape of the primordial spectrum from upcoming cosmological data. It is equally important for theorists to keep an open mind towards early universe scenarios that produce features in the primordial power spectrum.

The robustness of the features in the primordial power spectrum motivates study of models of inflation that predict such features. **Souradeep** has initiated a long term research programme with L. Sriramkumar and collaborators on this front. In a recent publication, they have proposed 'Punctuated Inflation' models, where a brief interruption of inflation produces features similar to that suggested by direct deconvolution work. The punctuated inflation model can be realized in a single scalar field model of inflation with a simple, well motivated, potential. Punctuated inflation predictions have an improved fit to the CMB data ($\Delta\chi^2_{\rm eff} = 6$) relative to the power law primordial spectrum case with the addition of only one extra parameter. The improvement should be contrasted with that obtained by adding a parameter that allows the spectral index to 'run' (change at fixed rate) with wave-number.

Besides, providing a better fit to data, punctuated inflation scenario brings to the fore new aspects in the understanding of inflationary predictions. Typically, in single scalar field models of inflation, the tensor to scalar ratio (r) does not exceed unity. In another paper submitted for publication, it has been shown that these models present the first published instance of a single scalar field model that allow $r \gg 1$(i.e., exceed unity by large factor). Large r values possible in these scenarios could lead to observable effects of inflationary gravity waves in CMB B-mode polarization measurements in other implementations of Punctuated inflation. **Gaurav Goswami** has embarked on his Ph.D. work with a careful study of this phenomena and to construct punctuated inflation models with observable signals in the CMB B-mode polarization.

Systematic effects in CMB measurements

In this era of high precision CMB measurements, subtle systematic effects limit the ability to extract cosmological information with precision and reliability. The non-circularity of the experimental beam has become progressively important as CMB experiments strive to attain higher angular resolution and sensitivity. There has been sustained effort in addressing this challenging problem regularly reported in the previous annual reports. In the past year the group (S. Mitra, A. Sengupta, S. Ray, R. Saha, and **T. Souradeep**) has published a comprehensive analysis of the effect of beam non-circularity for CMB measurements accounting for incomplete sky coverage. Work on this front is being now carried out in the context of Planck mission by Sanjit Mitra at JPL-Caltech.

A CEFIPRA funded Indo-French collaborative research programme with Francois Bouchet and Simon Prunet on the systematic effects in the Planck CMB measurements has been underway over the past three years. Work continues on the challenging research programme to decompose the non-circular part of beam prior to the map-making stage that can allow CMB experiments, such as Planck, to produce final maps that are effectively smoothed by a circularly symmetric beam.

Experimental efforts in CMB and related observations

Inflationary gravity wave background in CMB B-mode polarization

Remarkably, the results from CMB experiments and other observations are completely consistent within the simplest realization of the inflationary paradigm. The next generation of CMB experiments aim at providing a direct evidence for the inflationary paradigm through the detection of an inflationary gravity wave background in the B-modes in CMB polarization.

Siddharth Malu is a part of the QUBIC (Q-and-U Bolometric Interferometer for Cosmology) collaboration, which aims to build a ground-based prototype of a bolometric (additive interferometer) at several frequencies. The first prototype, the MBI (Millimetre-wave Bolometric Interferometer) is currently taking data and **Malu** is involved with the analysis of data from it.

QUBIC, like all other planned B-mode probes, will have a large ($\sim 30\%$) bandwidth. This will lead to a so-called 'bandwidth-smearing' effect, leading to a loss of resolution in the power spectra estimated from the instrument. For a CMB interferometer, every baseline is sensitive to a fixed value of ℓ. The ℓ-bandwidth $\Delta\ell$ is determined by the bandwidth of the instrument ($\Delta\nu$), and $\Delta\ell \propto \Delta\nu$. This poses a serious problem: for very wide bandwidths, the signal in the power spectrum is "smeared" over $\Delta\ell$; for ℓ=100, $\Delta\ell$=30.

The signature of inflation in B-modes at $\ell \sim$100 is subtle, since it is expected to be found in between two other peaks, namely from lensing (at higher ℓ) and reionization (at low ℓ). Any smearing (with $\Delta\ell \sim$ 20–30) is, therefore, going to make it nearly impossible to detect any B-mode signature. In the Quasi-Optical Beam Combiner, visibilities are weighed with fringes, which are different for different wavelengths/frequencies. His ongoing effort focuses on the fact that since these fringes are planned to be sampled finely enough in the focal plane, visibilities can be split into sub-bands. Combined with the coherent addition of equivalent baselines, this technique yields a better signal-tonoise over any given ℓ–range.

Malu and **Souradeep** are also exploring the possibility of locating a CMB experiment at a dry, high altitude location in India, such as, Hanle.

SZ effect in galaxy clusters as probe of intra-cluster gas dynamics

There are surveys underway to use the Sunyaev-Zeldovich effect (SZE) to construct cluster catalogues out to cosmological distances. Using SZE along with X-ray emission images to infer cluster gas parameters, and cosmological parameters and evolution does depend on model assumptions for the gas distribution. The formalism becomes untenable if cluster gas is out of equilibrium, as would be the case when mergers of different magnitudes stir up the gas. For this reason, it is important to understand in detail the physical processes in the ICM, in different perturbed states, with high spatial resolution to examine whether significant departure of the gas from the underlying assumptions usually adopted are generic.

Malu is part of a collaboration led by Ravi Subrahmanyan on observations of the bullet cluster of galaxies towards such an estimate. First observations for point-source characterization, have been recently taken by them at ATCA. The main observations, meant for sub-structure resolution and extracting the SZ effect, are scheduled to be carried out in the last week of June 2009.

The GMRT epoch of reionization (EoR) project

The CMB photons come from the epoch of recombination at $z \sim 1100$ when the universe became neutral. However, it is well established the universe has been reionized recently at redshifts of $z \sim 6-10$ by first stars and/or quasar activity. The precise epoch and the evolution of the reionization process provides an observation probe into the process of star and galaxy formation. The epoch of reionization is constrained by CMB anisotropy and polarization measurements through the optical depth of free electrons. However, the complimentary measurement of fluctuations in the neutral hydrogen density during reionization can also be made by the (appropriately redshifted) 21 cm line at very low radio frequencies. There is a global growing frontier of cosmology involving number of ongoing and upcoming experiments to detect these fluctuations.

The low-frequency bands in the GMRT ($\sim$ 50 MHz) are ideal for probing the Epoch of Reionization (EOR) through the redshifted 21-cm line in neutral hydrogen. In the past few years, GMRT EoR project has made remarkable progress in addressing the challenges such as, the radio frequency interference, to bring GMRT within striking distance of detecting EoR signatures.

Souradeep and collaborators have recently joined in GMRT EoR project. Before even EoR foregrounds are characterized, a precise estimate of instrument response is needed. **Malu** plans to work on the implementation of a numerically efficient estimation technique, Gibbs sampling, to the estimation of the full polarized response of every antenna in the GMRT.

The EoR observation provide multi-frequency visibility maps dominated by foregrounds. While the foregrounds contribution is nearly constant, the small cosmic signal varies rapidly with frequency. This problem is complimentary to case of CMB foreground removal discussed earlier. **Tuhin Ghosh** and **Souradeep** are working to implement a similar model independent method to extract the cosmic reionization signal from the multi-frequency visibility maps.

Observational Cosmology and Extragalactic Astronomy

Size evolution of galaxies at high redshifts

In CDM models of disk formation, the scale size of a disk galaxy is determined by the angular momentum acquired via tidal torques between the merging dark matter halos. The specific angular momentum or the spin parameter of the dark matter halos has a lognormal distribution. It is therefore expected that the disk size distribution would also be similar, and any departure from the lognormal distribution would reflect the evolutionary effects in the baryonic component. **Swara Ravindranath** and collaborators showed that the sizes of disk galaxies had not evolved significantly since $z = 1$. In other words, large disks such as seen in the local universe, were already in place by that epoch. However, at high-redshift ($z > 2.5$), the galaxy sizes were 40-50% smaller in scalelength compared to the present-day galaxy disks. One of the main problems when trying to understand the size evolution, is the role of size-luminosity relation. Since, there is a correlation between the size and luminosity, any bias in the luminosity distribution will reflect on the observed size distribution. Therefore, the luminosity evolution and size evolution have to be studied hand-in-hand. Even at high redshifts ($z > 2$), the luminosity function of galaxies is fairly well-represented by the Schecter function. In collaboration with Harry Ferguson, and Huang Kuang-han, **Ravindranath** is involved in studying the bi-variate luminosity-size function of Lyman-break galaxies at $z = 3$ and $z = 4$ for which high spatial resolution images are available using the Hubble Space Telescope. At these high redshifts, it is important to characterize the completeness of the samples, and for this purpose we are carrying out extensive Monte-Carlo simulations. In addition, the size measurements suffer significantly from the cosmological surface-brightness dimming, and measurement biases. Extensive simulations are being performed to fully understand the selection effects and biases that drive the observed size-luminosity distribution. These simulation results will be then used to correct for the selection effects and biases, and study the evolution of the intrinsic size-luminosity relation at high redshifts.

Nuclear structure of lenticular galaxies:

The central regions of galaxies hold important clues to the physical processes that govern galaxy evolution. In the last decade, several studies focussing on early-type galaxies have shown a dichotomy in the nuclear structures, which can be traced to two possible formation mechanisms. While the low luminosity spheroids have steep cusps suggestive of recent gas accretion and star formation, the most luminous galaxies show flat cores in their centers. The core formation has been attributed to the scouring action of binary black holes during gas-poor galaxy mergers. Spiral galaxies, on the other hand, almost always have nuclei or star clusters in the centers, suggesting gas-rich, dissipative processes are important in their formation. Sudhanshu Barway and **Swara Ravindranath**, have undertaken a study of lenticular galaxies, the global properties of which straddle the regime between ellipticals and spiral bulges. The results show that the lenticulars along with the spiral bulges, and ellipticals form a continuous sequence of cusp slopes from the lowest luminosity ($M_V > -15$ to $M_V \sim -21$). The correlation between the cusp slope and luminosity, and the frequency of compact stellar nuclei, are suggestive of a dissipative formation history involving gas-rich mergers, gas accretion to the central region, and subsequent star formation. The most luminous ellipticals, and BCGs at $M_V < -21$ depart from this sequence and exhibit very flat cores, favouring a formation involving gas-poor mergers and binary blackhole effects. It appears that the observed dichotomy in the properties of spheroids that were reported in the literature previously, may have been the results of viewing only a part of the parameter space occupied by galaxies with $M_V < -19$. Taking all bulges, over a large range in luminosities, clearly shows a dominant, continuous sequence of gas-rich mergers, with core galaxies clearly falling off this sequence at high luminosities.

Diffuse bubble-like radio-halo emission in MRC 0116+111: Imprint of AGN-feedback in a cluster of galaxies

Recent X-ray observations with *Chandra* and *XMM-Newton* have revealed a surprising aspect of cooling flows in clusters; they showed far less cooling below X-ray temperatures than expected, altering the previously accepted picture of cooling flows. A cooling-flow is established when the central radiative cooling time (t_{cool}) of the intra-cluster medium (ICM) of a galaxy cluster is quite short ($t_{cool} \lesssim 1$ Gyr $<< H_0^{-1}$, the Hubble time). In the absence of a central heating mechanism, the pressure balance is disturbed and to restore the hydrostatic equilibrium, a steady convergent flow of cooling gas towards the cluster centre is setup, in which the gas cools below the X-ray temperature and accretes onto the central elliptical galaxy. Unless gas is thermally supported, radiative cooling leads to a 'cooling catastrophe', i.e., inexorable inflow of cold gas onto the central galaxy. To prevent this, some heating mechanism was required to raise gas temperature above ~ 2 keV, suppressing the cooling flow. Although, several such mechanisms are possible, the most effective heating process is the energy injected into the intra-cluster medium by radio jets from AGNs of central galaxies of clusters and groups (AGN feedback). Almost all cool-core clusters harbour powerful central AGNs, which suggests that they are fuelled by accretion of cooling gas, and possibly the flow rate itself is regulated by AGN-heating. Many details of how this AGN-ICM feedback process works are still far from clear. Radio jets from a central black hole (AGN) would be subjected to the confining influence of ICM, which would result in two bubble-like lobes of non-thermal plasma, filled with relativistic particles and magnetic field, and thus become visible in radio observations. This 'bubble model' was first proposed theoretically in 1970s and recently identified in several clusters using radio, and X-ray observations; such as those in clusters MS0735.6+7421, Hydra-A, and many others, showing an unusually large and energetic pair of radio emitting, X-ray dark cavities. Intermittent (on-off) activity of radio jets injects radio bubbles which may heat the ICM via weak shocks, and these plasma bubbles are largely responsible for the mechanical (PdV) work on the ICM for heating it, which is one of the suggested mechanism of AGN-ICM feedback. Therefore, radio and X-ray observations of bubble-like, diffuse radio sources near cluster centres can provide crucial data for understanding this very important yet poorly understood astrophysical process.

Joydeep Bagchi and his collaborators [Joe Jacob, Gopal-Krishna, Norbert Werner and university collaborators] studied the astrophysics of a intriguing, halo-like diffuse radio source MRC 0116+111, located at the centre of a sparsely populated galaxy cluster at redshift 0.131. To clarify the physical picture of this puzzling object, high sensitivity GMRT observations were taken at 1.28 GHz, 621 MHz and 240 MHz frequencies, and the earlier VLA observations taken in C-band (4.86 GHz) and L-band (1.4 GHz) were re-analysed. Deep optical broad-band (*B, V, R, I*) CCD imaging observations of the host galaxy cluster were also taken with the *IUCAA Faint Object Spectrograph and Camera* (IFOSC) on the 2m telescope of the IUCAA Girawali Observatory (IGO). For spectroscopy ESO 3.6 m New Technology Telescope (NTT) and EMMI (ESO Multi-Mode Instrument) was used, which gave a redshift $z = 0.1316$ for the brightest central cD galaxy and $z = 0.1309$ for the second brightest elliptical galaxy $\sim 15''$ south of cD, suggesting a cluster or group like environment (see Figure 8).

A radio-optical overlay of GMRT 1.28 GHz radio map and IGO optical CCD image of MRC 0116+111 show a highly diffuse 'halo' or 'bubble' like structure which closely resembles the so-called 'radio mini-haloes'. Mini-halos are $\sim$100 kpc scale, low surface brightness amorphous radio sources with a steep spectral index ($\alpha \lesssim -1$, $S_\nu \propto \nu^\alpha$), which are rare objects and found around powerful AGNs residing at the center of cooling-core clusters (such as; Perseus-A, M87, Abell 2626 etc.). On larger scales ($\sim$100 kpc) the radio-halo of MRC 0116+111 comprises of two diffuse 'cocoon'-like structures surrounding the central cD and its group of galaxies (Figure 9), which was interpreted as a pair of radio-emitting giant plasma bubbles, filled with relativistic particles (cosmic rays) and

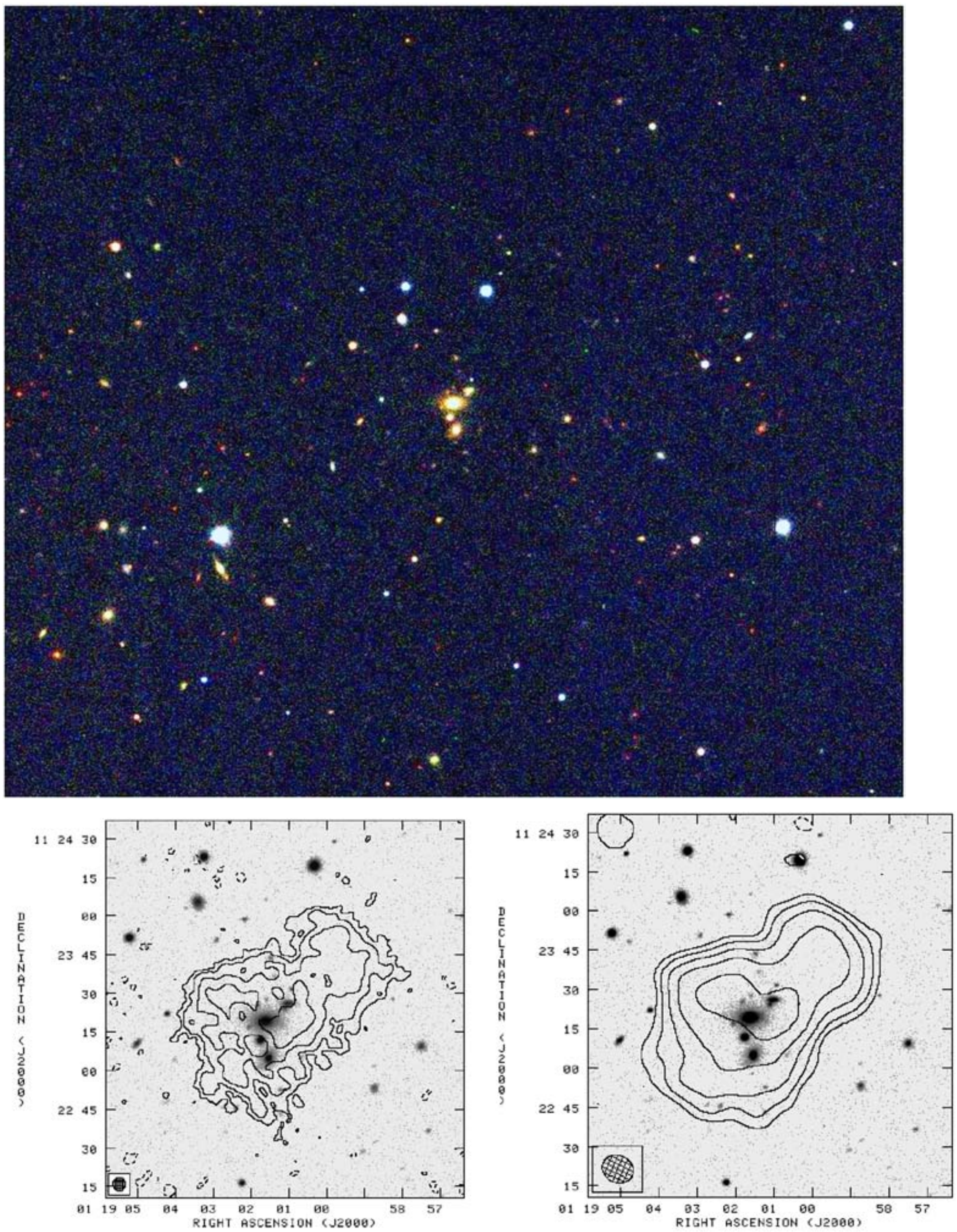


Figure 8: Upper panel: A *B,V,R* false-colour composite of the central region of galaxy cluster hosting MRC $\sim$ 0116+111. The region shown is about 8.3 arcmin $\times$ 7 arcmin in size and north is on top and east is to the left. This image is made using the IUCAA Girawali Observatory (IGO) 2 m telescope. Lower left pane: GMRT 1.28 GHz map of MRC $\sim$ 0116+111 shown with contours (levels: $\pm$ 0.24, 0.48, 0.96, 2, 4, 8 mJy/beam, noise r.m.s. 0.08 mJy/beam, beam: 5 arcsec FWHM circular, plotted inside box) overlayed on IGO R-band image. No AGN (radio core) is visible down to $\sim$ 1 mJy/beam flux density limit, and no radio jets or lobes are detectable either. Lower right panel: GMRT 240 MHz map shown with contours (levels: $\pm$ 4, 8, 16, 32, 64, 128 mJy/beam, noise r.m.s. 1.35 mJy/beam, beam: 12.15 arcsec$\times$10.31 arcsec FWHM at 65.4 deg PA, plotted inside box). In the background is shown the IGO R-band image of the galaxy cluster.

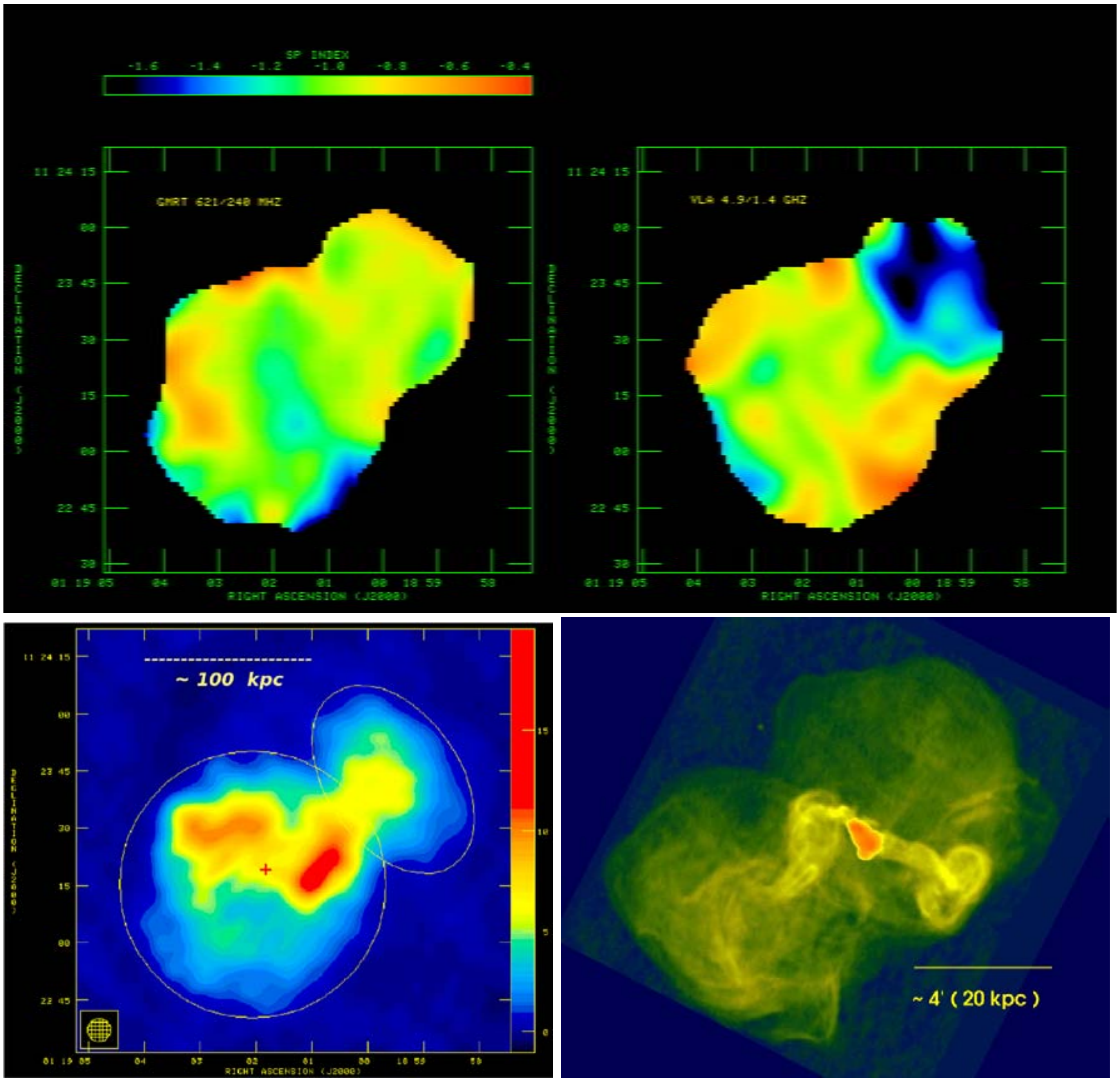


Figure 9: Upper panel: Low and high frequency spectral index maps of MRC $\sim$ 0116+111 obtained by combining the GMRT radio maps at 240 and 621 MHz (left panel), and VLA maps at 1425 and 4860 MHz (right panel). Both pairs of maps have the matched resolution of 12 arcsec (HPBW). The colour-bar shows the spectral index values. A significant spectral steepening (mean $\alpha = -1.6$; $(S_\nu) \propto$ frequency $(\nu)^\alpha$) for the north-western bubble at high-frequency can be clearly seen. Lower left panel: GMRT 621 MHz false-colour image of MRC $\sim$ 0116+111 (beam: 6 arcsec FWHM circular, plotted inside the box) showing the twin bubble-like diffuse radio structure. The position of brightest central galaxy (cD) is shown by a '+' symbol. The dotted lines delineate the two $\sim$100 kpc scale giant radio bubbles. Lower right panel: The VLA 90 cm radio image of M87, the dominant central radio galaxy in the Virgo Cluster. The original map has been reflected and rotated for a better comparison with the MRC 0116+111 radio map (reproduced by permission of the AAS). The morphological similarity between the two radio sources is striking.

magnetic field. The 1.4 GHz radio luminosity of MRC 0116+111, $L_{1.4\,\mathrm{GHz}} = 4.57 \times 10^{24}$ W/Hz, is quite large, comparable to the luminous radio-halos in Perseus and A2390 clusters. Its bolometric radio luminosity (over 10 MHz - 10 GHz range), $L_{\mathrm{radio}} = 3.64 \times 10^{34}$ W, would place it amongst the most luminous radio halos known. The integrated radio spectrum (Figure 9) shows a sudden spectral steepening beyond the 'break' frequency $\sim$ 400 MHz. The low-frequency spectral index is $-0.55(\pm0.05)$ (flux density $(S_\nu) \propto$ frequency $(\nu)^\alpha$) and the high-frequency spectral index is $-1.35(\pm0.06)$. The electron 'spectral age' was derived to be in the range $(1.33 - 0.64) \times 10^8$ y, for magnetic field range 1 - 10 μ G. The pair of huge ($\sim$ 100 kpc scale) plasma bubbles also show marked spectral index differences (Figure 9). Between 240 and 621 MHz (GMRT), both bubbles show a mean spectral index $\alpha_{mean} \approx -1$, indicating a lack of strong radiative losses. However, whereas between 1.4 and 4.8 GHz (VLA) the south-eastern bubble still has the same average spectral index value around -1 ($\alpha_{mean} = -1.06 \pm 0.15$), the north-west bubble, in contrast, shows an extremely steep spectrum ($\alpha_{mean} = -1.6 \pm 0.20$), clearly due to strong radiative energy losses.

Such a situation might be explained if the very steep spectrum north-western bubble is buoyantly rising in the hot cluster atmosphere and then detaching itself from a centrally located mechanism of energy injection, while this source or mechanism is still active and possibly injecting relativistic particles into the flatter spectrum south-eastern bubble. One possibility is AGN activity, though neither a radio core nor any jets could be detected (Figure 9). Thus, it is plausible that these bubbles were inflated by the pressure of radio-jets in a previous very energetic episode of AGN activity, which has now either ceased, or has become too feeble to be detectable. The central parts of radio-halo may be undergoing enegization by an ongoing in-situ particle reacceleration mechanism, which could arise in merger induced shocks, or through magneto-plasma turbulence acceleration acting on relic electron population left behind by the past episodes of AGN activity. The radio bubbles in MRC 0116+111 are also very interesting from the view point of X-ray observations, because such uprising bubbles are the potential precursors of the giant non-thermal, X-ray dark 'ghost' cavities observed by *Chandra* in a few clusters.

Comparison of the GMRT 621 MHz radio map with the deep VLA 90 cm image of M87 (the central radio galaxy in Virgo cluster) reveals striking morphological similarities. M87 shows an extensive diffuse outer structure extending upto $\sim$ 40 kpc from the nucleus. Two collimated flows emerge from the inner-jet region, one directed north-eastward and the other oppositely directed (orientation as shown on the rotated image, Figure 9). The south-west flow ends in a well-defined pair of edge-brightened torus-like vortex rings. The north-eastern flow develops a gradual but well-defined S-shaped southward twist, starting only a few kiloparsecs beyond the inner lobes. Finally, both flows are embedded in a giant diffuse structure that might be described as two overlapping 'bubbles', each extending about 40 kpc from the nucleus. After reaching the halo, the flows gradually disperse, the north-eastward flow particularly, and appear to be filling the entire halo with radio-loud, filamented plasma. Very similar flow pattern was found in the central region of MRC 0116+111; an edge brightened torus-like 'mushroom' structure about 40 kpc west of the center, analogous to the peculiar 'ear-shaped' vortex structure of M87. Here the flow pattern sharply turns northward and appear to be flowing into the steep-spectrum radio bubble to the north-west. Also present is an S-shaped flow pattern to the east north-east of the center, which further bends southward, and clearly resembles the filamentary structure visible in the southern bubble of M87 (Figure 9). Both these radio sources are surrounded by a pair of huge radio emitting 'bubble' like lobes. The similarity of large scale radio structures indicates that both sources might have originated in, and their evolution governed by, similar physical process and conditions prevailing in the central regions of their host clusters. Several Hydrodynamic simulations of AGN-fed bubbles in cluster medium have suggested that these twin bubbles in M87 are buoyant bubbles of cosmic rays, inflated by jets launched during an earlier nuclear active phase of the central galaxy, and which rise through the cooling gas at roughly half the sound speed. As shown above, detection of a ∼100 kpc scale very steep-spectrum radio bubble ∼100 kpc north-west of center of MRC 0116+111 strongly supports this model. The flattened 'mushroom' shape of this plasma bubble suggests a rapidly rising vortex-ring form, into which an intially spherical bubble would naturally transform due to viscosity and drag forces.

Bagchi and collaborators have been allocated observing time on *Chandra*. High resolution X-ray imaging of MRC 0116+111 with *Chandra* will probe the intracluster medium, look for a cooling-core and search for tell-tale signs of radio plasma-ICM interaction: such as giant X-ray dark cavities, bright filaments and evidence for shock heating. Detection of such giant cavities will allow 'calorimetry' for estimating the energy injected into the cooling gas by the rising bubbles. It is also feasible to search for non-thermal inverse-Compton X-ray emission of radio bubbles from lower energy electrons (with Lorentz factor $\gamma \sim 600$ - 3000) up-scattering the CMB photons. Combination of the observed non-thermal X-ray and radio fluxes will determine the volume averaged magnetic field of intra-cluster medium in cluster core, which is currently unknown.

AGNs, Quasars and IGM

A complete sample of 21 cm absorbers at z ∼ 1.3: Giant Metrewave Radio Telescope survey using MgII Systems

Observations of high-z galaxies suggest that the global comoving star-formation rate density peaks at $1 \leq z \leq 2$ and then sharply decreases towards $z \sim 0$. The determination of the mass density of the gas and its content (molecules, dust and cold H I gas) over the same redshift range provides an independent and complementary understanding of the redshift evolution of star-formation at similar epochs. While the H I content of galaxies can be best probed by the surveys of 21 cm emission, limited sensitivity of current radio telescopes does not allow them to reach beyond the local Universe. On the contrary, detection of H I in the spectra of distant QSOs in the form of damped Lyman-α absorption provides a luminosity unbiased way of probing the evolution of the H I content in the universe.

Our understanding of physical conditions in DLAs at $z \geq 2$ is largely based on the analysis of H_2 and/or atomic fine-structure transitions. Unfortunately, for the time being, the above mentioned tracers can not be used to probe the physical state of the absorbing gas at $z \leq 1.8$, because the useful transitions are located below the atmospheric cut-off. It has been shown by that DLAs essentially have Mg II rest equivalent width, W_r(Mg IIλ2796) $\geq$ 0.6Å. Therefore, the search of 21-cm absorption in a sample of strong Mg II absorbers is an unique way to probe the redshift evolution of physical conditions in DLAs like absorption systems at intermediate and low-z.

R. Srianand, P. Noterdaeme and their collaborators (Neeraj Gupta, Patrick Petitjean, D. J. Saikia) have carried out a complete survey using GMRT. Their sample is drawn from the identification of strong Mg II systems, W_r(Mg II λ2796)$\geq$ 1.0Å, by in SDSS DR3 and using an automatic procedure for additional systems in DR5. They have selected the absorbers that are in the redshift range: $1.10 \leq z_{abs} \leq 1.45$ such that the redshifted 21 cm frequency lies in the GMRT 610 MHz band. GMRT is the only radio telescope available at present in the *relatively* RFI-clean environment (say compared to Green Bank Telescope or Westerbork Synthesis Radio Telescope) for covering this redshift range. These absorbers are then cross-correlated with NVSS and FIRST surveys to select the Mg II absorbers in front of compact radio sources brighter than 50 mJy and hence, suitable for the 21 cm absorption search. The redshift distribution of the 35 Mg II absorption systems observed as part of their GMRT survey along with the sample of Lane (2000) are plotted in Figure 10. Latter is the only large survey at low-z for which both detections and non-detections are systematically reported. It includes 62 systems observed with the WSRT and 10 other systems from the literature satisfying their selection criterion. The detections shown as a hatched histogram include detections reported in Lane (2000) together with detections from better quality data for systems that

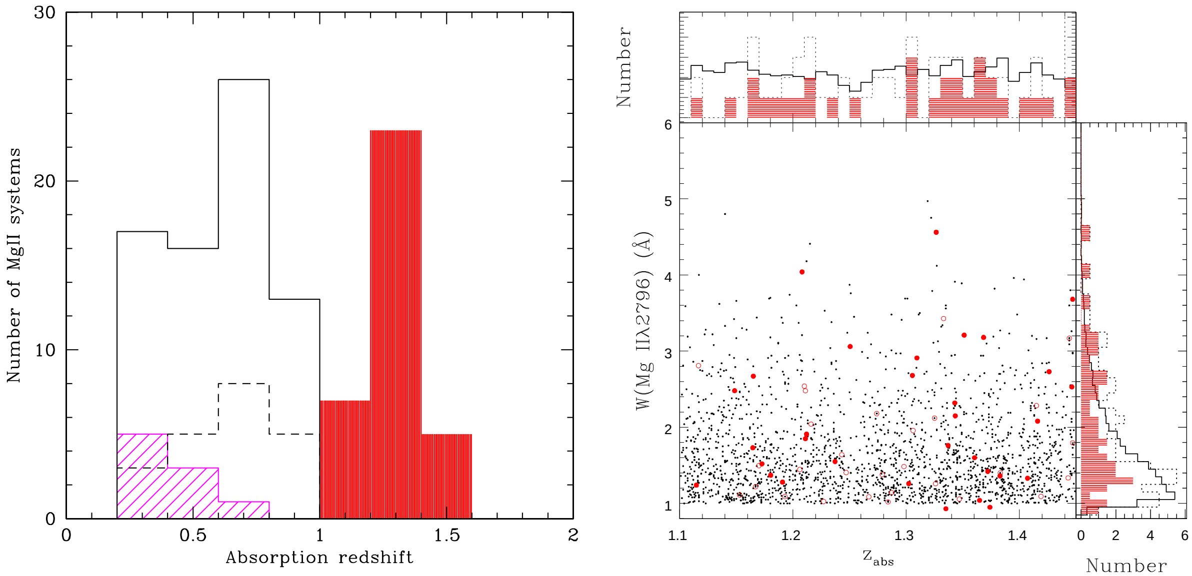


Figure 10: (left) Redshift distribution of Mg II systems that were searched for 21 cm absorption. The filled histogram is the GMRT sample of 35 Mg II systems presented in the work of **R. Srianand**, et. al. (33 of these absorption systems have W_r(Mg IIλ2796)≥ 1Å). The solid line histogram is for the sample of Lane (2000). The hatched histogram corresponds to 21 cm detections in this sample. The distribution for the W_r(Mg IIλ2796)≥ 1Å sub-set of these systems is given by the dashed line histogram. (right) Mg IIλ2796 rest equivalent width as a function of the absorption redshift. Small dots are for the whole sample of Mg II systems. Open and filled circles are for the complete sample of Mg II systems in front of radio-loud QSOs with flux density greater than 50 mJy. The filled circles are the ones observed in this survey. Histograms for the distribution of $z_{\rm abs}$ and W_r are also shown. The solid, dashed and shaded histograms are for the overall Mg II sample, the Mg II sample in front of radio-loud QSOs and the sample observed with GMRT respectively.

were originally reported as non-detections. In the same figure, the filled histogram shows the distribution of Mg II systems in their GMRT sample. For equivalent width cutoff of $\sim$ 1Å, GMRT sample of **Srianand** and team has more than twice the number of systems investigated by Lane.

They observed 35 Mg II systems with GMRT 610 MHz band using in total $\sim$ 400 hrs of telescope time mostly spread over the years 2006-2008. For their survey, they have usually used the 1 MHz baseband bandwidth split into 128 frequency channels yielding a spectral resolution of $\sim 4\,\mathrm{km\,s^{-1}}$. GMRT data were reduced using the NRAO Astronomical Image Processing System (AIPS) following the standard procedures.

The survey has resulted in 9 new 21 cm detections and good upper limits for the remaining 26 systems (Figure 11). This is by far the largest number of systems detected in a single systematic survey in a narrow redshift range. Two of these systems also show 2175 Å dust feature at the redshift of the absorbers.

They study the dependence of detectability of 21 cm absorption on different properties of the UV absorption lines detected in the SDSS spectra (Figure 12). They found that if absorption systems are selected with a Mg II doublet ratio, DR < 1.3, and a ratio W_r(Mg I)/W_r(Mg II) > 0.3, the success rate for 21-cm detection is very high (up to 90%; see *right* panel of Figure 12). They notice that the detections found in a low-z sample by Lane (2000) also obey these joint constraints (see left panel of Figure 12). In their sample, they found an apparent paucity of 21 cm absorption among systems with W_r(Mg IIλ2796)>1.8 Å, the median W_r of their sample. This is contrary to what has been seen at low-z . Interestingly, most of these high W_r systems have high DR and low values of W_r(Mg I)/W_r(Mg II). This strongly suggests that the equivalent width in these systems is dominated by velocity spread and not by line saturation.

Srianand, Noterdaeme and their collaborators estimated the number of 21 cm absorption systems per unit redshift interval for a given limiting value of the integrated 21 cm optical depth and W_r(Mg IIλ2796). They showed that the fraction of Mg II systems with 21 cm absorption and the number per unit redshift decrease from $z \sim 0.5$ to $z \sim 1.3$. The decrease is larger when they used higher equivalent width cutoff. Using a subsample of compact sources, with high frequency VLBA observations available, they showed that this could not be accounted for by simple covering factor effects. As mentioned above and based on the available data, it appears that most likely the main reason behind this cosmological evolution is the decrease of the CNM covering factor (and volume filling factor) in the strong Mg II absorbers. Indeed, it is known that the number of Mg II systems per unit redshift increases with increasing redshift. The evolution is steeper for stronger systems It was found that the strongest redshift evolution was seen among the Mg II absorbers with W_r(Fe II)λ2383/W_r(Mg II)λ2796 $<$ 0.5. This clearly means that the physical conditions in strong Mg II absorbers are different at high and low-z.

They have estimated the velocity spread of the 21 cm absorption systems using the apparent optical depth method. They do not find any statistically significant correlation between W_r(Mg IIλ2796) and the 21 cm velocity width in their sample. A marginal correlation is found for the low-z sample. The absence of correlation in the high-z sample is related to the lack of 21 cm absorbers among Mg II systems with W_r(Mg II)>1.8 Å in the GMRT sample. This is probably due to a true evolution with redshift of the physical state of the Mg II systems and consistent with the idea that the Mg II equivalent width is mostly correlated with the overall kinematics of the gas in the absorbing system and not with the column density in the component associated with the cold gas. When high spectral resolution data are available, they note that the 21 cm absorption is not always associated with the strongest Mg II component.

As the energy of the 21 cm transition is proportional to $x = \alpha^2 G_p/\mu$, high resolution optical and 21 cm spectra can be used together to probe the combined cosmological variation of these constants. This GMRT survey provides systems in a narrow redshift range in which, this measurement can be done. Thus, high resolution optical spectroscopy of the corresponding QSOs are suitable to

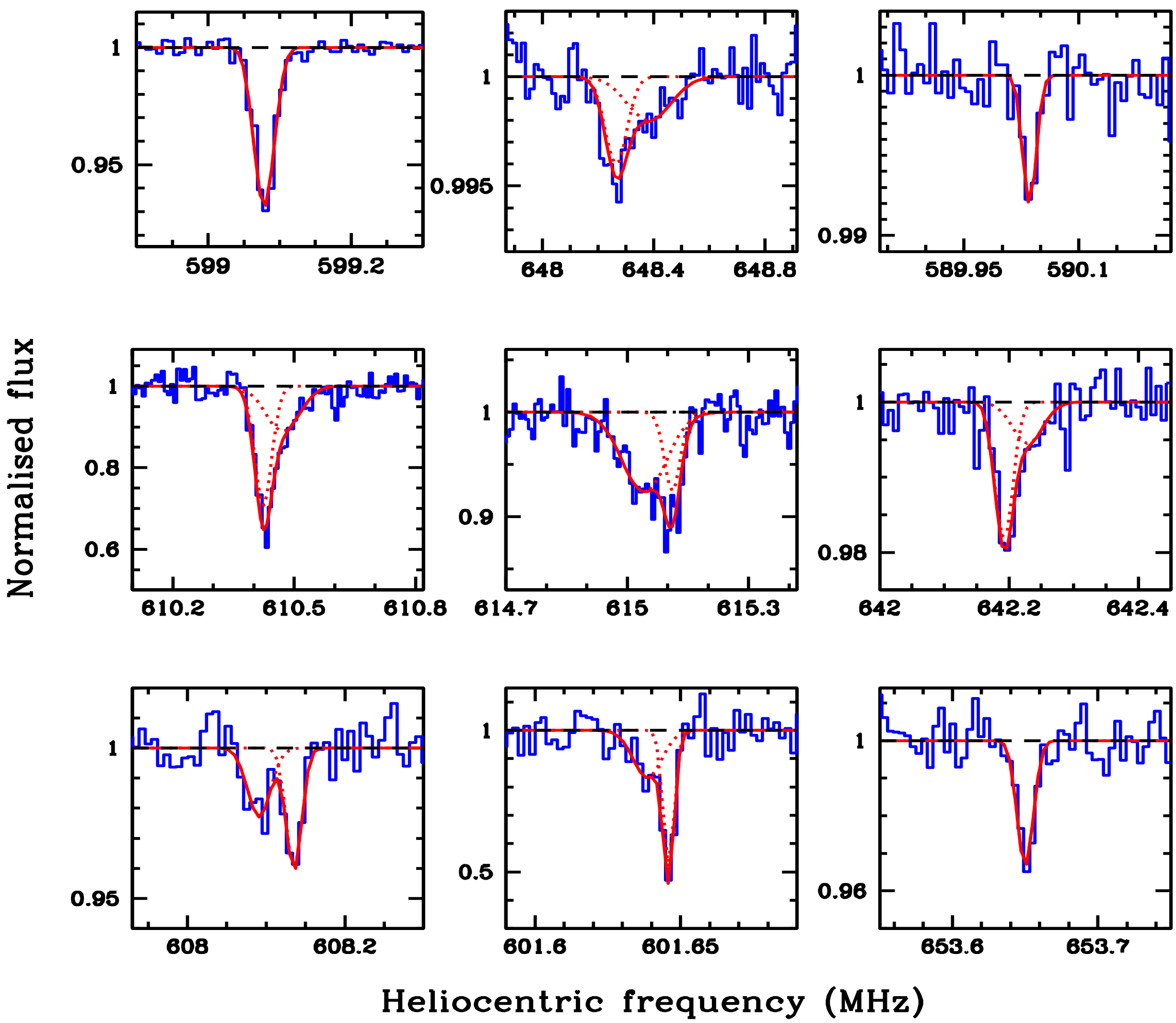


Figure 11: GMRT spectra of detected 21 cm absorption lines. Individual Gaussian components and resultant fits to the absorption profiles are overplotted as dotted and continuous lines respectively.

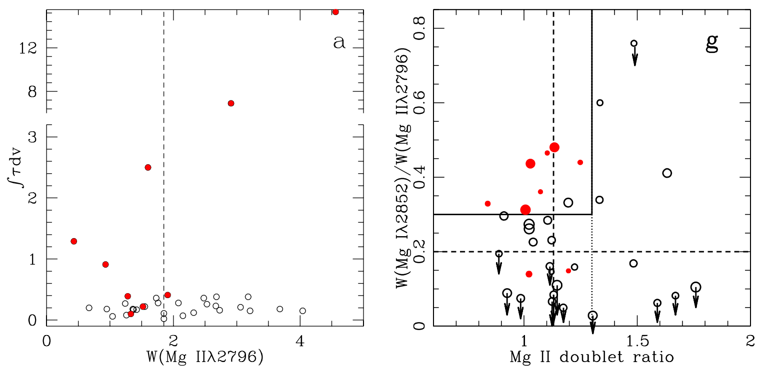


Figure 12: The integrated 21 cm optical depth is plotted against W_r(Mg IIλ2796). In the case of detection (filled circle) the optical depth is obtained by integrating over the observed absorption profile. Open circles are for 21 cm non-detections in which case, limits are obtained by integrating the optical depth over a Gaussian component with peak optical depth corresponding to the 3σ rms limit in the continuum and width 10 km s^{-1}. The ratio W_r(Mg I)/W_r(Mg II) is plotted against the Mg II doublet ratio. In both the panels, the vertical dashed line gives the median value. Other lines indicate limiting values and/or allowed ranges as discussed in the text.

perform this test at $z \sim 1.3$.

Detection of the 2175 Å extinction feature and 21 cm absorption in two Mg II systems at $z \sim 1.3$

Studying the physical conditions in the interstellar medium (ISM) at high redshift and the processes that maintain these conditions is important for our understanding of how galaxies form and evolve. The presence of dust influences the physical state of the gas through photo-electric heating, UV shielding, and formation of molecules on the surface of grains. However, we know very little about dust properties in the ISM at high redshifts. Properties of the dust can be derived from extinction curves observed in different astrophysical objects.

A correlation is observed in DLAs between metallicity and dust-depletion, which is confirmed by the higher detection rate of H_2 in DLAs with higher metallicities. The corresponding gas is cold (T∼150 K); as expected from multiphase ISM models in which, the gas with high metallicity and dust content has lower kinetic temperature than the gas with lower metallicity and dust content. However, even in the highest metallicity DLAs typical dust signatures like high extinction (i.e., 0.16 $\leq$ E(B−V)$\leq$ 0.40), 2175 Å absorption bump or the diffuse interstellar bands (DIBs) are not seen.

Recently, **R. Srianand**, **Pasquier Noterdaeme** and their collaborators (Neeraj Gupta, Patrick Petitjean and D. J. Saikia) have reported the detection of 21 cm absorption (see Figure 13) from two strong Mg II systems at z_{abs}∼1.3 towards red (u-K $\geq$ 4.5 mag) QSOs. The optical spectra of these two quasars possess 2175Å dust absorption features.

They have computed the extinction due to the Mg II system by assuming the reddening of the quasar to be a consequence of the presence of dust at z_{abs}. The optical depth at an observed wavelength λ can be written as,

$$\tau(\lambda) = 0.92 A_{\lambda_a} = 0.92 A_{V_a} \xi(\lambda_a).$$

Here, A_{λ_a} and A_{V_a} are the extinction in magnitude at $\lambda_a = \lambda/(1+z_{abs})$ and at the rest V band of the absorber respectively. $\xi(\lambda_a)$ is the relative extinction at λ_a to that in the rest V band. We consider $\xi(\lambda)$ for the SMC, the LMC2 supershell and the galaxy in order of increasing UV bump strength.

They have developed a robust χ^2 minimiza-

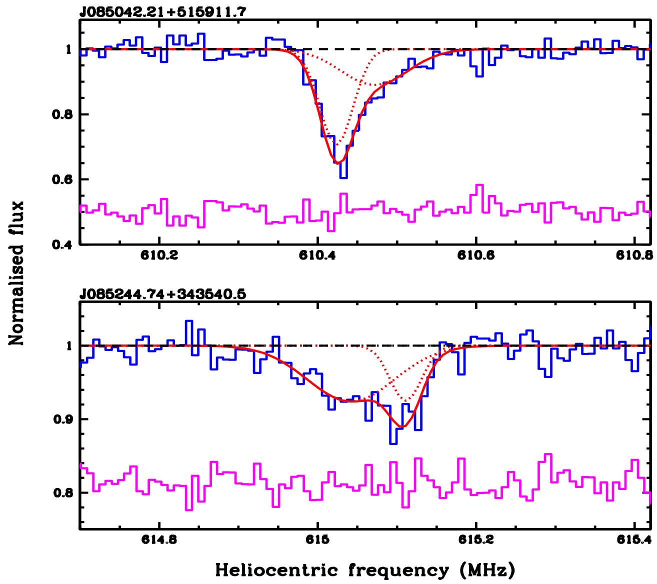


Figure 13: GMRT spectra of J085042.21+515911.7 (top panel) and J085244.74+343540.5 (bottom panel). H I 21 cm absorption is detected at $z_{\rm abs}$ = 1.3265 and 1.3095 respectively. The solid lines represent the fits to the overall profiles. Individual Gaussian components are shown with dotted lines. Residuals, on a scale arbitrarily shifted for clarity, are also plotted.

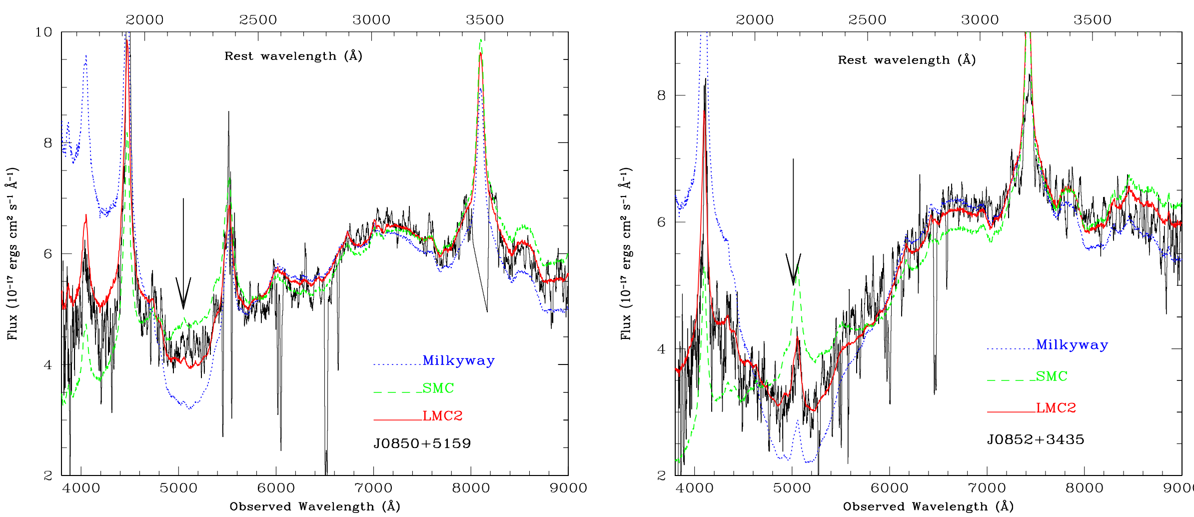


Figure 14: The SDSS spectrum of J0850+5159 (top) and J0852+3435 (bottom) are fitted with SDSS composite spectrum corrected using average extinction curves from the Milky Way (dotted), the LMC2 Supershell (solid) and the SMC (dashed). Rest wavelengths at $z_{\rm abs}$ are indicated at the top of the figure. The arrow marks the location of 2175 Å feature at $z_{\rm abs}$. For presentation purpose the observed spectrum is boxcor smoothed by 10 pixels.

tion code using the IDL routine MPFIT[1] that uses Levenberg-Marquardt technique to get best fit values of A_{V_a} and normalization of the flux scale compared to the composite spectrum.

First, they shift the composite spectrum to the QSO emission redshift. For each extinction curve they predict the reddened QSO spectrum by multiplying the shifted composite spectrum by $\exp[-\tau(\lambda)]$. By varying the flux normalization and A_{V_a} (or E(B-V)), they match the observed spectrum with the model reddened spectrum (see Figure 14). For both the systems, the lowest value of χ^2 is obtained for the dust extinction models with the extinction curve of LMC2 supershell irrespective of our choice of composite spectrum.

Therefore, the observed spectral energy distribution of these QSOs are consistent with the QSO spectrum being reddened by dust in the intervening Mg II systems. The neutral hydrogen column densities, N(H I), inferred from the extinction are consistent with the absorbing gas being of high column density (i.e., log N(H I) $\sim$ 21.7). Inferred metallicities are consistent with near-solar values and depletion factors are similar to what is measured in the cold neutral medium of LMC.

The two quasars are rather weak ($\sim$ 50 mJy) in radio emission and are not ideally suited for 21cm absorption observations. They nonetheless detect 21 cm absorption from both systems thanks to the favorable physical conditions in the absorbing gas. These are the first detections of 21 cm absorption at high-z towards such faint background sources. The inferred spin temperatures in these systems are consistent with that of a cold neutral medium gas.

The metal line equivalent widths and E(B-V) about 0.3 measured in the two systems discussed here are higher than those derived from the SDSS composite spectra of Mg II and Na I absorption systems. The E(B-V) values are also higher than the median E(B-V) found for star forming galaxies at $z = 2-3$ and a factor of 2 less than that measured in submillimetre-selected galaxies. The dust content and N(H I) in the two systems discussed are comparable to that observed in the 21-cm system toward AO 0234+164. Thus, these two systems are ideally suited for high resolution spectroscopic investigation of physical conditions in the interstellar medium of the corresponding absorbing galaxies.

[1]details of MPFIT IDL routine can be found from http://cow.physics.wisc.edu/~craigm/idl/fitting.html

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.

Magnetic quenching of alpha and diffusivity tensors in helical turbulence

An important aim in mean field dynamo theory is to determine how the turbulent mean-field coefficients are quenched due to the Lorentz forces. Much work has been done on the quenching of the α-effect but not on the quenching of the turbulent diffusivity. To address this issue, **K. Subramanian**, A. Brandenburg, K-H-Radler and M. Rheinhardt have studied the effect of a dynamo-generated mean magnetic field of Beltrami type on the mean electromotive force. In the absence of the mean magnetic field, the turbulence is assumed to be homogeneous and isotropic, but it becomes inhomogeneous and anisotropic with this field. Using what is referred to as the testfield method, the dependence of the alpha and turbulent diffusivity tensors on the magnetic Reynolds number R_m was determined for magnetic fields that have reached approximate equipartition with the velocity field. The tensor components are characterized by a pseudoscalar α , and a scalar turbulent magnetic diffusivity η_t. Increasing R_m from 2 to 600 reduces η_t by a factor about 5, suggesting that the quenching of η_t is, in contrast to the 2-dimensional case, only weakly dependent on R_m. Over the same range of R_m, however, α is reduced by a factor about 14, which can qualitatively be explained by a corresponding increase of a magnetic contribution to the α-effect with opposite sign.

Galactic dynamo action in presence of stochastic alpha and shear

The potential driver of mean-field dynamos is the α-effect, arising whenever there is rotation and stratification in a turbulent flow. Mean-field dynamo (MFD) models using a coherent α-effect and shear have been invoked to explain large-scale fields observed in disk galaxies. The possibility of efficient galactic dynamo action arising from random fluctuations in the α-effect in combination with shear is also of considerable interest. Using a simple one-dimensional $\alpha\omega$-dynamo model appropriate to galaxies, the possibility of dynamo action driven by a stochastic alpha effect in combination with shear, was studied by **S. Sur** and **K. Subramanian**

To determine the field evolution, one needs to examine a large number of different realizations of the stochastic component of α. The net growth or decay of the field depends 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. The critical dynamo number needed for the growth of the mean field in most realizations was determined. 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_{eq} for dynamo numbers $|D| \sim 40$, while fields comparable to B_{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 disk galaxies.

The shear dynamo problem: quasilinear kinematic theory

Shear flows and turbulence are ubiquitous in astrophysical systems. Recent work suggests that the presence of shear may open new pathways to the operation of large scale dynamos. S. Sridhar and **K. Subramanian** have studied the large scale dynamo action due to turbulence in the presence of a linear shear flow. Their treatment is quasilinear and kinematic, but is non-perturbative in the shear strength. They derived the 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. 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 the shear current assisted dynamo, invoked by several authors recently, is essentially absent, although large scale non-helical dynamo action is not ruled out.

High Energy Astrophysics

Gamma ray bursts

Continued Radio monitoring of the afterglow of the Gamma Ray Burst (GRB) of March 29, 2003 with the GMRT by **D. Bhattacharya** and his collaborators has revealed a simultaneous rise of the radio light curve at 1280 and 610 MHz spectral bands, peaking around 1000 days after the burst. The nature of this excess emission has close similarities to that expected from a receding jet, after its entry into non-relativistic regime of expansion. Detailed scrutiny of this result and theoretical modelling is currently ongoing.

The GRB of March 29, 2003 is well known for having displayed the first known signature of a double jet like ejection of matter - a fast-moving narrow jet at the core is surrounded by a more energetic, but slower moving "wide jet" cone. **Bhattacharya** and his colleagues have been looking for the evidence of such double jet behaviour in other GRBs as well. The GRB of April 1, 2005 (GRB 050401) turned out to be one such object. The afterglow of this GRB had been observed using the 104 cm Sampurnand Telescope in ARIES, Nainital, during 2005. Using these and other published data at multiple wavebands, a detailed, new model of this event has been constructed and it has been shown that the presence of a double jet and selective extinction can explain the large discrepancy between the X-ray and optical brightness of this afterglow.

Such a double jet model had been claimed in the literature also for the bright GRB of March 19, 2008 (GRB 080319). This afterglow was observed at the IUCAA Giravali Observatory by **Bhattacharya, A.N. Ramaprakash, K. Misra and Vijay Mohan**. Combining this with data from other observatories worldwide it has been possible to demonstrate that double jet geometry is not favourable for this object, in fact a single jet propagating in a homogeneous or a stellar-wind like medium can fit the late evolution of the afterglow light curve much better than the double jet.

Bhattacharya, along with his collaborator L. Resmi has also been working on the modifications required in the standard GRB afterglow model, when the energy distribution of radiating electrons is harder than usual. If the power-law index of the energy distribution is less than 2, then substantial changes in the standard fireball model are necessary. These have been worked out by this team and the revised model has been used to fit the observed light curves of several such GRBs.

Misra has been studying the gas and dust properties of GRB afterglows using optical and X-ray spectroscopy. Afterglow spectroscopy provides a unique window on the near environment of GRBs allowing to probe the absorbing dust and gas properties in more detail. This study of the circumburst gas and dust properties focuses on GRBs in the redshift range 1-2. She and collaborators have used the low resolution VLT data and X-ray spectra from the archives to constrain the dust and gas properties of the host galaxy. A considerable number of GRB hosts have been found to be low metallicity galaxies with low dust content.

Misra has been studying a transient black hole X-ray binary A0620-00 in its quiescent state, using orbital phase resolved Doppler spectroscopy. The new measurements, combined with past measurements will either help to put strong upper limit, or lead to determination of orbital evolution time scales in such a system. The quiescent state X-ray emission plays a role in the X-ray outbursts of the transient sources. The quiescent X-ray intensity in black hole and neutron star X-ray binaries can be significantly different and therefore, the long term average mass transfer rates can also be significantly different in the two classes of objects.

The existence of astrophysical black holes (BHs) in two mass ranges, stellar mass BHs with $\sim 10M_{\odot}$ in X-ray binaries and supermassive BHs (SMBHs) with masses in the range of $\sim 10^6 - 10^9 M_{\odot}$ at the centres of active galaxies, is well supported by observations. Intermediate mass BHs (IMBHs), bridging the gap between the stellar mass and SMBHs, remain relatively unexplored. Recent optical and X-ray observations have revived the possibility of existence of IMBHs. There is indirect evidence for IMBHs with $\sim 10^4 - 10^6 M_{\odot}$ at the centre of some galaxies based on radiative signatures or dynamical measurements. **G. C. Dewangan**, S. Mathur, R. E. Griffiths and A. R. Rao continued their work on X-ray study of AGNs with IMBHs. They have performed a systematic X-ray study of eight AGNs with IMBHs ($M_{BH} \sim 8 - 95 \times 10^4 M_{\odot}$) based on 12 XMM-Newton observations. The sample includes the two prototype AGNs in this class - NGC 4395 and POX 52 and six other AGNs discovered with the Sloan Digitized Sky Survey. These AGNs show some of the strongest X-ray variability with the normalized excess variances being the largest and the power density break time scales being the shortest observed among radio-quiet AGNs. The excess variance - luminosity correlation appears to depend on both the BH mass and the Eddington luminosity ratio. The break time scale - black hole mass relations for AGN with IMBHs are consistent with that observed for massive AGNs. The FWHM of the Hβ/Hα line is uncorrelated with the BH mass, but shows strong anti-correlation with the Eddington luminosity ratio. Four AGNs show clear evidence for soft X-ray excess emission ($kT_{in} \sim 150 - 200$ eV). X-ray spectra of three other AGNs are consistent with the presence of the soft excess emission. NGC 4395 with lowest L/L_{Edd} lacks the soft excess emission. Evidently, small black mass is not the primary driver of strong soft X-ray excess emission from AGNs. The X-ray spectral properties and optical-to-X-ray spectral energy distributions of these AGNs are similar to those of Seyfert 1 galaxies. The observed X-ray/UV properties of AGNs with IMBHs are consistent with these AGNs being low mass extension of more massive AGNs; those with high Eddington luminosity ratio looking more like narrow-line Seyfert 1s, while those with low L/L_{Edd} looking more like broad-line Seyfert 1s.

Ultra-luminous X-ray sources (ULXs) are extremely bright, off-nuclear, compact X-ray sources in nearby galaxies. Their luminosity surpasses the Eddington limit of even the most massive stellar mass black holes, sometimes by large factor. Hence, ULXs are the possible intermediate mass black holes bridging the gap between stellar mass black holes in X-ray binaries in our galaxy and supermassive black holes in active galaxies. However, X-ray characteristics of ULXs can be very different from both the galactic black holes and active galaxies. Based on deep X-ray observation with XMM-Newton, **Dewangan**, R. Mayra, Rao and Griffiths have found unusual temporal-spectral transition of a bright ULX NGC 1313 X-1. With a $0.3-10$ keV luminosity of 1.5×10^{40} ergs/s and $2-10$ keV fractional variability amplitude of 24 percent, the ULX was in a high flux and strongly variable state in March 2006. In this state, the power spectral density is rednoise-like, while the energy spectrum is curved around 6 keV. In October 2006, the ULX was observed in a low flux state when its flux reduced by a factor of about two. In this state, X-ray emission from the ULX was steady, the energy spectrum was curved, and showed a clear evidence for soft X-ray excess emission with kT =0.2 keV. Based on their detailed spectral modeling, **Dewangan** and collaborators have explained the X-ray spectra of the ULX in both the states in terms of an accretion disk and optically thick, and relatively cool corona around a $\sim 100M_{\odot}$ black hole. In this picture, the spectral transition is caused by changing geometry of the disk-corona, likely driven by changes in the accretion rate. The energy-dependent variability of the ULX in its high flux state is also consistent with the above model.

X-ray binaries

Cyg X-3 is a high-mass system with a Wolf-Rayet companion, with an unusually short orbital period, P = 4.8 hrs. In spite of its discovery in 1966, the system remains poorly understood. In particular, due to the lack of a reliable mass function, it remains uncertain whether its compact object is a black hole or a neutron star. The spectrum of the source is different than other X-ray binaries at having a peak at 20 keV instead of 100 keV. Moreover, the source exhibits little variability as compared to standard X-ray binaries. A. A. Zdziarski and **R. Misra** have been exploring the possibility that this unusual spectrum and variability is due to a optically thick ionized plasma surrounding the system. They have used Monte Carlo codes to understand the effect of such a cloud on the spectrum and temporal behaviour.

Low-mass X-ray binaries containing accreting weakly magnetized neutron stars exhibit luminosity and spectral variations on time scale of hours to days, and are usually divided into two classes: Z and atoll sources. Using Suzaku and RXTE observations V. K. Agrawal and **Misra** have done an extensive spectral analysis of the extragalactic Z-source, LMC X-2. Since the distance to this source was better known than other Z-sources, they were able to define the spectral property of the source as function of its absolute luminosity. The bolometric unabsorbed luminosity of the source is well constrained to be 2×10^{38} ergs/sec which if the source is Eddington limited implies a neutron star mass of 1.6 solar masses.

AGN, are known to be variable in the soft X-ray band (0.3 - 10 keV). Apart from providing important information on the accretion structure, the variability is also known to correlate and be used as a measure of the black hole mass in them. However, little is known of the hard X-ray (10-50 keV) variability. V. R. Chitnis, J. K. Pendharkar, D. Bose, V. K. Agrawal, A. R. Rao and Misra have studied a selected set of AGNs in the hard X-ray band using Swift data. They find that interestingly the hard X-ray variability of AGN is distinctively different than seen in the soft X-rays.

Stars and Interstellar Medium

Interstellar extinction curve (spectrum) in the UV and far-UV have been semi-analytically modeled, and corresponding expressions for silicate and graphite grains have been derived (see Figure 15).

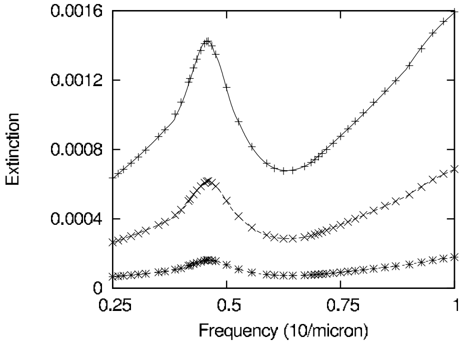


Figure 15: Comparison of predictions of equations in "$\frac{2}{3} - \frac{1}{3}$" approximation (solid lines) with exact computations (points). In this figure, $a_m = 0.25\mu m$ and $a_0 = 0.005\mu m$ (solid line), $a_0 = 0.0035\mu m$ (large dashed line) and $a_0 = 0.002\mu m$ (small dashed line)

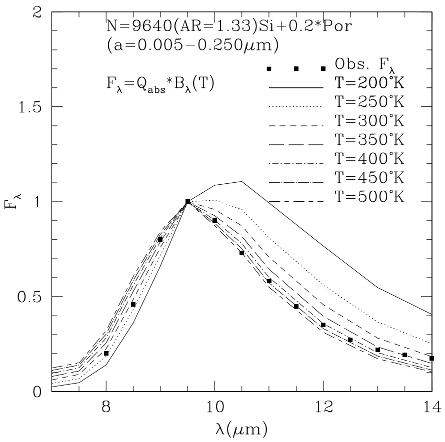


Figure 16: Infrared flux for the composite grains with voids as inclusions at various dust temperatures. The average observed IRAS IR flux values are also shown (in square dots) for comparison.

These analytical expressions have been validated for the expected dust size distributions. **Ranjan Gupta**, along with Ashim Roy, Subodh K. Sharma plan to extend this work to cover the entire extinction spectrum in the region NIR-Visible-UV-FarUV in near future.

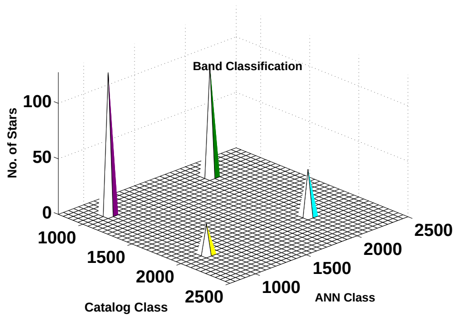
The well known IR dust emission feature at 10.0μm has been modeled by D.B. Vaidya and **Gupta**, using Discrete Dipole Approximation (DDA) method with porous Silicate dust grains in the environment of circumstellar dust shells around stars. The model curves for composite grains with axial ratios not very large (AR $\sim$ 1.3) and volume fractions of inclusions with f = 0.20, and dust temperature of about 250-300°K, fit the observed emission curves reasonably well (see Figure 16).

Artificial neural networks

Ranjan Gupta, Archana Bora, Harinder P. Singh and K. Duorah have employed Artificial Neural Networks (ANNs) to automatically segregate star-galaxy objects of the expected observed data from the upcoming satellite UV missions TAUVEX and ASTROSAT. The classification accuracies for success rates in deciding whether the objects are point like (stars) or extended (galaxies/AGNs, etc.) are about 76%, if one uses the full UV flux information (expected from ASTROSAT) and about 57%, if only the limited band data is available (expected from TAUVEX) (see Figure 17).

Stellar evolution

A proposal for observing a specific area of the sky with the VLT in Chile, with the aim of finding very old stars had been accepted by the ESO and time was allotted to the extent of 20 hours. The participants in the programme were Ferdinando Patat (PI, from ESO), Ken Freeman (from ANU, Canberra), **Vijay Mohan** and **J.V. Narlikar** (from IUCAA). The data has been analysed. Although there are some stars whose colour-magnitude diagram could be understood on the grounds that they are about 20 Gyr old, provided they could be conclusively shown to be part of the LMC, the issue of the star-field being contaminated by foreground galactic stars cannot be ruled out. Further spectroscopic studies will be needed to pursue this direction further. Meanwhile an account of the work is being prepared for publication.



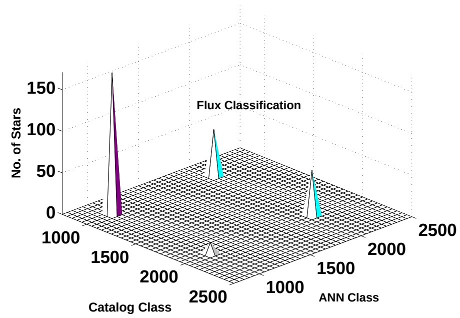


Figure 17: Scatter plot of classification of 229 IUE stars and 69 galaxies using Band data (left) and flux data (right); (class-code: 1000-stars; 2000-galaxy)

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, which is expected to be launched in the near future. UVIT consists of two telescopes, each of aperture 380 mm. The two telescopes make images in a field of 0.5 degree with a resolution of 1.5", simultaneously in three channels: 1300 - 1800 A, 1800 - 3000 A, and 3200 - 5300 A. In addition to UVIT, four X-ray telescopes are used on ASTROSAT to provide simultaneous wide band coverage in the observations. 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 developement as Programme Manager for the project.

This year, the engineering models of the detectors and mirrors were completed by the Canadian Space Agency and LEOS (ISRO) respectively. Tests with this detector show that it gives the required PSF in photon-counting mode of imaging. Tests with the mirrors show that the overall concept of polishing and mounting can give the required surface accuracy of 1/50 wavelength, as required for the shortest wavelengths of observations. Further, the reflective coating developed by LEOS (ISRO) gives a reflectivity of >70% for the shortest wavelengths of observations, as compared to > 60% in the specifications. The other subsystems are being fabricated and it is expected that an engineering model of the full payload be tested in the second half of year 2009. The final model of the payload is expected to be ready for launch in the second half of the year 2010.

Imaging characteristics of UltraViolet Imaging Telescope (UVIT) through numerical simulations

In order to have a realistic evaluation of the various instrumental effects, **Mudit K. Srivastava** and **Shyam Tandon** have numerically simulated the performance of UVIT. These effects are studied by doing simulations on the archival images of a galaxy from GALEX and Hubble ACS data archives. As a galaxy (or other extended astronomical sources in general) has complex structure, several artificial point sources are also simulated to explore these effects. It is found that the imaging characteristics of UVIT would be affected by a number of factors. In addition to performance of the optics, the other important factors are the drift of the satellite and functioning of photon counting detectors. The final image is to be reconstructed with the UVIT data frames using some centroid algorithms. Also, the satellite drift has to be removed from the UVIT data frames before using them for image reconstruction. Simulations have been done to minimise the observations of some sky fields containing point sources through the visible channel of the UVIT. The centroids of the sources in the field are used to track the satellite drift. These simulations show that despite large drifts in pointing of the satellite (0.2 arc sec/sec to 2 arc sec/sec), a series of short exposures ($\ll 1 sec$) can be processed to get spatial resolution of ~ 1.5 *arcsec* for long observations lasting tens of minutes.

UVIT data frames have been simulated including all the known effects of satellite drift, optics and photon counting detectors to study the photometric properties of the system. The centroids of photon events can be determined by three different algorithms (namely 5-Square, 3-Square and 3-Cross) with different pixels shape using centre of gravity method. Several detector parameters (photon energy thresholds) have been used in this process. The fluctuations in the background dark frames and in photon event footprint could result error in centroid estimations. These errors are estimated to be ~ 0.01 CMOS pixel or ~ 0.03 arcsec. Images reconstructed with 3-Square and 3-Cross algorithms show a modulation pattern in form of a grid structure (with frequency of one CMOS pixel) superimposed on the images. It has been corrected before reconstructing the images for these two algorithms. Figure 18 shows the original and reconstructed images using 3-Square algorithm.

Simulations with artificial point sources show that the photometry of the reconstructed images would depend on the choice of two energy thresholds used by centroid algorithms to detect photon events in the UVIT data frames. For given energy thresholds, events falling in the centre of CMOS pixel would be more probable to detect than the events falling near the corners of the pixel. By choosing suitable energy thresholds, one could reduce such variations to $< 1\%$ over the pixel face. Further, the photometric accuracy of the reconstructed images would be affected due to appearance of double or multiple photon events, which occur with a significant probability in and around bright sources. The double photon events can be identified and rejected by another threshold called *rejection threshold*. These photometric effects could be serious issue of concern for bright sources. It turns out that the presence of a strong source could also produce complicated photometric patterns in the surrounding. It is found that these patterns depend on the choice of the rejection threshold. The photometric distortion in the reconstructed images of galaxy is of complex nature and depends on the intensity profile of bright sources present in the galaxy. The regions away from such bright sources offer nearly accurate photometry while the nearby regions of such sources suffer from higher photometric inaccuracies. The results of simulations shows that the photometric accuracy in these regions can be as low as $\sim 60\%$. Also, the strong sources in the galaxy themselves suffer from photometric saturation effects, causing the recovery of $\sim 80\% - 90\%$ of total photon events. This effect is related to details of the detectors being used and has to be corrected for. Figure 19 shows the photometric distortion in case of GALEX Far-UV image reconstructed using 3-Square algorithm with rejection threshold of 40 Digital Units (DU).

The PSF of the reconstructed images follows a 2-D Gaussian profile with σ of 0.7 arc sec on either axis, and is dominated by the performance of the optics and detectors. Further, the PSF is found to be the same in case of different centroid algorithms and different rejection thresholds. However, the presence of double/multiple photon events could also cause PSF profile to vary in case of bright sources. The simulations of a Hubble ACS image shows (see Figure 20) that sources separated by 3.0 arc sec are clearly resolved in the reconstructed images.

FIFUI - Fibre-based Integral Field Unit for IFOSC:

Mudit K. Srivastava has been working with **A. N. Ramaprakash** on building an optical fibre-based integral field unit for the IUCAA Faint Object Spectrograph and Camera (IFOSC). FIFUI when mounted on IUCAA telescope, it will have a field of view of about 13 x 6 square arcseconds covered by 100 fibres. It will offer three sampling scales of 0.8", 1" and 1.2" per fibre projected on the sky through a fore-optics section, which also couples the light properly at the input of the fibres. The job of fibre units assembly is to provide an efficient configuration of optical fibre bundle to reformat a

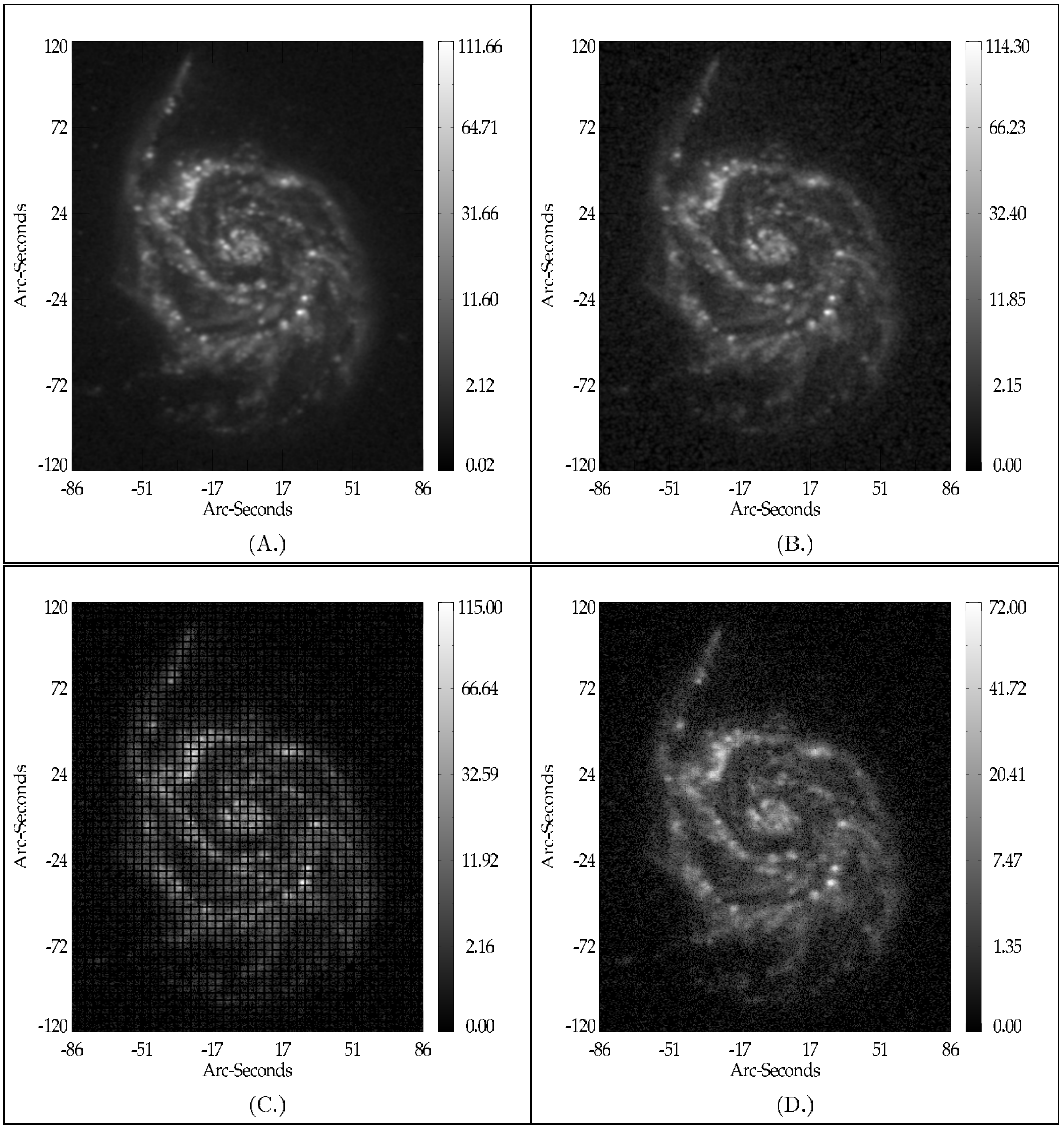


Figure 18: The input and simulated images of a galaxy. An archival Ultra-Violet image of M51 Galaxy from GALEX data archive is used for simulation. To match the scales of GALEX and UVIT, necessary corrections have been applied to this archival image and thus, an input image is obtained. This input image is shown in (A). (B) shows the simulated image of the input image, using Poisson statistics. This image is to be processed within UVIT subsystems. Both the images correspond to 3000 seconds integration time with the frame rate of 30 frame/second and are convolved with Gaussian function with σ of 0.5 arc sec. An uncorrected reconstructed image of the same galaxy using 3-Square algorithm is shown in (C). The superimposed grid pattern is a modulation pattern related to the centroid algorithm. It has frequency of one CMOS pixel. The corresponding corrected image is shown in (D). The pixel scale in all the images is 0.5 arc sec/pixel.

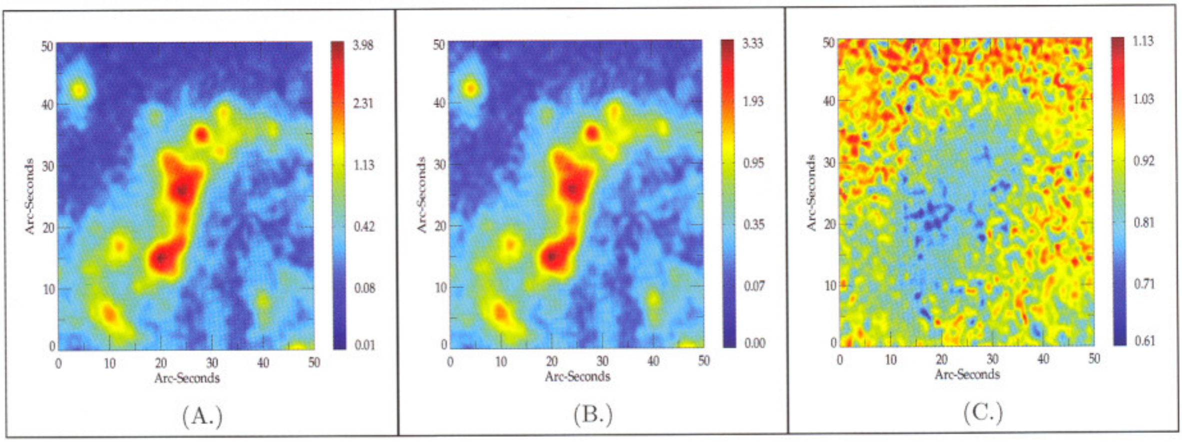


Figure 19: Images showing the photometric distortion present in reconstructed image. A section of the image shown in Figure 18 is used for this purpose. (A) is the image constructed using '*true*' positions of the photon on the UVIT detectors, while (B) is the reconstructed image using 3-Square algorithm with rejection parameter of 40 DU. Both the images are convolved with Gaussian having σ of 0.5 arc-sec. (C) is ratio of images (B) and (A). The location of minima in the ratio image are away from the position of sources indicating a complex structure of photometric distortion in the reconstructed image.

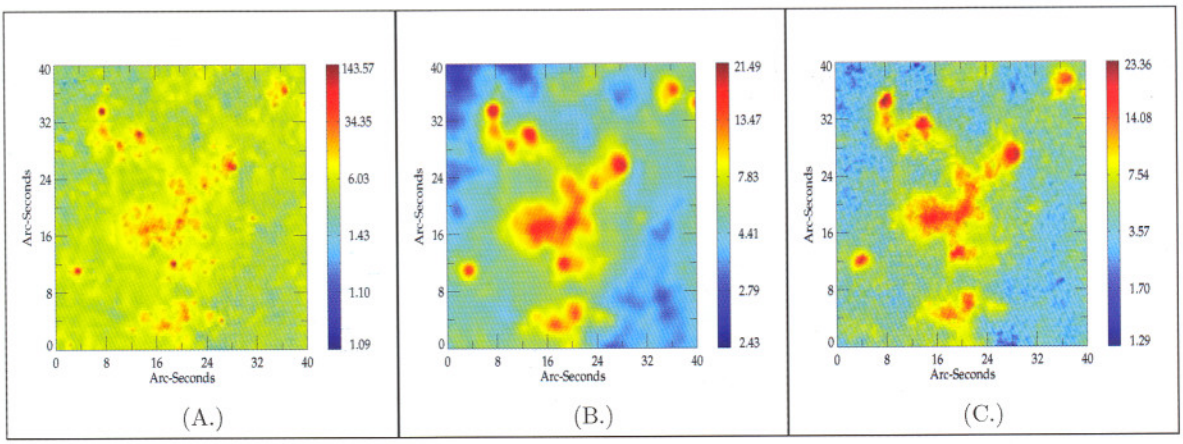


Figure 20: Input and simulated images of a portion of the galaxy's spiral arm, showing the effect of UVIT Point Spread Function on the image. (A) is the input Hubble ACS image in B band. This image is convolved with PSF of the UVIT. The resultant image is shown in (B). The reconstructed image using 3-Square algorithm with Rejection Threshold of 500 DU is shown in (C). The pixel scale is 0.05 arc sec/pixel and the integration time is 6000 seconds. All the images are convolved with Gaussian function having σ of 0.2 arc sec for smoothing purpose.

2-D field of view at input into 1-D array at output, for coupling into a spectrograph. This demands a high fill factor at the input and a high degree of spatial precision to reduce coupling losses. Further, for highest throughput, focal ratio degradation (FRD) of the fibres has to be minimized. This demands minimal stress to the fibres. The fibre units assembly has been fabricated keeping these objective in mind. This includes the construction of fibre units and their polishing for both the ends.At the slit end of the fibre assembly it is another optical train, which collects an f/4 beam out of the fibres and re-image a virtual slit of f/10 at the slit plane of IFOSC. In order to accommodate the 100 fibres within IFOSC's field, a staggered double slit arrangement is made.

For our application, the optical fibres from Polymicro Technologies, USA has been chosen, having core diameter of 70 microns, cladding diameter of 98 microns and buffer diameter of 125 microns. Also, these fibres contains acrylate jacket of 150 microns diameter. This combination is used to provide strength and protection to fibres from external mechanical stress. However, the acrylate jacket of the fibres was removed from the ends using iso-propyl alcohol as solvent. 130 fibres of 1m length are used for the construction purpose. Out of this, 30 fibres were taken as buffer while manufacturing. The mechanical part of Fibre Head Mount Unit has been developed with a rectangular cavity (40 mm x 24 mm) in it. The input end of the fibre had been fabricated first. The fibres were first glued inside the cylindrical quartz ferrules (60 mm long) using Epo-Tek 301-302 epoxy (2 component heat curing epoxy) and then these ferrules were glued to the fibre units using the same epoxy. The ferrules at this end have the ID of 0.20 mm and OD of 1.85 mm. A closed packed stack of ferrules was constructed inside the cavity with 13 rows of ferrules with 19/20 fibres in each row. The central 100 fibres in the middle 8 rows contain optical fibres, while the rest of the ferrules act as buffer ferrules. At the output end, the Fibre Slit Unit has similar structure as the Head Mount Unit. It consists of the cavity of size 28 mm x 6 mm. The ferrules here have the dimensions of 200 micron ID and 350 micron OD. With the glue thickness of 20 microns, they provide the required pitch of 370 microns between two fibre core. Here, the fibres were aligned in two vertical layers with 50 fibres in each layer, creating the two fibre slits. At last, both the units were polished with aluminum oxide slurry of various particle size, i.e., 13.5 microns, 9 microns, 3 microns and 1 microns.This Fibre Head Mount Unit would be attached to Front Unit while the Fibre Slit Unit would be coupled to the IFOSC through the Output Optics. Figure 21 shows the various stages in the fabrication of Fibre Units Assembly.

The entire optical design of the system was carried out in IUCAA and the components were manufactured to custom specifications by various vendors like JML Optics. Of particular difficulty was getting the 2 mm diameter lenslets made to specification - these lenslets play the crucial role of feeding the light into the fibres at the required input beam angle of f/4. All the mounts for the optical components were designed in the laboratory and manufactured with the help of local industry. The support structure for the opto-mechanical system and the mounting arrangement on the telescope are made of standard components procured from LINOS Photonics, Germany. It would consist of linear motorized translation stage from Newport Corporation for linear motion of the Fore optics lenses, to achieve different sampling scales. Further, provision for calibration lamps is also made to this unit, for the calibration of observed spectra. Here, the tight constraints from the load and moment limit at the side port of the telescope as well as the volume envelope available are given attention.

At the time of writing this report, the optics is being integrated in the laboratory. Quartz ferrules have been fixed at both ends of the fibres and the integral field as well as the slit unit have been assembled together. Polishing of the units have been completed following which the lenslets are to be fixed at the IFU end. Simultaneously, the opto-mechanical assembly is being integrated, while the necessary modifications have been made on the calibration unit assembly on the telescope on which the slit end will get mounted.

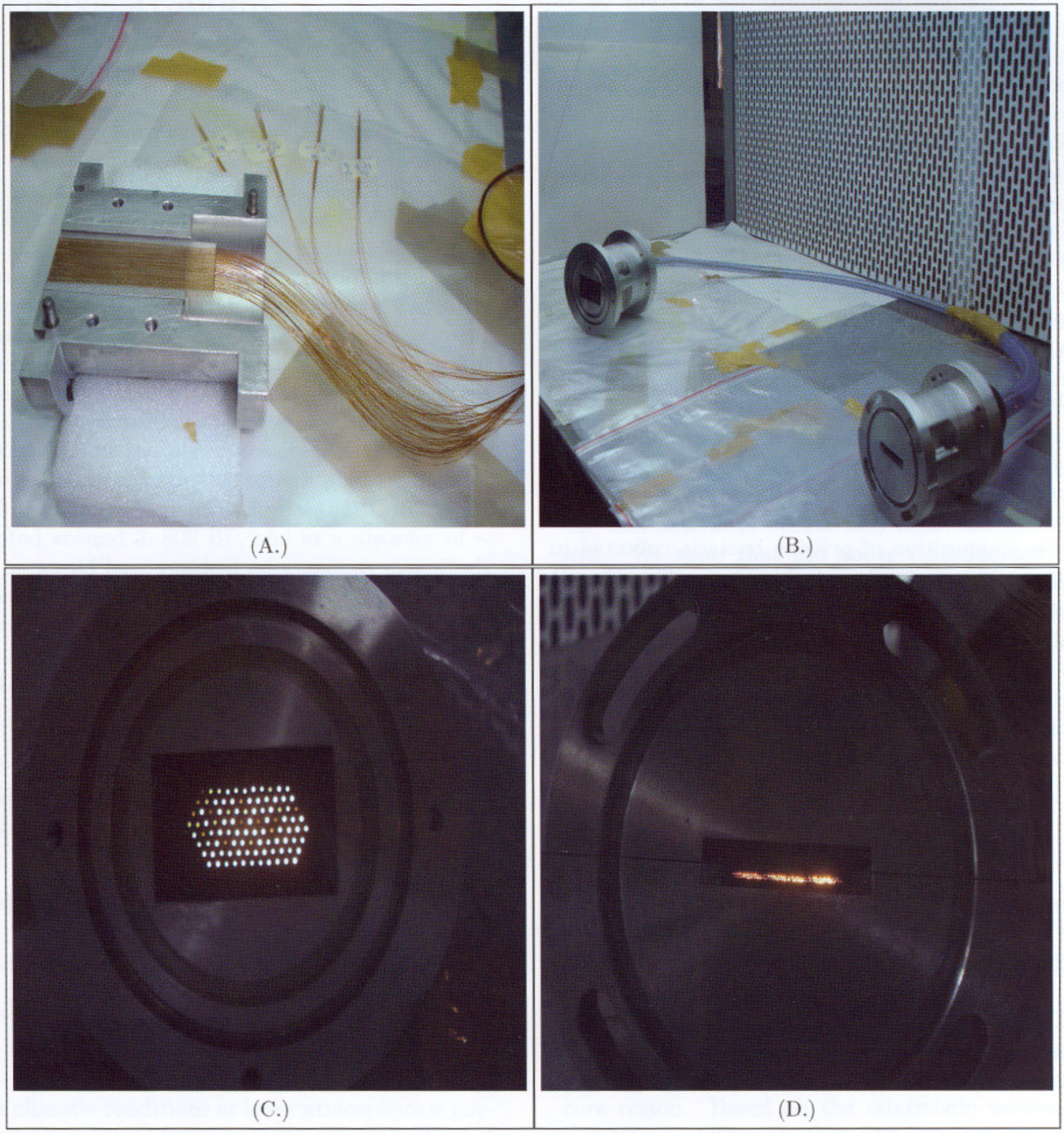


Figure 21: Figures showing various stages in the fabrication of Fibre Units Assembly. (A) Fibre Slit Unit in making, (B) Fabricated Fibre Unit Assembly of the IFU, (C) Input End of the assembly : Fibre Head Mount Unit, (D) Output End : Fibre Slit Unit.

Astrobiology

Jayant Narlikar has been involved in some of the recent experiments in Astrobiology. The results of the second balloon flight from the TIFR balloon facility in Hyderabad in April 2005, were finally ready and accepted for publication in the IJSEM. The findings by two groups working in the CCMB, Hyderabad and NCSS, Pune of 12 bacterial species including three entirely new ones named after ISRO (Bacillus Isronensis), Aryabhata (Bacillus Aryabhatai) and Fred Hoyle (Janibacter Hoylei) have shown that life exists at a height band of 41 km. Moreover, the survival ability of these species against the UV-rays indicates that they may have mutated in a region of high UV flux. The possibility of their having come to that height from outside the Earth remains, although one cannot rule out some process of lifting the microorganisms from the Earths surface to those heights. Future experiments including determination of nuclear isotopic composition of pristine bacteria collected in the sample, are under consideration. This project is sponsored by ISRO.

(II) RESEARCH BY VISITING ASSOCIATES

Archaeoastronomy

N. Iqbal

N. Iqbal along with M. N. Vahia, T. Masood and A. Ahmad has studied some early astronomical sites in the Kashmir region in northern India and neighboring Pakistan, and suggest that some of these contain depictions of astronomical events. Our studies suggest that during ancient period, some of the ancient astronomers recorded supernova, meteorite impacts, the sun, the moon and the seasons in the rock art. One of the sites, namely Burzuhama Srinagar depicts the astronomical scene of a supernova with a possible candidate of HB9. Although, G182.4+4.3 is the other possible candidate. We have preferred the possible supernova candidate for HB9 because some studies reveal that G182.4+4.3 erupted around 3, 800 BP, and at a distance of $\sim$ 3 Kpc would have reached an apparent magnitude of between -7 and -5 at maximum. HB9, exploded some time between 7,000 and 4,000 BP. The age of this SN is in accordance with the age of this astronomical site.

Atmospheric and Ionospheric Physics

S.N.A. Jaaffrey

Detection of the atmospheric X-rays produced after the interaction of high energy secondary cosmic ray shower with pollutants in the troposphere has become a new technique to monitor the local climatic conditions. Recently, it was realized that climatic conditions at lower atmosphere is governed by anthropogenic activities from surface of the earth and secondary cosmic radiation with meteoric shower from extraterrestrial space. To investigate these components, ground based and vertical profile data are to be taken by S.N.A.Jaaffrey in the first phase of the project CAIPEEX (Cloud Aerosol Interaction and Precipitation Enhancement Experiment). Indian Institute of Tropical Meteorology, Pune (IITM), has chosen S.N.A.Jaaffrey to undertake climatic study at Udaipur during monsoon 2009 under the CAIPEEX project. In the second phase, he will analyze observational data taken at ground and higher altitudes (vertical profile), and in third phase cloud seeding would be done infusing silver iodide and salty compounds.

Compact Object, X-ray Binaries

Gour Bhattacharya

Gour Bhattacharya in collaboration with Manjari Bagchi, Sushan Konar, Jishnu Dey and Mira Dey has studied whether existing observations can definitely establish if the members of the only known double pulsar system PSR J0737-3039 are neutron stars or strange stars. Understandably, the most convincing proof for a strange star would come from a direct indication of the Equation of State (EoS). One interesting method of constraining the dense matter EoS is to measure the advancement of the periastron of the orbit of a binary pulsar. The moment of inertia of a member of the binary system can be determined by measuring the extra advancement of the periastron of the orbit above the standard post-Newtonian one, due to spin-orbit coupling. The moment of inertia can also be calculated for a given EoS and thus, on comparison, one can determine which EoS best describes the star. We show that the above methodology can be applied to constrain the EoS of one of the members PSR J0737-3039A of the double pulsar system, and which may allow us to deduce whether it is a strange star or a neutron star. This is not possible for the second member of the binary pulsar at present, although one can use indirect methods e.g., modeling its formation scenario, to be able to comment on its nature.

Somenath Chakrabarty

In this work, the effect of strong quantizing magnetic field on the equation of state of matter at the outer crust region of magnetars has been studied by Somenath Chakrabarty along with two of his students, Nandini Nag and Sutapa Ghosh. The density of such matter is low enough compared to the matter density at the inner crust or outer core region. Based on the relativistic version of semi-classical Thomas-Fermi-Dirac model in presence of strong quantizing magnetic field they have developed a formalism to investigate this specific problem. The equation of state of such low density crustal matter is obtained by replacing the compressed atoms/ions by Wigner-Seitz cells with nonuniform electron density. The results are compared with other possible scenarios. The appearance of Thomas-Fermi induced electric charge within each Wigner-Seitz cell is also discussed.

Following some of the recent articles on hole super-conductivity and related phenomena by Hirsch, they have developed a simple model to explain the observed low surface magnetic field of the expected quark stars. It has been argued that the diamagnetic moments of the electrons circulating in the electro-sphere induce a magnetic field, which forces the existing quark star magnetic flux density to become dilute. For the sake of completeness, they have also included the analyses of instability at the normal-super-conducting interface due to excess accumulation of magnetic flux lines. The instability at the interface has also been studied numerically.

Tanuka Chattopadhyay

Tanuka Chattopadhyay has carried out an objective classification of the globular clusters (GCs) of NGC 5128 using a model based approach of cluster analysis (CA). The optimum set of parameters for this type of CA is selected through a new method of Principal Component Analysis (PCA), which differs from the classical PCA in the sense that it takes into consideration the effects of outliers present in the data. The efficiency of the techniques used are tested through the comparison of the misclassification probabilities with those obtained using the well known K-means clustering technique. On the basis of the above classification scheme, three coherent groups, (viz., G1, G2 and G3) of GCs have been found. G2 might be considered as the remnants of the major merger of two spiral galaxies in the early stage of evolution, whereas G1 and G3 have an external origin possibly tidally stripped dwarf galaxies on random orbits around NGC 5128,the former in the process of settling dynamically. The above work is carried out in collaboration with Emmanuel Davoust, Sharina Margarita, Asis Kr Chattopadhyay, and Saptarshi Mondal.

S.N.A. Jaaffrey

Jaaffrey, S.N.A. and his group have studied X-ray binary systems namely 4U 0115+63, XTE J0111.2-7317 using archival data from NASA-HEASARC site. They have detected quasi periodic oscillation of very low frequency of 43 mHz, which has origin in magnetic field coupling with dynamic accretion disc around the X-ray Be- star. This work has been carried out in collaboration with R. Misra. Gamma Ray Bursts detected by BAT onboard the Swift satellite has been investigated in collaboration with D. Bhattacharya. Delay time was discovered for different energy bands and resolved multipeaks in GRBs. It was found that high energy bands were delayed as compared to soft bands.

Classical and Quantum Cosmology

S. K. Banerjee

S.K. Banerjee has investigated some Bianchi Type VI_0 cosmological models in the presence and absence of magnetic field and bulk viscosity in massive cosmological string, together with Raj Bali and Ratna Banerjee. Bianchi Type VI_0 universes give a better explanation to some of the cosmological problems like primordial helium abundance and also isotropize in a special sense. For a deterministic structure of the model, authors have considered expansion proportional to the shear. Various dynamical and physical features of the models are also looked into.

S.K. Banerjee, together with Raj Bali and Ratna Banerjee has also studied the LRS (Locally Rotational Symmetric) Bianchi Type VI_0 spacetime and obtained cosmological models with free gravitational field of purely magnetic type and also in the presence of gravitational wrench of unit pitch in the free gravitational field. The concept of gravitational wrench of unit pitch was first explored by S.K. Banerjee and S.R. Roy in 1990. Further, it is found that the magnetic part of the free gravitational field induces shear in the fluid flow, which is zero for a electric type free gravitational field representing an unrealistic distribution in this case. The role of the free gravitational field has been emphasized in the determination of the flow of matter in the cosmological models. It is well known that near the singularities, the curvature of spacetime becomes dominating so that the evolution of the universe in its early stages is largely affected by the character of the free gravitational field. The study of models with specific types of the free gravitational field has also become necessary due the speculative existence of copious amount of gravitational radiation following the Big Bang. Models for which the free gravitational field is of the electric type are considered to have their Newtonian analogues, while a magnetic type free gravitational field is purely general relativistic.

U. Debnath

U. Debnath and collaborators have investigated the occurrence of shell crossing singularities in quasi-spherical Szekeres dust models with or without a cosmological constant. The conditions for shell crossing singularity both from physical and geometrical point of view have been found. The gravitational collapse of a spherical dust cloud in the background of unified dark matter-dark energy model in the form of modified Chaplygin gas has been studied. It has been found that invisible matter (dark matter-dark energy) alone in the form of modified Chaplygin gas forms black hole. Also, when both components of the fluid are present, then the collapse favours the formation of black hole in cases the invisible matter dominates over ordinary dust. It has been investigated exact solution in higher dimensional Husain model for a null fluid source with barotropic fluid, polytropic fluid and variable modified Chaplygin gas. It has been studied the nature of singularity in gravitational collapse. It has been found that the nature of singularity is independent of the choices of different equation of state except for variable Chaplygin model.

Also they have considered a model for FRW spacetime in the presence of coupled scalar field and potential with causal viscous fluid and polytropic fluid.

It has been shown that irrespective of fluid, the causality theory provides late time acceleration of the universe. In all the cases, the potential always decreases due to evolution of the universe. It has been considered that the universe is filled with normal matter and phantom field (or tachyonic field). If the universe is filled with scalar field, Ellis, et. al. have shown that emergent scenario is possible only for k = +1, i.e., for closed universe and one has shown that the emergent scenario is possible for closed universe if the universe contains normal tachyonic field. But for phantom field, the negative kinetic term can generate the emergent scenario for all values of k (= 0, +1, -1). From recently developed state finder parameters, the behaviour of different stages of the evolution of the emergent universe have been studied. It has been shown that the new modified Chaplygin gas (NMCG) model, which interpolates between radiation at early stage and Λ CDM at late stage. This model is regarded as a unification of dark energy and dark matter (with general form of matter). They have derived the density parameters from the equation of motion for the interaction between dark energy and dark matter. Also the evolution of the various components of density parameters have been studied.

Recently, tachyonic field has been depicted as dark energy model to represent the present acceleration of the universe. It has been assumed that the universe is filled in with only tachyonic field with potential, which gives the acceleration of the universe. From recently developed statefinder parameters, the role of tachyonic field in different stages of the evolution of the universe has been investigated. Also it has been considered mixture of tachyonic fluid with a perfect fluid (i.e., barotropic fluid and generalized Chaplygin gas). It has been shown that the nature of the potentials vary so as the interaction term reduces the potential in both the cases.

Deepak Jain

The most important and challenging problem in cosmology is to explain the physical mechanism behind the observed acceleration of the universe. Broadly,there are two categories which explain the positive acceleration of the expanding universe. The first category contains those models which incorporate the modification in the stress-energy tensor of Einstein's equation. The other category assumes that gravitation is not described by general theory of relativity. In this case cosmic acceleration would arise from the dynamics of modified gravity. The simplest generalization consists of replacing the Ricci scalar, R, in the Einstein-Hilbert action by function $f(R)$.

Deepak Jain has studied the $f(R)$ theory of gravity by using the metric approach. In particular he has studied the recently proposed model by Hu-Sawicki and Starobinsky, and checked the compatibility of this model with the $H(z)$ and baryon acoustic oscillation data. He finds that the model resembles exactly the standard ΛCDM model at high redshift.

S. Jhingan

S. Jhingan has looked at various cosmological models from the view point of late time accelerated expansion of the universe. In collaboration with colleagues, he has analysed models which implement string corrections to gravity, and also looked at models which incorporate non-local corrections to Einsteins general theory of relativity. They are now analyzing observational constraints on cosmological models arising due to supernovae observations and baryon acoustic oscillations (BAO) data. Jhingan and Tarun Souradeep are developing estimators for measuring statistical anisotropies in the CMB power spectrum. They are carrying out a systematic study of the relation between bipolar harmonic coefficients and the broken symmetries of the correlations in the CMB maps.

Bikash Chandra Paul

B.C. Paul and coworkers have studied cosmological models with phantom field in an anisotropic Bianchi-I universe in the presence of a cosmological constant. They note that kinetic energy dominated regime of the phantom field inflates and later transits to an inflationary universe. A class of new cosmological solutions are found for anistropic Bianchi-I universe with an initial anisotropy satisfying an upper bound, which is determined by the parameter of the kinetic part of the field. The anisotropy of the universe decreases and it smoothly transits to a flat FRW universe. It is also found that phantom field admits a nonsingular universe.

Also they have taken up a multi-dimensional universe with nonlinear scalar curvature terms in the gravitational action to evaluate the probability for creation of a universe with primordial black holes. For this, they determine Euclidean instanton solution in two different topologies: (a) S^{D-1} -topology, which does not accommodate primordial black holes, and (b) $S^1 \times S^{D-2}$-topology, which accommodates a pair of black holes. The probability for quantum creation of an inflationary universe with a pair of black holes has been evaluated in the above gravitational action using the framework of semiclassical approximation of Hartle-Hawking boundary conditions. They have obtained a class of new gravitational instantons solutions for the gravitational action with a R^4-term, which are relevant for cosmological model building. They also note that the gravitational instantons are permitted even without a cosmological constant in the modified theory of gravity in four and in higher dimensions.

Saibal Ray

Saibal Ray has been continuing the investigations on dynamical models of the cosmological term Λ in connection to the dark energy theory. He, along with U. Mukhopadhyay, has re-examined the status of the $\Lambda \propto H^2$ model by considering a time-varying equation of state parameter to see whether some new features can be explored.

T.R. Seshadri

With K. Subramanian, T.R. Seshadri has shown that bi-spectrum of the CMB anisotropy can be used as a tool to probe the cosmic magnetic fields worked out the non-Gaussian signals in the CMBR due to cosmic magnetic fields. 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.

With M. Sami and Shruti Thakur, Seshadri has been studying the observational effects that can distinguish f(R) gravity action from other models that produce accelerated expansion of the universe.

G.P. Singh

In order to unify gravity with other fields, a number of modifications of general relativity have been proposed and extensively studied by many researchers. The anisotropic cosmological models have taken considerable interest of researchers due to the belief that present day homogeneous, isotropic universe, might not have so smooth behaviour in its early stages. The anisotropic stages of the early universe might have phased out during its evolution and approached to present day isotropic one. About a decade ago, researchers had a belief that the universe was decelerating and now a number of observations suggest that the expansion of the universe is accelerating. The expansion of the universe is dominated by an energy component with an effective negative pressure. There are several possibilities for such component viz., the cosmological constant Λ, quintessence, etc. Another parameter of the Einstein field equations is the gravitational constant G, which plays the role of a coupling constant between geometry and matter in the Einstein field equation. Due to the possibility of the large extra-dimensions in the brane-world models, the cosmological models of the early universe must be studied with careful consideration of the effect of the higher dimensional geometry. The role of dissipative effects in the evolution of the universe, particularly during its early stages, is also a subject of importance. Considering various developments in science, we cannot claim a particular cosmological model represents a final picture of the universe because human mind has not yet reached to perfection.

G. P. Singh and coworkers have been continuing the investigations on anisotropic and isotropic cosmological models within the framework of general relativity and alternative theories of gravitation.

Anisul Ain Usmani

A.A. Usmani has continued to study dynamical models of the cosmological term, Λ, in connection to the dark energy theory. Various forms of time varying equation of state parameter have been examined to explore physical observables of the universe.

Galaxies and Quasars

N. Iqbal

The virial theorem have been used to investigate the dynamical stability of Hickson compact groups of galaxies. The work done by Selim and N. Iqbal suggest that virial theorem can be used to estimate virial mass. The average virial mass calculated for a group of galaxies attributes to the presence of large amount of dark matter, which is more than 90% in this group. We have also calculated virial to luminous mass ratio and suggest that Hickson compact groups of galaxies are unstable system due to luminous masses ratio. Although some groups are in dynamical equilibrium and physically bounded groups with general mode of stability.

Pushpa Khare

Pushpa Khare, along with her collaborators, has observed 2 Damped Lyman Alpha systems (DLAs) and 14 sub-DLAs at $z_{abs} < 1.5$ in the spectra of QSOs, with the VLT and the Magellan telescope, with the aim of determining the metal abundances in these systems. Three sub-DLA systems were found to have super solar abundance of Zn, the least depleted metal. Large relative abundance variation from component to component are observed in Si, Mn, Cr and Zn. A clear trend is visible for these systems as well as systems from the literature, with [Mn/Fe] increasing with increasing metallicity, in good agreement with Milky Way stellar abundances.

They have also studied the distribution of narrow C IV and Mg II lines near QSOs. The clustering of absorbers around QSOs was measured by correlating absorbers with quasars on different but neighbouring lines of sight. Comparing correlations between absorbers and the quasars, in whose spectra they are identified, they concluded that (i) quasars destroy absorbers to comoving distances of 300 kpc (C IV) and 800 kpc (Mg II) along their lines of sight; (ii) more than 40 % of CIV absorbers within 3000 km/s of the quasi-stellar object are directly associated with the quasar itself and (iii) the intrinsic absorber population extends to outflow velocities of the order of 12000 km/s.

S.K. Pandey

The programme of studying faint outermost region of the galaxies from the Large Format Camera (LFC) field has been continued during the year. A sample of 266 galaxies was selected from the LFC field SDSS 1208, with sufficient brightness and size to ensure reliable morphological study. A subsample of 180 early-type galaxies was chosen for isophotal study using the value of bulge-to-total luminosity ratio obtained from the 2-dimensional bulge-disk decomposition. Redshift measurements for 72 of these galaxies were made using the data from AAT observations.

Isophotal shapes of sample galaxies were obtained and revisited the already known correlations of isophotal shape with other galactic properties. Isophotal shapes in regions significantly beyond the characteristic radius have been investigated for the first time. Spectral properties of the nuclear region of the galaxies and its possible correlation with the isophotal parameters have also been examined. This is a collaborative research programme involving A. K. Kembhavi, Russell Cannon, Ashish Mahabal, which constitutes the Ph.D. thesis work of Laxmikant 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 has been continued during the year. Deep CCD images of 5 early-type galaxies was obtained during the February-March, 2009, observing run using the 2 m HCT. Likewise, the 2 m IUCAA telescope at IGO was used to obtain deep imaging in H-alpha band for three early-type galaxies during April 4 - 5, 2008. So far good quality data of 40 early-type galaxies has been obtained. Detailed analysis of dust properties is in progress. This work constitutes the doctoral work of Samridhi Kulkarni.

M.K. Patil

M.K. Patil, in collaboration with S.K. Pandey and Ajit Kembhavi has been involved in studying the multi-wavelength surface photometric properties of early-type galaxies with an objective of studying physical properties of dust and other phases of ISM in this class of galaxies. They have studied the wavelength dependent nature of the dust extinction in a fairly large sample of galaxies and have derived the extinction curves for these galaxies. To address the issue of origin of dust in this class of galaxies, they have determined the dust injection rate into the ISM by mass-losing evolved stars and have observed that internal mass-loss from evolved stars alone cannot account for the observed dust in these galaxies. This in turn implies that at least a part of dust has been acquired by the galaxies through a merger like event.

They are also involved in studying properties of Multi-phase ISM in early-type galaxies. To examine the morphology of the hot (X-ray emitting) gas, they have used data from the archives of Chandra and XMM-Newton space missions. This study has shown that the morphology of dust closely matches with that of ionized gas, and in some cases with the X-ray emitting gas too, pointing towards a physical connection between different phases of ISM. X-ray studies of early-type galaxies, compared to its radio and optical counterparts provide unique and complementary insights into the nature of these systems. With a view to get information about the metal enrichment of the ISM, and hence about the star formation history of the host galaxies, they have carried out spectral analysis of the X-ray emitting gas in host galaxies.

M.K. Patil in collaboration with S.K. Pandey, Ajit Kembhavi and Gulab Chand Dewangan has been involved in studying morphological and spectral properties of hot gas in normal early-type galaxies. For this study, they have used the high resolution X-ray images of target galaxies available in the archives of Chandra and XMM-Newton space missions. X-ray emission from early-type galaxies partly originate from the diffuse gas and partly from the population of point-like sources, known as low-mass X-ray binaries (LMXBs). They have studied the 2D distribution of the discrete sources in the host galaxies compared to its optical counter part. Spectral analysis of the resolved point sources was well-fit by a power law model with X-ray luminosities in the range between 5 x 10^{37} and 2.5 x 10^{39} erg/s. They found that X-ray luminosity function (XLF) for the discrete sources (LMXBs) showed a break near the Eddington luminosity for a neutron star of 1.4 $M_{\odot}$.

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. It is interesting to study the X-ray variability of AGNs. The starting data consist of measurements of flux as a function of time, i.e., lightcurve. To quantify the variability, most commonly used method is to Fourier analyse the lightcurve 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 timescale, 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 97 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 97 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.

C.D. Ravikumar

C.D. Ravikumar has been involved in the studies on galaxies. He, along with his collaborators from Paris Observatory and IUCAA, has studied intermediate mass galaxies (with mass $> 10^{10}$ solar masses) at z $\sim$ 0.6, which form mostly the progenitors of present day spiral galaxies. Analysis of metal abundances and Tully-Fisher relation of these systems suggests that at least 30% of the present day galaxies are to be formed from an external supply of gas, thus excluding the closed box model of evolution for galaxies. The galaxies observed with dominant rotating disks are indeed emission-line galaxies that are either starbursts or LIRGs, which implies that they are forming stars at a high rate, suggesting that a significant fraction of the rotating disks are forming the bulk of their stars within 6 to 8 Gyr.

General Relativity and Classical Cosmology

Subenoy Chakraborty

S. Chakraborty in collaboration with T. Bandyopadhyay has studied the geometry of black hole thermodynamics in Gauss-Bonnet theory. They have presented the five dimensional black hole solutions in Einstein-Maxwell-Gauss-Bonnet theory and have investigated the thermodynamical geometry of this black hole by analyzing the Ruppeiner and Weinhold metrices. They have found that the thermodynamic geometry of the black hole is releated to some sort of duality between the entropy and mass of the black hole. They have obtained the Weinhold metric to be curved, but the flatness of the Ruppeiner metric indicates that the corresponding statistical mechanics is simple (non-interacting).

In Gauss-Bonnet theory (GBT), they have obtained cosmological solutions for perfect fluid in five dimensions. They have also obtained the modified version of the energy conditions in GBT and also examined the cosmic no hair conjecture with dilatonic scalar coupled to Einstein gravity.

Traversable wormhole solutions have been obtained them for modified Chaplygin gas model. They have found that for the existence of wormhole solution, there are some restrictions concerning the parameters in the equation of state for modified Chaplygin gas and the throat radius of the wormhole. They have also analysized physical properties and characteristics of such modified chaplygin wormholes. S. Chakraborty, in collaboration with T. Bandyopadhyay and S. Nath has obtained a class of wormhole solutions in brane world scenario assuming the trace of the resulting matter, i.e., the Ricci scalar on the brane to be zero.

A model of an emergent universe in brane scenario with Schwarzschild-deSitter bulk has been obtained by S. Chakraborty, T. Bandyopadhyay and A. Banerjee. As matter in the brane, they have chosen perfect fluid with equation of state, which is effectively a radiation equation of state at high energy. Also S. Chakraborty and T. Bandyopadhyay have obtained analogus Schwarzschild solution on the brane.

In gravitational collapse, S. Chakraborty has considered both spherical and quasi-spherical models. He, in collaboration with U.Debnath, has examined the shell-crossing singularity in Szekers model and have studied it from both physical and geometrical points of view. S. Chakraborty and T. Bandyopadhyay have studied the gravitational collapse of an inhomogeneous spherical star model, consisting of inhomogeneous dust in the background of perfect fluid or anisotropic fluid. They have concluded that inhomogeneity favours formation of trapped surfaces, while homogeneous cases support the singularity being naked. Also S. Chakraborty, with U. Debnath has studied spherical dust collapse in the background of unified dark matter- dark energy model in the form of modified Chaplygin gas, and has shown that collapse favours the formation of black hole when invisible matter dominates over ordinary dust. Finally, S. Chakraborty, with his collaborators has investigated gravitational collapse in higher dimensional Husain spacetime and has matched Szekeres model with exterior Husain model.

Ramesh Tikekar and K. Jotania

Ramesh Tikekar and K. Jotania, have shown that spherically symmetric spacetimes with spatial sections having the geometry of a 3-paraboloid are useful to describe physically viable relativistic models of compact stars containing strange exotic matter in equilibrium. Theoretical investigations on compact stars having matter densities exceeding nuclear density tend to support the view that the matter in the central region of such exotic objects may be anisotropic. Accordingly, they have studied a number of core envelope models of spherical super dense stars with the feature core consisting of anisotropic fluid engulfed by an envelope containing fluid with isotropic pressure built up in this set up. If the equilibrium is unstable such configurations are bound to collapse under self gravity. In view of this, they have set up relativistic equations governing the non-adiabatic shear free collapse of massive super dense stars in the presence of dissipative forces producing heat flow on the background of spacetimes of parabolic spacetimes and shown that the system admits analytic solutions, which can be used to investigate the collapse of radiating massive compact stars.

Ng. Ibohal

Ibohal has obtained a class of non-stationary de-Sitter, rotating and non-rotaing, solutions of Einsteins field equations with a cosmological term of variable function $\Lambda^*(u)$. It is found that the spacetime of the rotating non-stationary de-Sitter model is an algebraically special in the Petrov classification of gravitational field with a null vector, which is geodesic, shear free, expanding as well as non-zero twist. However, that of the non-rotating non-stationary model is conformally flat with non-empty space. The spacetime geometry of the solution is non-asymptotic and conformally flat, whose energy-momentum tensor possesses the energy density and the negative pressure with the energy equation of the state parameter w = -1/2. It is shown 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 space-time geometry. Hence, the spacetime metric is referred to as dark matter solution of the Einsteins field equations, possessing dark energy with negative pressure. An approximate size of the dark matter mass is found as $m < (1/2)x10^{-60}$ in Boussos length scale $r > 10^{60}$. Ibohal, Ishwarchandra and Yugindro Singh have obtained an exact solution of Einsteins field equations describing a rotating stationary dark matter, which is an extension of non-rotating dark matter solution. The rotating stationary solution is a non- asymptotic, Petrov type D spacetime whose energy-momentum tensor admits a non-perfect fluid having negative pressure and the energy equation of state parameter with minus sign. It is found that the time-like vector fields of the matter distribution is expanding, shearing and rotating with acceleration. It is also found that, due to the negative pressure, the energy-momentum tensor of the solution violates the strong energy condition leading to the repulsion of the gravitational field of the rotating spacetime geometry. The entropy and surface gravity have been analyzed for the horizon of the rotating dark matter solution.

By using Wang-Wu functions, Ibohal and Kapil have obtained a class of embedded solutions 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, we also find the Kerr-Newman-Vaidya black hole, when Kerr-Newman is embeded into the rotating Vaidya solution. The Reissner-Nordstrom-Vaidya solution is type D, whereas Kerr-Newman-Vaidya metric is algebraically special type II of Petrov classification of spacetime. These embedded solutions can be expressed in Kerr-Schild ansatze on different background spaces. The energy momentum tensors for both non-rotating as well as rotating solutions satisfy the energy conservation equations, which show that they are solutions of Einstein's field equation. They have also studied the Hawking's electrical radiation of non-rotating Reissner-Nordstrom-Vaidya and rotating Kerr-Newman-Vaidya black holes. By considering the charge to be a function of radial coordinate, it is found that there is a change in the masses of the variable charged black holes. If such radiation continues, the mass of the black hole 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. These embedded black holes can also be expressed in Kerr-Schild ansatze. The surface gravity, area, temperature and entropy, which are important parameters of a black holes, are also presented for each embeded black holes.

Gravitational Theory

V.C. Kuriakose

Studies on black hole scattering and quasi normal modes(QNMs) play important roles in the hysics of black holes. QNMs describe the damped oscillations under perturbations in the surrounding geometry of a black hole with frequencies, and damping times of oscillations entirely fixed by the black hole parameters. It is expected that QNMs play an important role in the attempt for the experimental observation of black holes. It has been recognized that certain gauge theories allow the possibility of topological defects, such as, strings, magnetic poles, etc. and that these defects represent objects which might have been created in the very early universe. Cosmic strings are strand of matter, which could be created in a cosmological phase transition.The possibility of having strings in the early universe has been suggested by Kibble in 1976. These cosmic strings might be responsible for large-scale structures in the universe. R. Sini and V.C. Kuriakose have evaluated quasinormal mode frequencies for Schwarzschild, RN, RN extremal, SdS and near extremal SdS black hole space times with cosmic string perturbed by massless Dirac field. We have used WKB approximation for our analytical studies supported by numerical calculations.

The idea that, our universe is in a phase of accelerated expansion rather than holding steady, indicates the presence of some mysterious form of repulsive gravity called dark energy. It is being proposed that a model of scalar-field dark energy is the so-called "quintessence". It is important to see how the "foot prints - QNMs" of black holes behave in the presence of quintessence. Nijo Varghese and Kuriakose have evaluated the complex frequencies of the normal modes for the charged scalar field perturbations around a RN black hole surrounded by a static and spherically symmetric quintessence using third order WKB approximation approach. Quintessence decreases the oscillation frequency and increases the damping time of quasinormal frequencies. We have studied the variation of quasinormal frequencies with charge of the black bole, mass and charge of perturbing scalar field and the quintessential parameters.

No-hair conjecture of black holes demands the non-existence of any information other than mass, charge and angular momentum of a black hole. There are reports for and against the existence of scalar hair. In order to prove the no-hair conjecture, no-hair theorems had been established by coupling the classical fields with the Einstein gravity. Kuriakose and Kuriakose have proposed a nontrivial black hole solution of a massive, but self interacting scalar field showing no divergence at the horizon and asymptotically falling to the vacuum value. The reported metric shows trace of scalar charge.

K.K. Nandi

K.K. Nandi together with his collaborators, has been engaged in studying various aspects of the solutions of Einsteins theory including those in the minimally coupled theory. A new technique of generating rotating wormhole solutions in the scalar tensor theory has been found and certain interesting aspects of the solutions have been investigated. It was shown that the known classes of Brans-Dicke solutions were connected by Wick rotations and, thus, are not independent. Next a measure of gravitational energy content has been advanced for wormholes and condensate stars. Finally, a stability analysis of circular orbits is carried out using phase space analysis.

K.D. Patil

The study of the strange stars has been one of the most important topics in astrophysics. It is theorized that when the neutron degenerate matter, which makes up a neutron star, is put under sufficient pressure due to the stars gravity, the individual neutrons break down in to their constituents quarks, viz. the up (u) and the down (d) quarks. Some of these quarks may then become strange (s) quarks. A star composed of the u , d and s quark matter is called a strange star. K. D. Patil and S. S. Zade have studied the non-spherical gravitational collapse of the strange quark null fluid. The interesting feature which emerges is that the non-spherical collapse of charged strange quark matter leads to a naked singularity, whereas the gravitational collapse of neutral quark matter proceeds to form a black hole. Thus, the non-spherical gravitational collapse of charged strange matter contradicts the cosmic censorship hypothesis, whereas the collapse of neutral strange matter respects it.

Saibal Ray

Tolman-Bayin type static charged fluid spheres in general relativity have been considered by Saibal Ray and his collaborators to solve field equations in isotropic coordinates. They have provided conditions for boundary of the charged sphere. The exterior Reissner-Nordtröm solution is compared and constants of integrations are expressed in terms of mass and radius. They also have found out pressure-to-density ratio at the centre of the charged sphere.

Biplab Raychaudhuri

B. Raychaudhuri, in collaboration with Farook Rahaman, Mehedi Kalam and their group has investigated the physical nature of charged brane-world black holes. The timelike and null geodesics of the charged brane-world black holes are presented. They analyze all the possible motions by plotting the effective potentials for various parameters for circular and radial geodesics. They also investigate the motion of test particles in the gravitational field of the charged brane-world black holes using the Hamilton-Jacobi formalism. They consider charged and uncharged test particles and examine their behaviour in both static and nonstatic cases. The thermodynamics of the charged brane-world black holes are studied and it is shown that there is no phenomenon of superradiance for an incident massless scalar field for such a black hole.

Ruffini and his group discussed a special region just outside the horizon of charged black holes where the electric field goes beyond its classical limit. This is a situation where effects of vacuum fluctuations should be considered. When the electromagnetic field exceeds the Heisenber-Euler critical value for e^+e^- pair production, in a very short time of the order $\sim \mathcal{O}(\hbar/mc^2)$, a very large number of e^+e^- pair is created there. This reaches in thermodynamic equilibrium with a photon gas. The period of over critical state is of approximately 10^7 s. The dissipation occurs through a process involving the *dyadosphere* of a black hole. The one-loop correction due to QED to the first order of approximation introduces a correction term in the RN spacetime geometry. This is called dyadosphere geometry. Motion of massive and massless test particle in equilibrium and non-equilibrium case is discussed in a dyadosphere geometry by B. Raychaudhuri and coworkers through Hamilton-Jacobi method. Scalar wave equation for massless particle is analyzed to show the absence of superradiance in the case of dyadosphere geometry.

Anirban Saha

Anirban Saha, together with his collaborator S. Bhattacharya, has studied the emissions of massive scalars and charged massive Dirac spinors from (4+1)- dimensional rotating Gödel black hole, via complex path analysis of semiclassical tunneling approach. The Gödel universe is a cosmological solution of Einsteins equations in 4-dimensions with pressureless dust satisfying weak energy condition, and a negative cosmological constant. The spacetime is spatially homogeneous but unlike the FRW cosmological solutions, it has a rotation parametrized by j, a constant determined by the energy density of the dust and the cosmological constant. In fact, a universe with rotation was the principal motivation to this solution. A few years ago, a solution of Einsteins equations without any cosmological constant in the (4+1)-dimensional minimal supergravity was found, where the bosonic part of the matter consists of a U(1) Chern-Simons gauge field in 5-dimensions. This solution mimics the salient features of the 4-dimensional Gödel universe. A solution, with the same matter content and without preserving any supersymmetry, representing a rotating black hole embedded in the 5-dimensional Gödel universe was immediately found. Such Gödel-type solutions are interesting in the context of string theory because, they are related by T -duality to pp-waves. The conserved charges and their variations for the Kerr-Gödel black hole were computed and the resulting Smarr formula was in full agreement with the first law of black hole thermodynamics (with the horizon temperature given by the surface gravity κ, and entropy by horizon area) like the 4-dimensional black holes.

To get further insight, therefore, they have studied Hawking radiation for this spacetime via semiclassical tunnelling method for both scalar and spinors. They presented a suitable choice of basis expansion for the gamma-matrices, which proved to be crucial to properly analyze the case of spinor emission. Ignoring the back reaction of the matter, they calculate the emission probabilities in the zeroth order approximation of the semiclassical theory. The Hawking temperature is found to be proportional to the surface gravity of the black hole event horizon and are identical for both spinor and scalar. It does not contain any parameter (mass, charge, spin) of the matter. This is due to the fact that back reaction of matter was ignored. The results are in full agreement with the thermodynamic Smarr formula for the Gödel black hole. One important thing to note is the effect of the rotation of the background (parametrized by j) on emissions process. It shows an increment in the Hawking temperature with j. The emission probabilities also increase with j. This can naively be interpreted as the centrifugal effect on the particles due to the rotation of the Gödel background.

S.K. Sahay

The current status of the search for gravitational waves indicates that for an all sky search, its important to detect the gravitational wave rather finding the source location more accurately. Hence, one would like to minimize the Doppler correction requested to make search templates. In reference to this, S.K. Sahay, numerically investigated the independent points in the sky required to search for a signal, assuming the noise power spectral density to be flat. He found that the number of search templates varies significantly. Hence, the computational demand for the search may be reduced up to two orders by time shifting the data. Sahay has also studied the feasibility of the coherent search in small frequency band in reference to advanced LIGO.

Sanjay B. Sarwe

Sanjay Sarwe and Ramesh Tikekar have studied the "non-adiabatic gravitational collapse of superdense star". The relativistic equations governing the non-adiabatic shear free collapse of massive super dense star in the presence of dissipative forces producing heat flow on the background of spacetimes of Vaidya-Tikekar ansatz with associated physical 3-spaces having the 3-spheroidal geometry have been set up. It is shown how the system can be used to examine the development and progress of the collapse during subsequent epochs until the radiating star becomes a black hole.

High Energy Physics

Sukanta Dutta

Sukanta Dutta, along with his collaborators has estimated the accuracy with which the coefficient of the CP even dimension six operators involving Higgs and two vector bosons (HVV) can be measured at linear e^+e^- colliders. Using the optimal observables method for the kinematic distributions, their analysis is based on the five different processes. First is the WW fusion process in the t-channel ($e^+e^- \to \bar{\nu}_e \nu_e H$), where they use the rapidity y and the transverse momentum p_T of the Higgs boson as observables. Second is the ZH pair production process in the s-channel, where they use the scattering angle of the Z and the Z decay angular distributions, reproducing the results of the previous studies. Third is the t-channel ZZ, fusion processes ($e^+e^- \to e^+e^-H$), where they use the energy and angular distributions of the tagged e^+ and e^-. In the fourth, they consider the rapidity distribution of the untagged e^+e^-H events, which can be approximated well as the $\gamma\gamma$ fusion of the Bremsstrahlung photons from e^+ and e^- beams. As the last process, they consider the single tagged e^+e^-H events, which probe the $\gamma e^\pm \to He^\pm$ process. All the results are presented in such a way that statistical errors of the constraints on the effective couplings and their correlations are read off when all of them are allowed to vary simultaneously, for each of the above processes, for $m_H = 120$ GeV, at $\sqrt{s} = 250\,\mathrm{GeV}$, $350\,\mathrm{GeV}$ $500\,\mathrm{GeV}$ and $1\,\mathrm{TeV}$, with and without e^- beam polarization of 80%. They find for instance that the HZZ and HWW couplings can be measured with 0.6% and 0.9% accuracy, respectively, for the integrated luminosity of $L = 100$ fb^{-1} at $\sqrt{s} = 250\,\mathrm{GeV}$, $350\,\mathrm{GeV}$ and $L = 500$ fb^{-1} at $\sqrt{s} = 500\,\mathrm{GeV}$, $1\,\mathrm{TeV}$, for the luminosity uncertainty of 1% at each energy. They infer that the luminosity uncertainty affects only one combination of the non-standard couplings, which are proportional to the standard HWW and HZZ couplings, while it does not affect the errors of the other independent combinations of the couplings. As a consequence, they observe that a few combinations of the eight dimension six operators can be constrained as accurately as the two operators, which have been constrained by the precision measurements of the Z and W boson properties.

Pradip Mukherjee

Pradip Mukherjee has continued studies in noncommutative gravity with Anirban Saha. Along with Anirban Saha and Anisur Rahaman, he has studied the question of deconfinement in noncommutative Schwinger model.

M. Sivakumar

M. Sivakumar has studied the duality of self interacting scalar field coupled to gauge field governed by Chern Simons action in noncommutative spacetime. Polyakovs spin factor formalism was applied to the Seiberg Witten mapped theory to obtain dual Fermionic theory. The dual theory involved only Dirac field and was found to be non-local and non-polynomial, and has a smooth commutative limit.

Machine Learning and Virtual Observatory

Asis Chattopadhyay

Chattopadhyay has proposed some modifications under VOSTAT, so that users of VO and also scientists from other disciplines may use different statistical techniques for their research using large data sets. The programmes have been written in R so that any body can freely use it as R is a free access software in the internet. The basic advantage of VOSTAT is its user friendly environment and wide coverage. Attempts have been made to make VOSTAT a good menu driven statistical package

Application of statistics in astrophysics: Chattopadhyay has carried out a multivariate analysis to explain the best chosen HB morphology parameter (through PCA) and selected the optimum number of parameters to explain that morphology (through step wise regression) considering all the parameters simultaneously in collaboration with G. J. Babu, Tanuka Chattopadhyay and Saptarshi Mandal. They have also tested the robustness by taking several bootstrap samples and extended the study for M31 and LMC globular clusters.

Ninan Sajeeth Philip

Machine learning is a science and an art. It is a science because of its ability to deduce precise relations between a set of features and its respective labels. It is an art because the results it produce are dependent on the data that was used to train the learning tool. It is a common practice to use randomized subsets of a dataset as the training sample. Randomization can produce a representative subsample if the data size is larger than $N = \frac{1}{p}$, where p is the probability to pick the most sparsely represented data from a random distribution of the dataset. Usually, it is required to select a training sample several times larger than N to average out possible bias in the random process. Despite all these efforts, there is no guarantee that the resulting training sample will be optimal.

Generating an optimal training sample is a nontrivial problem. This is because a representative sample alone is not a sufficient condition to produce an optimal training data. In many practical situations, there may be overlapping features for objects from different classes. This would require more samples from such regions in the training sample so that appropriate modeling of the distribution may be estimated. One of the contributions of his research this year was to develop an algorithm for identifying an optimal training data for a given neural network using an incremental learning algorithm. Such a dataset will have maximum information per sample.

Consider the photometric determination of quasars from an whole sky survey reaching fainter and deeper into the sky. Due to the intrinsic variations in individual stars and quasars, the resultant fluxes of these objects may vary. In addition to that, redshifted continuum of quasars also results in flux variations. It, thus, happens that the colours (defined as the ratio of the fluxes in different bands) of quasars at certain redshifts may merge with that of stars. Knowing the redshifts where the colours of quasars merge with that of stars is important in many applications like photometric redshift estimation and optical filter design for telescopes. Bayesian machine learning tools trained on optimally selected data can efficiently determine such regions in the feature space. In a study conducted using SDSS DR6 magnitudes, it was found that colours of quasars at redshifts around 0.6 were having lot of similarity with the colours of some stars. This information can be used to design a new filter that corresponds to some band for which the magnitudes from these objects are distinct so that photometric estimates can be made more reliable.

N.S. Philips research during the year was mostly focused on the above applications of Bayesian machine learning tools in astronomy.

Non-linear Dynamics

K.P. Harikrishnan

The correlation dimension (D2) and correlation entropy (K2) are both important quantifiers in nonlinear time series analysis. However, use of D2 has been more common compared to K2 as a discriminating measure. One reason for this is that D2 is a static measure and can be more easily evaluated from a time series. But in many cases, especially those involving coloured noise, K2 is regarded as a more useful measure. K.P. Harikrishnan, in collaboration with R. Misra and G. Ambika has developed an efficient algorithmic scheme to compute K2 directly from a time series data and shown that K2 can be used as a more effective measure in analyzing practical time series involving coloured noise. They also show that the combined use of D2 and K2 as discriminating measures can extract a more accurate information regarding different types of noise present in a time series data. For this, they undertake a systematic analysis of both synthetic and real world data involving white and coloured noise. This is the first time that such combined analysis is undertaken on real world data.

V.C. Kuriakose

When an optical beam propagates in a suitable non-linear optical medium, solitons can be formed and they can be propagated without any diffraction effect. Spatial solitons with various dimensionality have been observed in various non-linear media. The study of spatial solitons is considered to be important because of its possible applications in optical switching and routing. C.P. Jisha and V.C. Kuriakose have studied the formation of spatial solitons in photorefractive polymers and modulational instability and beam propagation through a photorefractive polymer in the presence of absorption losses. The mathematical analysis used to study these problems is variational analysis supported by numerical calculations. They have also studied modulational instability in a photorefractive medium in the presence of two-wave mixing and derived a model for forward four-wave mixing in the photorefractive medium and investigated the modulational instability induced by four-wave mixing effects. Jisha, Kuriakose and others have performed an experiment to observe self-written wave guide 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.

Josephson junction (JJ) has been identified as an ideal physical system to study chaos and chaos in JJ has been studied extensively. Time-delayed systems are interesting, because the dimension of chaotic dynamics can be made arbitrarily large by increasing the time delay and hence finding applications in secure communications. Most of the chaos based communication techniques use synchronization in a unidirectional drive response system. A limitation, which arises in this case is that messages can be sent only in one direction. Thus, for a two way transmission of signals, a bidirectional coupling is required. Chitra and Kuriakose have dealt with an array of three mutually coupled Josephson junctions with a finite time delay in coupling, and study the system dynamics in the presence of an external driving field. The effect of phase difference and a small frequency mismatch between the driving fields on a chaotically synchronized system with time delay is then studied

H.P. Singh

H.P. Singh has applied analytical signal analysis to strange non-chaotic dynamics. Through this technique, it is possible to obtain the spectrum of instantaneous intrinsic mode frequencies that are present in a given signal. It is found that the second-mode frequency and its variance are good order parameters for dynamical transitions from quasiperiodic tori to strange non-chaotic attractors SNAs and from SNAs to chaotic attractors. Phase uctuation analysis shows that SNAs and chaotic attractors behave identically within short time windows as a consequence of local instabilities in the dynamics. In longer time windows, however, the globally stable character of SNAs becomes apparent. This methodology can be of great utility in the analysis of experimental time series, and representative applications are made to signals obtained from Rssler and Dufng oscillators. The work has been done in collaboration with Kopal Gupta and A. Prasad and R. Ramaswamy.

Plasma Physics

Nagendra Kumar

The spatial structuring of solar and space plasmas is known to have a dispersive effect on waves. Many solar features possess a periodic structure with structures having alternating properties. Nagendra Kumar, along with his student Anil Kumar, has studied the oscillations of a magnetic medium periodic in the x-direction and parallel to z. The case with a stepwise profile for magnetic field has been examined and dispersion relation has been derived. The dispersion curves display two types of modes: kink and sausage, like in the isolated slab, but the profiles are different and depend on the Blochs number k_0. They have also studied the magnetosonic modes of magnetic plasma structures in the solar atmosphere taking into account steady flows of plasma in the internal and external media of a slab immersed in the complex magnetic field, consisting of large longitudinal and small sheared magnetic field components. The investigation brings nearer the theory of magnetosonic waveguides, in such structures as coronal loops and photospheric flux tubes, to realistic conditions of the solar atmosphere. The general dispersion relation for the magnetosonic modes of a magnetic slab in magnetic surroundings is derived, allowing for field-aligned steady flows in either region. It is shown that tangential magnetic field modifies the dispersion curves. The flow changes both qualitatively and quantitatively the characteristics of magnetosonic modes. The flow leads to the appearance of a new type of trapped modes, namely backward waves. These waves are the usual slab modes propagating in the direction opposite to the internal flow. The disappearance of some modes due to the flow is also demonstrated.

Radio Astronomy

Joe Jacob

Recent X-ray observations with Chandra and XMM-Newton have revealed a surprising aspect of cooling flows in clusters; they showed far less cooling below X-ray temperatures than expected, altering the previously accepted picture of cooling flows. Unless gas is thermally supported, radiative cooling leads to a 'cooling catastrophe', i.e., an inexorable inflow of cold gas onto the central galaxy. To prevent this, some heating mechanism is required to raise gas temperature above ~ 2 keV, thus, suppressing the cooling flow. Although several such mechanisms are possible, the most effective heating process is believed to be the energy injected into the intra-cluster medium (ICM) by radio jets from AGNs of central galaxies of clusters and groups. This AGN-heating mechanism is also found to be particularly effective in suppressing the star formation activity that one expects to be quite large around the brightest cluster galaxies due to their preferential position in clusters. The observed strong association of an AGN in the central galaxy and the surrounding cooling-core lends good support to this model, which suggests that they are possibly fuelled by accretion of cooling gas, with the flow rate itself regulated by the AGN-heating, indicating a complex feedback loop with tight coupling between a central black hole and the gaseous atmosphere of the surrounding cooling core.

Energetic processes occurring in clusters of galaxies are usually very well imprinted in radio frequencies. Radio observations of galaxy clusters reveal variety of phenomena, which are not very well understood as yet, but are excellent tools for shedding light into the unknown facets of structure formation and the high energy processes taking place in the intra-cluster gas, thereby guiding tomorrows astronomy. Among these, the extended, steep-spectrum diffuse radio emissions (radio-haloes and radio-relics) are a rare class of radio phenomena shown by a few galaxy clusters, which gives direct insight into the dissemination of energy injected by energetic outflows and jets from quasars and AGNs into the intra-cluster environment. Joe Jacob, in collaboration with J. Bagchi has been continuing his research in the field of extended radio emissions, particularly focussing on the investigation of radio-halo phenomenon in groups and clusters and its impact on the intra-cluster medium environment. During the last year, he has participated in the detailed radio and optical observations of a radio source MRC$\sim$ 0116+111, a luminous, diffuse halo-like emission discovered around the central cD galaxy in a poor, low-mass cluster at a redshift of 0.132.

Extensive radio observations of the galaxy cluster hosting MRC$\sim$0116+111 were taken with GMRT at 240 MHz, 621 MHz and 1.28 GHz with high sensitivity and resolution, and in collaboration with J. Bagchi have also carried out an improved analysis of the existing VLA data at 1.4 and 4.8 GHz. Additionally, deep (B, V, R, I) CCD images of the galaxy cluster were taken with the 2 m optical telescope located at the IUCAA Girawali Observatory (IGO). These observations have provided fresh insight, revealing an amorphous, very steep-spectrum mini radio-halo source of ~ 240 kpc diameter with puzzling properties. The optical and multi-wavelength radio observations also revealed another highly unusual aspect of this radio source: showing a pair of giant (~ 100 kpc diameter) bubble-like diffuse structures. These structures were interpreted as direct manifestation of energetic feedback by radio jets from a central AGN into the hot cluster atmosphere. When the radio jets emerging from the central black hole (AGN) interact with the dense intra-cluster thermal gas, two bubble-like diffuse lobes of non-thermal plasma are inflated, which are filled with relativistic particles and magnetic field and thus, become visible in radio observations. This 'bubble model' was first proposed theoretically in 1970's and recently identified in several clusters using radio and X-ray observations. The most clear example of this phenomenon are the non-thermal bubbles in intra-cluster medium, such as those revealed by Chandra telescope in clusters MS0735.6+7421, Hydra-A, Abell 2052, Perseus and others, showing an unusually large and energetic pair of radio emitting, X-ray dark cavities.

Another interesting fact revealed by the GMRT images of MRC∼ 0116+11 is that these 'radio bubbles' are morphologically quite similar to, but in linear dimension are about three times larger than, the analogous extended radio emission observed in M87 - the well known central radio galaxy in the Virgo cluster. However, in MRC∼ 0116+111, no ongoing AGN activity, such as a compact core and active radio jets maintaining the plasma bubbles have been detected, which are obviously present in M87. So, by what process are the relativistic particles and magnetic field which radiates the synchrotron emission observed in MRC 0116+111 originated? The radio emitting non-thermal plasma was probably seeded in the past by a pair of radio-jets originating in a very energetic episode of AGN in the central cD galaxy.

It is possible that the central super massive black hole (SMBH) which created MRC∼0116+111 have been caught during a low or even quiescent state of its feeding cycle. If the heat input into the cluster medium by these expanding radio bubbles is large enough to significantly offset the cooling loss, the flow of accreting matter onto the SMBH may stop, thus, starving the central engine. So we expect that this radio bubble-fed energy exchange should give rise to a periodic triggering of the AGN itself, establishing a self-regulated activity pattern between cooling and AGN activity. The extremely steep high-frequency radio spectrum of the North-Western bubble indicates radiation losses and this suggests that it is possibly rising buoyantly in the putative hot intra-cluster medium. A uniform spectral index between low to high frequencies for the other bubble near the cluster centre suggests ongoing particle re-acceleration. In the absence of a current AGN activity, the central bubble could be powered by some ongoing energy mechanism, such as particle re-acceleration in magneto hydrodynamic (MHD) turbulence, or in shocks induced by merger activity of galaxies.

Also, the empirical calorimetric calculation of the energetics of the bubbles indicates that the mechanical energy expended by radio jets in blowing the bubbles in the ICM gas is much larger compared to the present radiative output of the bubbles. These calculations imply that the radio jets that inflated these giant bubbles might have also fed enough energy into the intra-cluster medium to create an enormous system of cavities and shock fronts, and to drive a massive outflow from the AGN, which could counter balance and even quench a cooling flow. Therefore, this source presents an excellent opportunity to understand the energetics and the dynamical evolution of radio-jet inflated plasma bubbles in the hot cluster atmosphere. The observed bubble-like structure of the diffuse radio source residing near the cluster centre is an extremely effective probe of the poorly understood physics of the radio galaxy-ICM feedback process.

More new results and good data on the properties of the intra-cluster medium are expected from the approved observations in X-ray region by it Chandra telescope, which are expected to take place anytime soon this year.

Stars and Interstellar medium

Suresh Chandra

Suresh Chandra and his research group are working in the field of anomalous absorption in molecules present 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 (CMB) is an unusual phenomenon. Recently, they have investigated SiC_3, H_2CN and CH_2CN molecules and found that some lines of them are found showing anomalous absorption. In the investigation, they have solved a set of statistical equilibrium equations coupled with the equations of radiative transfer. The required radiative transitions probabilities were calculated quantum mechanically by expressing the wave functions of asymmetric top molecules in terms of the wave functions for symmetric top molecules.

Ajay Chaudhari

Interstellar molecules are found to serve as extremely useful diagnostic tools of star formation and the dynamics of the interstellar medium in general. The IR part of the spectrum is, where the emission and absorption lines of virtually all molecules as well as numerous atoms and ions lie. Until now many interstellar molecules have been identified. It is expected that many more interstellar molecules will be discovered in space once their characteristic spectra are known. Ajay Chaudhari and his group are working on possible astrobiological relevant cosmic molecules (neutral as well as their cation and anion) using quantum chemical methods. The effect of ionization on the charge distribution and its relation to structural changes in IR spectra of these molecules have been also studied. This study will enrich the IR information of astrobilogical molecules.

Shantanu Rastogi

Mid-IR emission features at 3.28, 6.2, 7.7, 8.6 and 11.2 μm are attributed to Polycyclic Aromatic Hydrocarbon (PAH) molecules. Spectral variations with shape, size and ionization state of PAHs have been studied to relate the source to source feature variations with type of PAHs surviving in different regions. Quantum chemical calculations of IR features of a large number of PAHs, carried out using the HPC facility at IUCAA, and model composite IR emission by these PAHs compare with observations of the 7.7 μm feature. The results point towards large PAHs forming in the outflows of post-AGB stars with only compact medium sized PAHs surviving in strong UV sources. For a complete match with observations, in particular the 6.2 μm band, which are obtained at lower frequency for most PAHs, study of PAHs with vinyl side groups is being done. The mode is found to shift close to the observed features characterized as type C.

The extinction properties of nanodiamonds are studied using the discrete dipole approximation technique. There is very little extinction due to nanodiamond grains in the IR – visible with sharp increase in the far-UV. Calculations for core-mantle model taking nanodiamond core and non-spherical mantle of graphite or amorphous carbon modifies the 220 nm peak. Incorporating nanodiamonds in dust models show better match with the average galactic extinction curve. There is lowering and broadening of the 220 nm peak that is accompanied by sharp rise in far-UV extinction as observed along several galactic sightlines.

H.P. Singh

In many numerical studies, the flux of kinetic energy, Fk, is used as the indicator of presence of turbulence. The extent of its penetration into the stable layer is taken as the depth of overshooting. Below a convection zone, this is understandable, as Fk tracks the continuation of the down flow columns into the region below. Above the convection zone, however, this interpretation does not hold. Upward flows disperse and do not form narrow coherent columns. For the convenience of application, another physical quantity needs to be found as a proxy for overshooting. Based on a set of recently computed numerical models, H.P. Singh has attempted to address this question. The study, however, focuses on discussing the problem of non uniqueness, as it is not yet possible to offer a definite suggestion. The work has been done in collaboration with K. L. Chan.

H.P. Singh has built a model spectra of stellar populations at high resolution and with variable α-element enhancements. Analyzing spectra of galactic globular clusters shows that it is possible to derive [Mg/Fe] reliably and efficiently using spectra integrated along the line of sight, thus, opening perspectives for investigating the enrichment process in galaxies and star clusters. The work has been done in Collaboration with M. Kolava, Ph. Prugniel and R. Gupta .

The Solar System

H.S. Das

H. S. Das has studied the light scattering properties of comets Levy 1990XX and Hale-Bopp through simulations using Ballistic Particle-Cluster Aggregation (BPCA) or Ballistic Cluster-Cluster Aggregation (BCCA) aggregates of different compositions (e.g., silicates, carbonaceous materials etc.).

The observed linear polarization data of comet Levy 1990XX have been studied using superposition T-matrix code. The best-fitting refractive indices coming out from the analysis show silicate behaviour when monomer radius is a $_m = 0.12\mu m$ and provide excellent results on the maximum and negative degrees of linear polarization at a single wavelength $\lambda = 0.485\mu m$ for BCCA aggregates.

Also, the observed linear polarization data of comet HaleBopp have been studied at wavelengths $\lambda = 0.485$ and 0.684 μm through simulations using BPCA and BCCA. Using Superposition T-matrix code, the best-fitting values of complex refractive indices are calculated, which can well match the observed polarization data at the above two wavelengths. It is found that there is not a single value of the monomer radius (a_m) that can simultaneously fit the observed polarization data at two wavelengths 0.485 and 0.684 μm. However, for different a_m in the two wavelengths, corresponding to similar size parameter of the monomer (x $\approx$ 1.56), better fit can be achieved. The best-fitting complex refractive indices coming out from the analysis show silicate behaviour as the values are close to amorphous olivine. Thus, it is concluded that the silicate composition can best match the observed polarization data of comet HaleBopp at $\lambda = 0.485$ and $0.684\mu m$.

S. Sahijpal

Sandeep Sahijpal has been working on various aspects of the origin and the early evolution of the solar system. He has been developing detailed thermal models of the planetary differentiation of the Vesta and other differentiated asteroids in the early solar system. Besides, he has recently initiated work on developing the numerical code on the galactic chemical evolution

Planetary Differentiation of Vesta of differentiated asteroids, including Vesta initiated within the initial few million years of the solar system. Distinct scenarios have been proposed for the core-mantle and mantle-crust differentiation of these bodies. He has numerically simulated the distinct scenarios for the origin of planetary basalts in order to understand the differentiation of Vesta. These scenarios differ from each other in term of the relative timings of the core-mantle and mantle-crust differentiation.

The universe was formed around ∼13.7 billion years ago by a series of events initiating with the big-bang. The primordial nucleosynthesis subsequent to the hadron and the lepton era resulted in production of hydrogen and helium. The galaxies were formed perhaps within the initial billion year of the universe. Inside the galaxy the process of stellar nucleosynthesis resulted in the gradual enrichment of the heavier elements. He has also initiated work in developing the Galactic Chemical Evolution (GCE) code. The GCE basically deals with the detailed understanding of how the stable isotopic abundances of the elements evolved over time due to the stellar nucleosynthetic contributions of numerous generations of stars. As an initial step in this direction, he has succeeded in developing a basic numerical code on the galactic chemical evolution model for all the stable isotopes from ^{1}H to ^{78}Zn, following the latest prescriptions in the star formation rates, initial mass function, stellar evolution and nucleosynthesis.

Asoke K. Sen

Assuming cometary grains to be compact spheres, the observed cometary polarization values are generally interpreted using Mie Scattering Theory. This technique helps to constrain the composition and size of the grains. However, recent STARDUST and other IDP measurements suggested the grains to be aggregates of monomers. An aggregate model can generate irregularly shaped and porous grains from a cluster of constituent particles known as monomers. The grains with such shapes and properties are believed to be most realistic.

The polarization data of comet Levy was recently explained by the A K Sen and co-authors using aggregate model and it gave closest fit to the observed data as compared to all other grain models (containing spheres, spheroids etc.). The authors have also recently explained the polarization data of comet Hale Bopp. Analysis of the observed data of comets Levy and Hale Bopp at 0.485 μm confirms the existence of aggregate grains, with the size of the monomer as 0.12 μm, and refractive indices (1.783, 0.052) and (1.778, 0.059) for the two comets. However, the analysis of data of Hale Bopp at two different wavelengths 0.485 μm and 0.684 μm, shows that we need monomer radii of 0.12 μm and 0.17 μm to provide best fitting to the observed data. So the model demands different values of monomer radii at different wavelengths for best fit, leaving the size parameter $2\pi a/\lambda$ fixed at 1.56. Similar trends are also seen, when we include data for comet Halley. This may suggest that, the actual cometary grains are more complex, than just having monomers with single size and composition in the aggregates.

Paniveni Udayashankar

Paniveni has been studying the Activity dependence of Solar Supergranular fractal structure. Using the Solar intensity data obtained in 2002 during the Solar Maximum phase from Kodaikanal, fractal analysis is being carried out. About 200 discernible cells close to the periphery of the plage and sunspots identified as active region cells and about 100 dinstinctly seen cells away from the plage and sunspots treated as quiescent region cells are analysed and the area and the perimeter of these cells are measured using IRAF and IDL software packages. Fractal dimension 'D' is obtained using the relation $P \propto A^{D/2}$. This paves a way for understanding the isobaric nature and turbulent characteristics of the supergranular cells.

S.N.A. Jaaffrey

S.N.A. Jaaffrey and collegues have modeled the azimuthal magnetic field contribution to the joule heating near the edges of umbral dot and found it to be consistent with earlier simulation work done in this field. They have compiled the publically available inversion codes for Solar data. With the help of inversion of Solar data it is possible to make magneto grams and Doppler grams. The main motivation is to use the available inversion codes for specific purposes. The group is mainly analyzing solar data obtained from Japanese satellite Hinode. The main problems being considered in solar physics are the following: (i) Theoretical fine structure model of umbral dots magnetic field. (ii) Study of the umbral and penumbral oscillations with the help of advance data analyzing techniques such as Bayesian analysis. (iii) Understanding the phenomenon of magneto convection with the Hinode observations.

Theoretical Physics

Moncy V. John

Trajectory interpretations of quantum mechanics, such as the de Broglie-Bohm approach, draw renewed interest in recent years. While pursuing the quantum cosmological features of a cosmological model which arises from a complex metric, Moncy V. John has suggested a complex trajectory interpretation of quantum mechanics in 2002. Now he has shown that in this complex trajectory representation, the Born's probability density can be obtained from the imaginary part of the velocity field of particles on the real axis. Extending this probability axiom to the complex plane, a probability density was found by solving an appropriate conservation equation. The characteristic curves of this conservation equation are found to be the same as the complex paths of particles in the new representation. The boundary condition in this case is that the extended probability density should agree with the quantum probability rule along the real line. For the simple, time-independent, one-dimensional problems worked out here, it was found that a conserved probability density can be derived from the velocity field of particles, except in regions where the trajectories were previously suspected to be nonviable. An alternative method to find this probability density in terms of a trajectory integral, which is easier to implement on a computer and useful for single particle solutions, is also obtained. Most importantly, he has shown, by using the complex extension of Schrodinger equation, that the desired conservation equation can be derived from this definition of probability density.

P. N. Pandita

The Higgs mechanism of spontaneous electroweak symmetry breaking is a necessary ingredient of the Standard Model (SM), which is crucial for its internal consistency. The search for the Higgs boson is, thus, one of the major tasks for the experiments at the Large Hadron Collider (LHC). In order to confirm the Higgs mechanism as the origin of spontaneous breaking of $SU(2)_L \times U(1)_Y$ gauge symmetry in the SM, not only must the Higgs boson be discovered, but also its trilinear ($\lambda^{\rm SM}_{HHH}$) and quartic ($\lambda^{\rm SM}_{HHHH}$) self-couplings must be measured in order to completely reconstruct the Higgs potential. Furthermore, one must be able to measure the couplings of the Higgs boson to gauge bosons and fermions.

P. N. Pandita, in collaboration with Per Osland and Levent Selbuz, has carried out a detailed analysis of the general two Higgs doublet model with CP violation. Different parametrizations of the model have been studied, and Higgs boson masses and trilinear couplings for the different parametrizations have been analyzed. Within a general model it has been found that the trilinear Higgs couplings have a significant dependence on the details of the model. The analysis has been carried out including the one-loop radiative corrections in the effective potential approximation.

On the other hand supersymmetry is the only known framework in which the Higgs sector of the SM is stable under radiative corrections.In the minimal supersymmetric standard model (MSSM) the fermionic partners of the two Higgs doublets (H_1, H_2) mix with the fermionic partners of the gauge bosons to produce four neutralino states $\tilde{\chi}^0_i$, $i = 1, 2, 3, 4$, and two chargino states $\tilde{\chi}^\pm_j$, $j = 1, 2$. In the MSSM with R-parity conservation, the lightest neutralino state is expected to be the lightest supersymmetric particle (LSP). The neutralino states of the minimal supersymmetric standard model have been studied in great detail, because the lightest neutralino, being the LSP, is the end product of any process involving supersymmetric particle in the final state. The lightest neutralino state, being typically the LSP, is stable and therefore a possible dark matter candidate. Since the neutralinos are among the lightest particles in low energy supersymmetric models, P. N. Pandita, in collaboration with Rahul Basu and Chandradew Sharma, has studied the production of the lightest neutralino in the radiative process

$$e^+ + e^- \to \tilde{\chi}^0_1 + \tilde{\chi}^0_1 + \gamma$$

in the minimal as well as nonminimal supersymmetric models. The signal as well as the background processes have been extensively discussed. The cuts on the photon angle and energy that are used to regularize the infrared and collinear divergences in the tree level cross sections are considered in detail. Using the experimental constraints, we have obtained the optimal set of parameters for the different supersymmetric models that are used to calculate the signal and the background cross sections, as well as the significance of the radiative production of the lightest neutralinos.

Cosmology and Structure Formation

Manzoor A. Malik

Manzoor A. Malik is continuing his work on the cosmological many-body problem using a statistical mechanical approach. This description makes it possible to account for the extended nature of galaxies, a more than one component system of galaxies and possibly account for a fraction of the dark matter in the universe, besides providing a more fundamental basis for the earlier thermodynamic results of Saslaw and his coworkers. Together with F. Ahmad and W. C. Saslaw; M. A. Malik has refined the Spatial Galaxy Distribution Function from time to time to include higher order contributions, two-component nature of the system etc. M. A. Malik has been involved with F. Ahmad in developing a cosmic energy equation for extended mass structures. Malik is also in the process of initiating some work in CMB with Tarun Sourdeep.

Quantum Cosmology, Brane World Quintessence

Sarbari Guha

Sarbari Guha studied the embedding of four-dimensional hypersurfaces in higher-dimensional spacetimes with particular reference to the study of five-dimensional models. Sarbari Guha with her collaborator Subenoy Chakraborty has considered RS2-type braneworlds with the bulk in the form of a five-dimensional warped product space-time, 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 motions of the particles and analyzed the conditions of stability. They have also determined the cosmology of the corresponding (3 + 1)-dimensional hypersurfaces. She is now working on the description of the corresponding braneworld scenario.

Anjan Ananda Sen

A. A. Sens research was mainly concentrated on the aspects of dark energy Quintessence. Together with Robert Scherrer, he proposed an equation state for scalar fields which have very flat potentials. This equation of state seems to be quite general and works for all the scalar fields which have a flat part in their potentials. Later they generalized to phantom type scalar fields as well. To check the universality of this equation of state, they also studied the tachyon type scalar field models with nearly flat potentials, and showed that the same equation of state holds true for the tachyon case also. This has been done in collaboration with Amna Ali and M. Sami. Next with Chandrachani Devi, Sen studied the scaling solution in different modified gravity models in the presence of a tachyon type scalar field. With Diego Pavon, he reconstructed the interaction rate for the Holographic Dark energy models using Supernova, BAO and X-ray cluster data.

Anisul Ain Usmani

In continuation to his previous study on rotation curves and brane world model, several aspects of the $4d$ imprint of the $5d$ bulk Weyl radiation are investigated by A.A. Usmani. It is shown that the radiation does not have the perfect fluid equation of state although the fluid itself is not exotic. Further, the model is capable of meeting the two crucial requirements dictated by observations, viz., stability of circular orbits and the attractive nature of gravity in the halo region.

(III) IUCAA-NCRA GRADUATE SCHOOL

Three IUCAA Research Scholars, Mahdi Bazarghan (Guide: Ranjan Gupta), Amir Hajian Forushani (Guide: Tarun Souradeep), Arvind C. Ranade (Guide: Ranjan Gupta; Co-Guide: H.P. Singh (Delhi University), 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:

Application of Artificial Neural Networks to Multi-dimensional Astronomical Data

Mahdi Bazarghan

In the recent years, Artificial Neural Networks (ANN) have become extremely popular as a tool for handling large data bases, particularly in astronomical application.

This project investigates the application of ANN in the analysis of stellar spectra. It is mainly, application of these techniques to the automatic classification of stellar spectra of stars.

In this thesis different stellar spectral libraries and data survey are classified using different algorithms of ANN, which are listed below:

- Classification of Jacoby, Hunter and Christian (JHC) library using Self-Organizing Map (SOM), which is an unsupervized learning algorithm, that means, there is no teaching of network using examples, by giving input vector and target output pair. Instead, the network tries to find patterns or regularities in the input data using minimum distance method. The SOM is trained iteratively, in each training step one vector x from the input data set is randomly chosen and then the distance between this vector and all the weight vectors of the map will be calculated and this distance measurement, typically is the Euclidian distance. In this technique, the inputs are organized in a two dimensional grid and the stars with similar spectral class, group together and make a cluster. So clustering of same type stars takes place at respective position and different classes get clustered in different positions of the map. The map size used in this project was $9 \times 8 = 72$, which in turn gives 72 neurons in the output map. The 158 labeled JHC spectra from a1 to a158 got well clustered and classified into 53 classes with success rate of 89%.

- Multilayered back-propagation neural network with supervised learning algorithm is used to classify 2000 brightest sources in the Atlas from Infrared Astronomical Satellite (IRAS) sources into 17 predefined classes. Various ANN configuration and learning rates were tried out in order to find the best network performance. The network configuration, which gives the highest classification rate is 93:40:17 with learning rate of 0.8. The number of correctly classified spectra achieved with this configuration was 1643 out of 2000 spectra that is the success rate of 82%, and time taken for network to converge was about 15 to 20 minutes. The highest misclassifications has occurred between classes, which could be even confusing for a human classifier.

- The ELODIE.3, an updated release of the ELODIE library was another data, which was classified using Probabilistic Neural Network (PNN), which was a supervised technique. This library covers the wavelength range of 4000 to 6800 Å , and contains 1962 spectra of which 1959 spectra are selected for the classification. The library is given at two resolutions, high and medium of which the medium resolution is selected. The training set was the JHC library, spectral resolution of JHC was FWHM=4.5 Å , with one flux value per 1.4 Å and the ELODIE has a resolution of FWHM = 0.55 Å with each flux value at 0.2 Å. The Principal Component Analysis (PCA) technique was also applied to both the data sets in order to compress the data optimally and remove the redundant information in the spectra. After preprocessing both the libraries to the same platform they were used for the classification and the result obtained was: spectral type accuracy of 3.2 sub spectral type and luminosity class accuracy of 2.7 for full spectra and spectral type accuracy of 3.1 sub spectral types and luminosity class accuracy of 2.6 with 26 PCs.

- Sloan Digital Sky Survey (SDSS) is another source of data used for the classification. About 5000 stellar spectra of stars are extracted from SDSS - Data Release 2, using Structured Query Language (SQL).

The spectra are in fits format and were converted into text format (*i.e.,* wavelength versus flux) using IRAF package. The PNN supervised technique is used for the classification of spectra. The training data set is from JHC library. A wavelength range of 3830 to 6800 Å is selected, which is common to both, train and test data sets. Both the data sets are brought to the same platform and normalized to unity. When both the data sets become uniform then they are given to neural network and classification results are analyzed. To illustrate the quality of fits of the SDSS spectra with respect to the JHC spectra, some typical spectro-luminosity classes from each main spectral types are plotted. The full classification result is given as a table, which lists the name of SDSS spectra; corresponding JHC class obtained by the PNN and the corresponding χ^2 value of these plots. The users of this catalogue can consider the $\chi^2 = 0.02$ as a kind of limit on which the specified classes of spectra having $\chi^2 > 0.02$ are less likely to be true.

The ANN makes it possible to have very fast classification and extraction of physical stellar parameters of data survey like SDSS, with tremendous number of objects available to the community, which will be otherwise very time consuming to do it by eye inspection.

Cosmology with CMB Anisotropy

Amir Hajian Forushani

One of the main challenges in the study of the Cosmic Microwave Background (CMB) anisotropy is to develop methods to extract maximum information from the rich source of information provided by this random field on the sky. When the condition of statistical isotropy (SI) holds, the widely used angular power spectrum has proved to be a very useful quantity, which contains the whole information encoded in the CMB anisotropy field. However, there are certain mechanisms that violate the SI condition. This thesis is dedicated to the study of this fundamental assumption in CMB studies. We have formulated the problem mathematically, constructed a quantitative method to describe SI violation (bipolar power spectrum), studied number of sources of violation of SI condition and finally examined this fundamental assumption using the most recent full sky CMB anisotropy maps provided by the first-year data of *Wilkinson Microwave Anisotropy Probe* (WMAP). The main conclusions are:

- SI of CMB anisotropy is an important property of CMB anisotropy field, which can be quantified and checked in distinct from Gaussianity of the field. **Bipolar Power Spectrum** (BiPS) is an orientation independent quantity, which is sensitive to structures and patterns in the underlying two-point correlation function, and is a very useful tool for searching for departures from SI.

- There is strong evidence for SI violation in the full sky CMB anisotropy maps based on the first-year data of WMAP up to $l \sim 60 - 70$.

- The possibility of compact spaces in cosmic topology is a theoretically well motivated possibility that has also been observationally targeted. The cleanest signature of the topology of the universe is written on the microwave sky. The existence of preferred directions along the highly correlated spots is the smoking gun of compact spaces and can be exploited to detect them. We propose BiPS as a fast and orientation independent method to look for such signatures in CMB anisotropy map.

- Hiding an anisotropic template such as those of Bianchi models in a ΛCDM CMB anisotropy temperature map, will lead to observable effects on bipolar power spectrum. The null BiPS of WMAP can be used to put tight constraints on the existence of such hidden patterns in the WMAP data.

- Observational artifacts such as non-circular beam, inhomogeneous noise correlation, residual striping patterns and foreground residuals are potential sources of SI breakdown. Our null BiPS results confirm that these artifacts do not significantly contribute to the first year data of WMAP up to $l \sim 60 - 70$.

A Stellar Spectral Library in Near Infrared

Arvind C. Ranade

Infrared has characteristic property of transparency through the dust. It is obvious from the Wien displacement law that cool objects radiate (thermally) maximum in infrared band of electromagnetic radiations. Moreover, from Hubble's observation of expansion of universe, it is known that visible light from distant objects is red-shifted thereby, moving the longer wavelengths to the infrared part. Since the infrared radiations penetrate more than the visible and UV light, they can easily reveal the processes at work in star forming regions which are typically enshrouded in clouds of gas and dust. Areas where infrared plays an important role are: (i) study of primeval galaxies and high red-shift Quasi-Stellar Objects, (ii) mapping the interstellar dust in the galactic plane, (iii) in the better understanding of stellar distributions and physical processes occurring near the galactic centre, and (iv) discovery of brown dwarfs and planetary candidates.

Most of the atoms and molecules in the universe have their origin in the stars. As stars burn and eventually die out, they produce heavier elements which are then ejected into interstellar space (as a star blows off its outer layers during its final phases). Some of these elements then combine to form molecules. Since every atom and molecule has unique spectral transitions the only way to understand the details of the atoms and molecules is through spectroscopy. Depending on the smallest wavelength interval ($\Delta\lambda$) that can be resolved, we have three categories of spectroscopy. One with the resolution R $\sim$ 100, named as low resolution spectroscopy. It is useful in measuring metallicity and gravity of a star as these parameters have subtle effects on the shape of the stellar continuum. The other category with R $\sim$ 1000, is named as medium resolution spectroscopy. With the medium resolution atomic features can be resolved in an average manner. With third category having R $>$ 10,000, named as high resolution spectroscopy, individual molecular lines can be resolved.

Infrared radiation is categorized into three regions: near, mid and far infrared. The boundaries between these regions are not strictly defined. The criterion that determines the wavelength to be included in any of these three regions depends on detector technology used for gathering infrared light. Infrared domain starts from 1 μm and extends towards longer wavelengths. The region from 1 μm to 5 μm is known as near infrared (NIR), from 5 to 30 μm is mid infrared and from 30 to 350 μm is far infrared. The wavelength longer than 350 μm is now referred to as sub-millimetre. The NIR is again sub-divided into three regions: J band with 1.25 μm, H band with 1.65 μm, K band with 2.2 μm, L band with 3.5 μm and M band with 4.8 μm as central wavelengths.

As a result of the efforts of placing the telescopes at high altitudes, most of the water content of the atmosphere, near infrared region is getting significant attention next only to the optical region of the overall electromagnetic spectrum. Moreover, the development in size and quantum efficiency of detectors is helping in the rapid growth of NIR technology. The spectroscopic studies and building of spectral libraries in NIR region has special importance in the stellar population synthesis of galaxies, clusters and AGNs. The libraries consisting of different spectro-luminosity classes can help in getting the composite spectra, which could be used to compare the observed integrated light spectrum of the above mentioned objects.

In the present thesis, a spectroscopic database of stars in NIR region has been compiled. This database has a large range in stellar parameters, e.g., temperature, metallicity and gravity. The necessary observations were carried out using the 1.2 m Gurushikhar Infrared Telescope (GIRT) at Mt. Abu, India. The instrumentation used was the HgCdTe 256 $\times$ 256 NIR array (NICMOS3) based spectrometer. The spectra have a moderate resolution of 1000 in J, H and K bands.

Chapter 1 starts with a brief introduction of different branches of observational astronomy, e.g., Gamma-ray astronomy, X-ray, UV, Optical, Infrared, Microwave and Radio astronomy. The role of infrared astronomy in understanding different process operating in planetary objects, stars, galaxies and interstellar dust has been reviewed. The importance of infrared and spectroscopy has been emphasized. The challenges of making observations in the infrared are discussed. A detailed survey of available libraries in ultra-violet, optical as well as in near-infrared has been carried out. It has been noticed that there are around 50 libraries in the wavelength range 1-25 μm, where substantial number of stars have been observed. Out of these only 21 libraries are available in an electronic form. The largest and most comprehensive libraries in the NIR have been described in greater detail. A summary of the present GIRT library is provided at the end of chapter 1. The significance of the GIRT NIR library has been emphasized.

Chapter 2 deals with the observations and basic data reduction steps involved in the development of GIRT database. The details about GIRT in regard to its location, aperture, focus, focal ratio, etc. have been given. The specifications of NICMOS3 HgCdTe 256 × 256 NIR array based spectrometer have been provided. The observational log for the date and time of observations, number of standard and programme stars observed in each observational run are catalogued. Since the selection of stars in the library is an important factor, special care has been taken in selecting the stars. Different criteria as well as references used for the same are listed. Set-up of the instrumentation and procedure for the data acquisition are listed here. Steps involved in basic data reduction procedure like cosmic ray removal, 2D to 1D frame conversion, aperture extraction, etc. have been explained at the end of this Chapter.

As compared to H and K bands, J band is the least explored NI region. The survey carried out on the presently available J band libraries in the literature is discussed in the beginning of **Chapter 3**. This chapter presents the spectroscopic data in J band (11300Å to 13100Å). This database developed is one of the few libraries available for work on stellar population synthesis. The J band database contains 126 spectra, covering a large range of spectro-luminosity classes. The distribution of stars with respect to spectral type and luminosity class are shown graphically. The distribution plots of stars as function of different combinations of parameters such as temperature, gravity and metallicity are also shown. The Image Reduction and Analysis Facility (IRAF) software developed by National Optical Astronomy Observatories (NOAO) was used for the spectral reduction. The steps involved in wavelength and flux calibration of J band spectra are highlighted. The wavelength calibration was done through the telluric absorption lines available in the spectra. The lines used for the spectral reduction are shown. Relative flux calibration was done using the standard method of calibrating the ratio of flux of standard star with the programme star. Each spectrum is continuum shape corrected to its respective effective temperature. To check the accuracy of GIRT spectra, a library of Wallace et al. was used. The sample spectra for a few supergiants, giants and dwarf stars from GIRT are also shown at the end of chapter 3.

Chapter 4 presents the spectroscopic data in H band. From a survey of the existing literature, it has been noticed that the H band is the most explored near infrared region as compared to J and K bands. This chapter starts with the survey of available H band libraries. Our GIRT H band database contains spectra of 135 stars. It has large range in spectro-luminosity classes similar to J band. The HR diagram depicting the parameter range covered for these 135 stars is shown. The wavelength calibration was done through the atmospheric OH emission lines printed on sky frames. The sample spectra indicating wavelength lines used is shown. The procedures for relative flux calibration and continuum shape correction were similar to those involved in J band except the change in wavelength region. Except for the sixteen stars observed in one particular observational run, rest of the stars have the coverage from 15200Å to 17800Å. Sixteen stars have the coverage from 15500Å to 17300Å. Validity checks have been performed on the GIRT spectra by comparing with the library of Meyer et al. The comparison between the two libraries has been graphically shown for several common stars.

On the pattern of J and H band database discussed in chapters 3 and 4, the K band database is presented in **Chapter 5**. K band is well known for the domination of H_2O and CO absorption in the earth atmosphere. Therefore, K band is crucial in NIR spectroscopy. Chapter 5 starts with the review of K band libraries available in the literature. Our GIRT K band database has 114 spectra. Similar to J and H band, a histogram, and distribution plots for combination of parameter spaces are shown. The steps involved in wavelength and flux calibration of K band are highlighted. The wavelength calibration was again done through the atmospheric OH emission lines printed on sky frames. The sample spectra indicating wavelength lines used are highlighted. Relative flux calibration and continuum shape correction was similar to J and H band spectra except a different wavelength range in the K band. It has been observed that OH lines were not registered at longer wavelengths and hence most of the K band database is restricted to 20300Å to 22600Å . Depending on the rotation of grating during the observation run, each star has different wavelength coverage in K band. To check the consistency and accuracy of the spectra in GIRT K band, a library of Wallace et al. was used.

Chapter 6 deals with the absolute flux calibration and data validation checks on J, H and K band GIRT spectra before it is made available in the public domain. J, H and K band libraries were normalized at their respective central wavelength value of 12500Å , 16500Å and 22000Å. The data validation of GIRT spectra is demonstrated through (i) comparison between GIRT and published synthetic spectra, and (ii) classification of stars through ANN trained on empirical spectra from Meyer et al. and Wallace et al. From these validity checks, it can be confirmed that the GIRT stellar spectral database may serve the scientific community working in the field of stellar population synthesis. Lastly, possible future work based on the information available in GIRT database is discussed.

(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.

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Supervision of Thesis:

N. Kumar (2008) On the heating of chromosphere and corona, M. J. P. Rohilkhand University, Bareilly, Ph. D. thesis of Pradeep Kumar.

N. Kumar (2008) Waves and instabilities in dusty plasmas, M. J. P. Rohilkhand University, Bareilly, Ph.D. thesis of Vinod Kumar.

K.D. Patil (2008) A study on spherical gravitational collapse and cosmic censorship hypothesis, RTM Nagpur University, Nagpur, Ph. D Thesis of S. S. Zade.

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M. Sivakumar (2008) Some aspects of duality in commutative and non-commutative space-time, University of Hyderabad, PhD Thesis of K. M. Ajit.

A. A. Usmani (2009) **V**araitional Study of $_{\text{ËË}}\text{He}^{6}$ hypernucleus and Ë Ë potential, Aligarh Muslim University, Ph.D. thesis of Zafrul Hasan.

(V) PEDAGOGICAL ACTIVITIES

(a) IUCAA-NCRA Graduate School

Dipankar Bhattacharya
A topical course on Gamma Ray Bursts (12 lectures), April-May 2008

Naresh Dadhich
Methods of Mathematical Physics II

Sanjeev Dhurandhar
Methods of Mathematical Physics I

Gulab Chand Dewangan
Electrodynamics and Radiative Processes I

Ajit Kembhavi
Electrodynamics and Radiative Processes II

Ranjeev Misra
Galaxies: Structure, Dynamics and Evolution

Maulik Parikh
Quantum and Statistical Mechanics I

T. Padmanabhan
Quantum and Statistical Mechanics II

A. N. Ramaprakash
Interstellar Medium

R. Srianand
Extragalactic Astronomy II

K. Subramanian
Extragalactic Astronomy I

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

Joydeep Bagchi
Stellar Structure and Evolution (15 Lectures)
Radio Astronomy Practicals (3 experiments, in collaboration with B.C. Joshi, NCRA)

Dipankar Bhattacharya
Astronomy and Astrophysics I (20 lectures)

Ranjan Gupta
Astronomy and Astrophysics I (Theory 10 lectures) and Laboratory for III and IV semester courses (10 sessions and night experiments)

Varun Sahni and Tarun Souradeep
Astronomy and Astrophysics II (about 21 lectures)

K. Subramanian
Astronomy and Astrophysics I, (about 18 lectures)

(c) Supervision of Projects

Dipankar Bhattacharya

Swetambar Das
(Patna Science College, Academy summer fellow)
Polarized Emission from Gamma Ray Burst Jets

Niti Madhugiri
(BITS, Goa, VSP)
Coded Mask Imaging of Burst Sources

Ankush T. Bhaskar
(St. Xavier's College, Mumbai, Summer School)
Basic Processes in Astrophysical Plasmas

Maithili Kalamkar
(Pune University, M.Sc.)
Cyclotron Absorption Line Spectroscopy of Accreting X-ray Pulsars

Suvodip Mukherjee
(Fergusson College, Pune, B.Sc.)
Radiation from a Relativistically Expanding Shell

Ajit Kembhavi

Kashmira Patil and Priyankar Pawar,
(B.V. B. College of Engineering and Technology, Hubli)
Quantitative Galaxy Photometry via Web Services

Naresh Dadhich

Kartik Prabhu
(Indian Institute of Technology, Kharagpur, VSP)
Gravity in Higher Dimensions

Abhas Saroha
(Indian Institute of Technology, Kharagpur, VSP)
Gravity in Higher Dimensions

Gulab Chand Dewangan

Archana Misra
(Utkal University, Bhubaneswar, VSP)
(jointly with R. Misra)

Seven projects in the X-ray astronomy school during February 2 - March 20, 2009
(jointly with R. Misra, Nilay Bhatt, Subir Bhattacharyya, D. Bhattacharya, and Kuntal Misra).

Kinjal Banerjee
Time-delay Interferometry Problem for LISA.

Siddharth Malu

Neeraj Goswami (IIT Kharagpur (part of the IUCAA Summer School))
CMB Sky and Instrument Simulation

Ranjeev Misra

Kshitija Kelkar (Fergusson College, Pune, B.Sc.)
Estimation of Pulse Period of a Pulsar in the Framework of a Toy Model

Shayantani Twisha (Fergusson College, Pune, B.Sc.)
The Universe

J. V. Narlikar

Summer School Students' Programme
(Foucault Pendulum)

Project sponsored by other agencies :

ISRO Cryosampler Balloon Project : This project completed a landmark in its ongoing quest for micro-organisms in space, when the paper based on its findings was accepted for publication in the International Journal of Systematic and Evolutionary Microbiology. A brief summary of the work has been published by the India Portal of *Nature* and has been summarized in the highlights of research. The project may continue if ISRO agrees to sponsor it for further studies.

Biswajit Pandey

Juzar Yahya Thingna (Pune University, M.Sc.)
Topological Characterization of Random Fields
(Co-guided with Tarun Souradeep.)

A. N. Ramaprakash

M. Deshmukh (Pune University, M. Sc.)
Position Angle Calibration of IFOSC polarimeter

T. Krishna, N. Patil, and A. Vilekar
(Maharashtra Institute of Technology, Pune, B.E.)
USB-RS232 and Ethernet-RS232 Bridge Board Testing

Swara Ravindranath

Dhairyashil Jagadale
(Fergusson College, Pune, M.Sc.)
HII Region Photometry of Circumnuclear Starbursts in NGC 6951

Shyamal Date (University of Pune, VSP)
Spectroscopy of Blue Compact Galaxies

R. Srianand

Sandhya (Indian Academy of Science)
QSO Absorption Lines

Kunal Mooley (IIT Bombay, VSP)
Probing the Variation of Fundamental Constants

Sowgat Muzahid
(IUCAA-NCRA graduate school)
O VI in the Intergalactic Medium

(d) Supervision of Ph.D.Thesis

Ranjan Gupta (Guide)
By Arvind Ranade
A Stellar Spectral Library in Near Infrared

By Mahdi Bazharghan
Application of Artificial Neural Networks to Multi-dimensional Astronomical Data

Tarun Souradeep (Guide)
By Amir Hajian Forushani
Cosmology with CMB Anisotropy

(e) Pedagogical Articles in Physics

T. Padmanabhan Schwarszchild Metric at a Discounted Price, *Resonance*,**13,** 312-318, 2008.

T. Padmanabhan Why are Black Holes Hot? *Resonance*, **13,** 412-419, 2008.

T. Padmanabhan The Logarithms of Physics, *Resonance*, **13,** 510-518, 2008.

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T. Padmanabhan Isochronous Potentials, *Resonance*,**13,** 998-1008, 2008.

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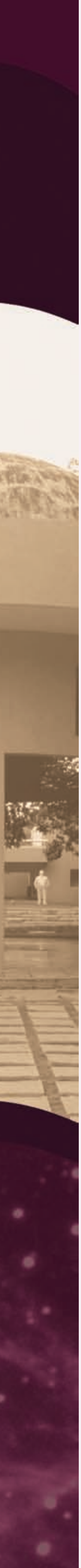


T. Padmanabhan The Optics of Particles, *Resonance*,**14,** 8-18, 2009.

T. Padmanabhan The Power of Nothing, *Resonance*,**14,** 179-190, 2009.

T. Padmanabhan Hubble Expansion for Pedestrians, *Resonance*,**14,** 259-271, 2009.

(VI) SEMINARS, COLLOQUIA, etc.

(a) Seminars

Pasquier Noterdaeme: *Molecular hydrogen absorptions in the remote universe,* April 3.

P.G.L.Leach: *Singularity analysis: The elements of implementation and the essence of interpretation of the results,* April 8.

Shrirang Deshingkar: *Can we see naked singularities?,* April 10.

Susmita Chakravorty: *Stability curve analysis for warm absorbers in AGN,* April 17.

Biswajit Pandey: *The luminosity-star formation relation and filamentarity of star forming galaxies in the Sloan Digital Sky Survey data release five,* May 8.

Tapan Nandi: *Laboratory atomic astrophysics using the fast highly charged ions,* May 27.

Chiranjib Konar: *Radio galaxies: Properties, environments and recurrent jet activities,* May 29.

Suchetana Chatterjee: *The Sunyaev-Zeldovich effect as a probe of black hole feedback,* June 11.

Pavan Chakraborty: *Development of the adaptive modular active leg at IIIT, Allahabad,* June 12.

Shirish Shevade: *Efficient machine learning algorithms for astronomical data analysis,* June 20.

Shamal S.Date: *Spectoscopy of blue compact dwarf galaxies,* June 25.

Niti Madhugiri: *Detecting gamma-ray bursts using coded mask telescopes,* June 25.

Archana Mishra: *X-ray spectra of active galactic nuclei,* June 25.

Kunal Mooley: *Probing the time variations in fundamental physical constants with 21cm.quasar absorption-line observations,* June 25.

Kaustubh Vaghmare: *Supermassive black holes in galaxies,* June 25.

Kartik Prabhu: *Gravity in higher dimensions,* June 25.

Abhas Saroha: *Gravity in higher dimensions,* June 25.

Kinsuk Acharyya: *Interstellar dusts and their laboratory analog,* July 3.

Siddharth Malu: *Gibbs' sampling-A computationally efficient algorithm for CMB power spectrum estimation,* July 4.

Kuntal Misra: *Multi-wavelength studies of energetic cosmic explosions,* July 4.

Dawood Kothawala: *Path integral duality corrections to scalar field propagators,* July 4.

Mudit Srivastava: *Opto-mechanical design of an optical fibre based integral field unit (IFU) for 2-D spectroscopy,* July 4.

Sharanya Sur: *Kinetic and magnetic alpha effects in mean-field dynamos,* July 4.

Soumya Mohanty: *Priors in gravitational wave detection,* July 17.

S.Mukherjee: *Boson stars: A geometric approach,* July 18.

Abhishek Rawat: *Studying the properties of intermediate redshift galaxies using large surveys,* July 21.

Arman Shafieloo: *Confronting cosmological models with observations,* July 21.

Gaurav Goswami: *Evolution of a neutron star magnetic field initially confined to the core,* August 14.

Sowgat Muzahid: *Searching for metals in IGM through QSO absorption line,* August 14.

Christopher Tout: *The progenitors of type Ia supernovae,* August 22.

Gianfranco De Zotti: *A simple physical model for young galaxies in the early universe*, September 4.

Bosanta Boruah: *Dynamic beam shaping with programmable differactive optics*, September 5.

Saifollah Rasouli: *Moire technique improves the measurement of atmospheric turbulence parameters*, September 5.

Patrick McCarthy: *The Giant Magellan Telescope project*, September 29.

Markus Kissler-Patig: *The European extremely large telescope - Project overview*, October 13.

Shrinivas Kulkarni: *The thirty metre telescope*, October 21.

Shrinivas Kulkarni: *Cosmic explosion*, October 22.

Yashodhan Hatwalne: *Morphology of polymer crystallites : A visit through Gaussiana*, October 23.

Saumyadip Samui: *Physics of structure formation and intergalactic medium*, November 20.

Ajith Parameswaran: *Searching for gravitational waves from binary black holes*, November 21.

Sami Dib: *Formation and properties of dense cores in molecular clouds*, November 26.

Kartik Sheth: *Discovery of a cold, low redshift submillimetre galaxy : CARMA observations of AzTEC\J095950.29+0244116.1*, December 2.

Kartik Sheth: *The assembly of galaxy disks and evolution of galactic structures in cosmos - Reconstructing the Hubble sequence*, December 4.

Ue-Li Pen: *Cosmological information galaxy, weak lensing and 21 cm power spectra*, December 11.

Ashutosh Kotwal: *Search for the Higgs boson*, December 12.

S.G. Rajeev: *The Hamiltonian dynamics of thermodynamics*, December 31.

Varsha P. Kulkarni: *In search of the galaxies producing quasar absorption lines*, January 5.

Atul Deep: *SSIST: The test set-up for VLT adaptive optics facility*, January 6.

Manjari Bagchi: *Effect of three body stellar interactions on binary radio pulsars in globular clusters*, January 13.

Dhrubaditya Mitra: *Turbulent dynamos in spherical domains: Some recent results*, January 15.

Chiranjib Konar: *Radio galaxies, their environments and clusters of galaxies*, February 5.

Subodh Patil: *Inflation with a stringy minimal length, redone*, February 18.

L. Sriramkumar: *Can reheating affect large scale curvature perturbations?* February 19.

Kailash C. Sahu: *Limits from HST on substellar and planetary-mass objects through microlensing*, March 12.

S. Afsar Abbas: *On the crisis of the 3+1+1 forces and on the connection between geometry and physics*, March 17.

Sharanya Sur : *Origin and evolution of cosmic magnetic fields*, March 20.

(b) Colloquia

Krish Bharutharam: *Scientific research in South America and role of National Research Foundation*, February 24.

Sandip Pakvasa: *Parity violation to Nobel 2008*, March 3.

(VII) TALKS AT IUCAA WORKSHOPS OR AT OTHER INSTITUTIONS

(a) Seminars, Colloquia and Lectures

Joydeep Bagchi

Observing Non-thermal Radio Emission from Intergalactic Shocks, ASI XXVII Meeting, IIA Bangalore, February 20 **.**

Dipankar Bhattacharya

Magnetic Evolution of Neutron Stars, Workshop on A Decade of Accreting Millisecond Pulsars, University of Amsterdam, April 17.

Millisecond Pulsars with ASTROSAT, workshop on A Decade of Accreting Millisecond Pulsars, University of Amsterdam, April 18.

Gamma Ray Bursts, IUCAA, VSP and Introductory Summer School on Astronomy and Astrophysics, June 4.

Gamma Ray Bursts: Collimated, Relativistic Explosions, (colloquium), Department of Physics, Indian Institute of Science, Bangalore, September 12.

Overview of ASTROSAT, Workshop on X-ray Timing with ASTROSAT: Science, Techniques and Tools, IUCAA, October 13.

Multiwavelength Space Facilities in India, Indo-South Africa Workshop on Astronomy, ARIES, Nainital, 30 October 30.

GRB Science with SALT, workshop on Science with SALT, IUCAA, November 4.

Probing the Universe: from Radio to Gamma Rays, Indian Science Congress , North Eastern Hill University, Shillong, January 6.

Probing Strong Gravity with ASTROSAT, 25th IAGRG, SINP, Kolkata, January 31.

Astronomy at X-ray Wavelengths, School on X-ray Astronomy, IUCAA, February 2 and 3 (2 talks).

Cosmic Explosions, Programme on Frontiers in Astronomy, Fergusson College, Pune, February 05.

Wide Band Electromagnetic Radiation Processes, IISER, Pune, February 18.

Overview of ASTROSAT, Workshop on Broadband X-ray Spectroscopy with ASTROSAT, IUCAA, February 23.

Modelling Cyclotron Line Spectra, Workshop on Broadband X-ray Spectroscopy with ASTROSAT, IUCAA, February 24.

Radiation-matter Interaction in Exploding Supernovae, Workshop on Radiation Matter Interaction Under Extreme Conditions, Banaras Hindu University, Varanasi, December 20.

Naresh Dadhich

Vidnyan Ani Samaj (a lecture in Marathi organized by Shrikant Mantri, Freelance Journalist, Sangli) May 10.

Why Einstein [Had I Been Born in 1844!]? (a Colloquium at Southern African Astronomical Observatory, South Africa) December 1.

Gravitational Dynamics (a seminar at the University of Cape Town, South Africa) December 2.

Relativity (seminars at the University of Mauritius, Mauritius) December 8, 9.

Why Einstein [Had I Been Born in 1844!]? (a Colloquium at the Department, Viswa Bharati, Santiniketan) January 27.

Gravitational Dynamics (a seminar during the 25th meeting of the IAGRG entitled, “From Black Holes to the Universe : Gravity at Work” at the Saha Institute of Nuclear Physics, Kolkata) January 29.

Why Einstein [Had I Been Born in 1844!]? (a lecture during the National Science Day celebrations of the Institute of Mathematical Sciences, Chennai) February 28.

Why Einstein [Had I Been Born in 1844!]? (a talk at the Department of Physics, Presidency College, Kolkata) March 2.

Universal Velocity and Universal Force (a talk during the national seminar on Recent Advanced in *Physics and Astrophysics* organized by the Department of Physics, North Bengal University, Siliguri and IUCAA Reference Centre, Siliguri) March 17.

Gravitational Dynamics (a seminar at the Centre for Theoretical Studies, Indian Institute of Technology, Kharagpur) March 18.

Relativity : A Common Sense Perspective (a talk at Pandit Ravishankar Shukla University, Raipur) March 21.

Samaj aur Vigyan (a talk in Hindi at Pandit Ravishankar Shukla University, Raipur) March 22.

Gulab Chand Dewangan

X-ray Variability of Radio-quiet AGNs, Workshop on X-ray Timing with ASTROSAT: Science, Techniques and Tools held at IUCAA during October 13 -15.

Soft X-ray Excess Emission from AGNs, Workshop on Broadband X-ray Spectroscopy with ASTROSAT , IUCAA , February 23 - 25.

Active Galactic Nuclei ? Central Engine and the X-ray Emission, X-ray Astronomy School, IUCAA, February 2 - March 20.

X-ray Spectroscopy X-ray Astronomy School, IUCAA, February 2 - March 20.

Ultra-luminous X-ray Sources, X-ray Astronomy School IUCAA, February 2 - March 20.

Sanjeev Dhurandhar

General Relativistic Treatment of LISA Optical Links,7th LISA Symposium, Barcelona, Spain, June 20.

Detecting Gravitational Waves from Inspiraling Binaries with a Network of Detectors: Coherent Versus Coincident Strategies, 10th Asia-Pacific Regional Meeting (APRIM) Kunming, China, August 5.

Data Analysis Techniques in Gravitational Waves, International symposium on experimental gravitation (ISEG), Kochi, January 6.

The Changing Face of General Relativity, 25th IAGRG Meeting held at SINP, Kolkata, January 30 .

Ranjan Gupta

Dust Modeling in Astrophysics, Colloquium, Saha Institute of Nuclear Physics, Kolkata, April 2.

Imaging Fabry-Perot for IGO Side Port, Meeting of IGO Users, IUCAA, Pune, July 22-23.

Comparison of Mie/EMA/T-Matrix/DDA Based Models with the Observed Interstellar Extinction and Other Parameters, 11th Electromagnetic and Light Scattering Conference at University of Hertfordshire de Haviland Campus, Hertfordshire, UK , September 7-12.

Interstellar Extinction Curve from Mie, TMatrix and DDA Models, Mie Theory 1908-2008 -- Present Developments and Interdisciplinary Aspects of Light Scattering, Martin Luther University, Halle, Germany, September 15-17.

Modeling Interstellar Extinction, National Workshop on Light Scattering: Its Applications in Astrophysics and Other Fields, Gujarat Arts and Science College, Ahmedabad, November 7-8.

Light Scattering Models and Applications to Astronomy, Department of Physics, University of Rajasthan, Jaipur, March 23.

Ajit Kembhavi

Supermassive Black Holes- Here, There and Everywhere, Physical Research Laboratory, Ahmedabad, April 10.

Web Based Technologies and Web Based Library Services (W2.0-L2.0), Gulbarga University, Karnataka, April 22.

Galaxies, Galaxy Clusters and Gravitational Lensing, Olympiad Students from HBCSE, Mumbai , IUCAA, Pune, May 11.

Galaxy Morphology and Supermassive Black Holes, IVOA Interoperability Meeting SISSA, Trieste, Italy, May 16.

Inter-University Centre for Astronomy & Astrophysics, Workshop on International Collaborations, Higher Education Cell of the Centre for the Study of Culture and Society, Bangalore, June 19.

The Virtual Observatory Programme as Developed in China and India, 10th Asian-Pacific Regional Meeting of the International Astronomical Union, Kunming, China, August 3.

A Supermassive Black Hole Fundamental Plane for Ellipticals, 10th Asian Pacific Regional Meeting of the International Astronomical Union, Kunming, China, August 4.

Morphological Properties of Galaxies from Palomar Large Format Camera [LFC] Fields to Very Faint, 10^{th} Asian Pacific Regional Meeting of the International Astronomical Union, Kunming, China, August 4.

Virtual Observatories-A New Paradigm for Astronomy, Shaastra 2008, IIT Madras, October 3.

Galaxy Photometry with SALT, Meeting on Science with SALT, IUCAA, Pune, November 4.

Data Archives and VO, Meeting on Science with SALT, IUCAA, Pune, November 4.

Dust in Extragalactic Objects, Workshop on Light Scattering: Its Applications in Astrophysics and Other Fields, Gujarat Arts and Science College, Ahmedabad, November 8.

Finding Extra-solar Planets, Workshop on Advances in Observational Astronomy, M.G. University, Kottayam, December 1.

Application of Machine Learning Methods to Astronomy, Workshop on Machine Learning Methods in Astronomy, Mar Althanasios College for Advanced Studies, Tiruvalla, January 19.

From Galileo to Einstein : A Journey over 400 years, St. Xavier's College, Kolkata, January 27.

Overview of Astronomy, X-ray Astronomy School, IUCAA, Pune, February 2.

Large Optical Telescopes, National Symposium on Indian Physics and Mega Projects : Research on the Frontiers, Miranda House, University of Delhi, February 3.

From Galileo to Einstein : A Journey Over 400 years, Frontiers in Astronomy, Fergusson College, Pune, February 5.

Large Telescopes, IUCAA-VNIT Telescope Making Workshop, Visvesvarya National Institute of Technology, Nagpur, February 15.

Large Astronomical Databases and Their Analysis, Astronomical Society of India, Bangalore, February 20.

Very Large Telescopes, Seminar on Astronomy, Gravity and Beyond Einstein, Cochin University of Science and Technology, Kochi, March 6.

Central Engines of AGNs and Host Galaxies, X-ray Astronomy School, IUCAA Pune, March 12, 13 & 16

Large and Extremely Large Telescopes, Pt. Ravishankar Shukla University, Raipur, March 20.

Kuntal Misra

An Optical View of Energetic Cosmic Explosions International Conference on Supernovae and Gamma Ray Bursts at low z and in the Era of Reionization, May 23-29, Darjeeling.

An Optical View of Energetic Cosmic Explosions, Indo-South Africa workshop in Astronomy, ARIES, Nainital, October 30 - November 0.

Supernovae and Gamma Ray Bursts, X-ray Astronomy School, IUCAA, February 02-March 20.

Ranjeev Misra

Observational Evidence For Black Holes, Colloquium at IISc, April 25.

Energy Dependent Time Lags in Khz QPO, Workshop on X-ray Timing with ASTROSAT Science, Techniques and Tools, IUCAA, Pune, October 14.

Siddharth Malu

CMB Polarization: Instrumentation and Analysis, University of Milano-Bicocca, Milano, Italy, November .

Gibbs' Sampling: An Efficient Algorithm for Power Spectrum Estimation for CMB, University of Milano-Bicocca, Italy, December.

mm-Wave Instrumentation for Cosmology: Probing the Early Universe with the CMB, ISoMM-2009, January 15.

Vijay Mohan

Optical Telescopes and Detectors, UGC sponsored National Seminar on Observational Facilities for Astronomical Studies held at Milind College of Science, Aurangabad, January 20 -21.

Our Universe - A Journey Through it, Konkan Gyanpeeth College of Engineering, Karjat, February 10.

Jayant Narlikar

Prachin se aadhunik kal tak brahmand ki sanklpanaye (Ideas about the universe from ancient to modern times)[in Hindi] (a talk delivered at the Indian Institute of Science, Bangalore, April 4.

A Critique of Big Bang Cosmology at the Indian Institute of Science, Bangalore, April 4.

A Critique of Standard Cosmology at the Tata Institute of Fundamental Research, Mumbai, May 28.

The Physics-Astronomy Frontier at the University of KwaZulu-Natal, Durban, South Africa, June 6.

Some Conceptual Problems in GR and Cosmology (a plenary talk during the workshop on Gravity held in Drakensburg, South Africa) June 13.

The Physics-Astronomy Frontier (a colloquim at the University of Cape Town, South Africa) June 25.

The Interaction Between Mathematics, Physics and Astronomy (a talk to the Winter School students at the South African Astronomical Observatory (SAAO), South Africa) June 26.

Cosmology from Sidelines (a lecture at the Brazilian Centre for Physics Research, Rio de Janeiro, Brazil) July 11.

Searches for Life in the Universe (a talk at the Shanghai Astronomical Observatory, Shanghai, China) August 8.

A Critique of Standard Cosmology (a talk at the Purple Mountain Observatory, Nanjing, China) August 12.

CMB : An Alternative Origin? (a lecture during the ICTS-IUCAA Programme on Cosmology with CMB and LSS, at IUCAA) August 25.

Cosmology and Mini-creation Events (a talk during the Conference entitled Evolution of Cosmic Objects through their Physical Activity, Byurakan Astronomical Observatory, Byurakan, Armenia) September 17.

Facts and Speculations in Cosmology (a lecture at the School of Computing, University of Colombo, Sri Lanka) December 3.

Why Study Astronomy (a lecture at the University of Moratuwa, Sri Lanka) December 4.

Facts and Speculations in Cosmology (a lecture at the Post Graduate Institute of Science, University of Peradeniya, Sri Lanka) December 5.

The Scientific Temper (a talk during the National Conference on National Agenda on Problems and Solutions at the Indian Institute of Chemical Technology (IICT), Hyderabad) December 13.

A Critique of Standard Cosmology (a seminar at the Utkal University, Bhubaneshwar) February 3. *Why Astronomy is Important?* (a colloquium at the National Institute of Science Education and Research, Bhubaneshwar) February 4.

A Critique of the Big Bang Cosmology (a lecture at the Physics Department, Pandit Ravishankar Shukla University, Raipur) February 11.

How Astronomy Has Contributed to Enrichment and Survival of Human Societies (a lecture during the Astronomical Society of India Meeting held at the Indian Institute of Astrophysics, Bangalore) February 18.

T. Padmanabhan

Gravity: The Inside Story, Bose Colloquium series, S. N. Bose National Centre For Basic Sciences, Kolkata, May 30.

Cosmology Today: Facts, Hypes and Myths, Physics Colloquium, University of Geneva, April 28.

Gravity: An Emergent Perspective, University of Geneva, May 1.

Story of the Calander, BARC, Mumbai, Trombay Colloquium, June 10.

Gravity: The Inside story, Symposium on Symmetries and Physics in the Universe, Munich, Germany, June 23.

Dark Energy-The Challenge of the Milennium, (Colloquium) National Centre for Biological Sciences, Bangalore, September 12.

Progress in Cosmology: Rumours and Reality, University of Sao Paulo Brazil, October 8 - 11.

Gravity: The Inside Story, Second Indo-Brazil Workshop on Cosmology, Natal, Brazil, October 12- 17.

Science Education in India: Issues and Prospects, 5th Rev. Dr. John Vallamattam Lecture, Newman College, Thodupuzha, Kerala, November 6.

Cosmology Today, Colloquium, IISER, Trivandrum, November 8.

Understanding our Universe: Status and Progress, Plenary talk, Indian Science Congress, NEHU, Shillong, January 6.

Dark Energy:the Challenge of the Millenium, Centre for Basic Sciences, University of Mumbai, January 13.
Gravity: The Inside Story, Vaidya-Raichaudhury Lecture 25th IAGRG Meeting on From Black Holes to the Universe: Gavity at Work, Kolkata, January 28.

Swara Ravindranath

Science with the Giant Segmented Mirror Telescopes GSMT meeting, IIA, Bangalore, September 27, 2008.

The World of Galaxies, at the Astronomy workshop University of Calicut, March 20.

A. N. Ramaprakash

IUCAA Girawali Observatory, Astrophysics Research Institute, Liverpool, Uk, May 14.

IGO Status Report, Scientific Advisory Committee Meeting, IUCAA, May 26.

Future Large Telescopes, VSP, IUCAA, June 12.

IUCAA Girawali Observatory Status Report, IGO User's Meet, IUCAA, July 22.

Science with IGO, IGO User's Meet, IUCAA, July 22.

IGO Future Plans, IGO User's Meet, IUCAA, July 22.

Technology with GSMTs, IUCAA, October 02.

Polarimetry with SALT, SALT Science Meeting, IUCAA, November 11.

A Technical Evaluation of GSMTs, Indian Institute of Astrophysics, Bangalore, February 17.

The YAM Model and its Future, YAM 2009 - Indian Institute of Technology, Kharagpur, March 15.

Adaptive Optics in Astronomy, Frontiers in Physics and Astrophysics, North Bengal University, March 16.

Varun Sahni

An Artificial Planetary System in Space (APSIS) to Probe Modifications to the Inverse Square Law and the Existence of Extra Dimensions at the NASA sponsored international workshop: From Quantum to Cosmos: Fundamental Physics in Space for Next Decade, Airlie Center, Warrengton, VA, USA , July 6 - 10.

Dark Energy, Cosmology with the CMB and LSS, IUCAA, Pune, July 21 - August 21.

Tarun Souradeep

Cosmic Saga Encrypted in the Cosmic Microwave Background, Indo-US Frontiers of Science Symposium, Agra, February 1-4.

Cosmic Saga Encrypted in the Cosmic Microwave Background, 3rd National Frontiers of Science, INSA, Delhi, January 21-22.

Cosmology with CMB and LSS, Course of two lectures at the IUCAA-NCRA Radio-Astronomy School, December 22-23.

Early Universe from CMB Anisotropy and Polarization, 2nd Indo-Brazil Workshop, Natal, Brazil, October 13-17.

Early Universe from CMB, Department of Physics, Delhi University. Ocober 22

Statistical Challenges in CMB Studies, Colloquium, Indian Statistical Institute, Bangalore, Mach. 23.

Cosmic Inferences from the Cosmic Microwave Background, Colloquium, Indian Statistical Institute, Bangalore, March 23.

Early universe from CMB: making the `Best' of Our `Ignorance' , Colloquium, Department of Physics IIT Kanpur, April 18.

R. Srianand

Probing the Universe and Fundamental Physics using QSO Absorption Lines, PRL, Ahmedabad, August 11.

Probing the Universe with QSO Absorption Lines, Utkal University Bhubaneswar, November 16.

Probing the Time Variation of Fundamental Constants using UVES/VLT, a review talk, Perimeter Institute, Canada, July 14.

Probing the Variation of Fundamental Constants Using QSO Absorption Line Colloquium, IOP, Bhubaneswar, November 17.

Molecules and Dust in High-z Protogalaxies, An invited talk, Coorg meeting, December 2.

Luminosity Function of Lyman-α Emitters Colloquium, IAP , Paris, July 8.

Probing the IGM with SALT, in the SALT Science workshop, IUCAA, November 3.

K. Subramanian

Magnetic Helicity Conservation in Galactic Dynamos, Harish Chandra Research Institute, Allahabad, September.

Galactic Outflows and the IGM, Harish Chandra Research Institute, Allahabad , September.

Primordial Magnetic Fields in the Universe, Indo-Brazil meeting, Brazil, October.

Galactic Outflows and the Intergalactic medium, Cosmological Evolution in Diffuse Baryons: Reionization Epoch to the Present Day, Coorg , November .

(b) Lecture Courses [3 or more talks on one theme]

Joydeep Bagchi

Radio Astronomy School (NCRA/TIFR): 3 Lectures and 3 Experiments (In collaboration with B.C. Joshi, NCRA) , June - July .

IUCAA-NCRA Radio Astronomy Winter School : 2 Lectures and 3 Experiments (In collaboration with B.C. Joshi, NCRA) , December.

Dipankar Bhattacharya

Fluids and Plasmas, (4 lectures), IUCAA, VSP and Summer School, May 12 - 15.

Astrophysics and Cosmology, 10 lectures as a part of a course on Astronomy and Astrophysics, IISER, Mohali, September 22 - 30.

Gulab Chand Dewangan

Radiative Processes in Astrophysics, 10 lecture course IISER, Mohali November 10 -21.

Sanjeev Dhurandhar

General Relativity and Gravitational Waves (5 lectures) Summer School and VSP, IUCAA, May-June .

Ranjan Gupta

6th PG course in Space and Atmospheric Sciences of CSSTEAP, (15 lectures) January 27 - February 6, Physical ResearchLaboratory, Ahmedabad.

Ajt Kembhavi

Stellar Structure and Evolution (11 lectures), Presidency College Students, Part of M.Sc. special paper in Astronomy at IUCAA, Pune, October 15-26 and Presidency College, Kolkata, January 27-28.

Stellar Structure and Evolution (5 lectures), VSP/VSRP/ Summer School, IUCAA, Pune, May 26-30.

Ranjeev Misra

Radiative and Accretion Processes in Astrophysics X-ray workshop (4 lectures), IUCAA, February.

Radiative and Accretion Processes in Astrophysics, Summer School, VSP (6 lectures) IUCAA, May.

J. V. Narlikar

Introduction to Astrophysics and Cosmology (3 lectures) Vacation Students' Programme, IUCAA, Pune, May 12, May 13, and May 14.

Alternative approaches to cosmology (5 lectures) XIII Brazilian School of Cosmology and Gravitation at Portobello Hotel, Mangaratiba, Brazil, July 21-25.

Introduction to Cosmology (4 lectures) Presidency College, Kolkata at IUCAA, Pune, October 20, October 21, October 22 and October 24.

T. Padmanabhan

Statistical Mechanics of Self-gravitating Systems, (8 lectures) Summer School on Long-Range Interacting Systems, Les Houches (France) August 4 – 29.

General Relativity and Cosmology, (30 lectures) Course in Physics, IISER, Pune, January – April 2009,

Swara Ravindranath

Observational Cosmology (4 lectures) Summer School on Gravitation and Cosmology, HRI, Allahabad, May.

Galaxies (3 lectures) and SExtractor (1 demonstration) Summer School on Astronomy & Astrophysics, IUCAA May-June.

A. N. Ramaprakash

Astronomical Detectors and Instruments: VSP and Summer School IUCAA, May -June.

Tarun Souradeep

Invited course (6 lectures) 3rd Asian Winter school on String Theory, KITPC, Beijing, China. January 9-17.

Cosmology with CMB & LSS (5 lectures) Vacation students programme at IUCAA, Pune.

R. Srianand

QSOs and Absorption lines (5 lectures) VSP, IUCAA, May-June.

K. Subramanian

Primordial Magnetic Fields and Cosmology (4 lectures), ICTS-TIFR and IUCAA School on Cosmology with CMB and LSS, IUCAA, July .

(VIII) SCIENTIFIC MEETINGS AND OTHER EVENTS

Introductory Summer School on Astronomy and Astrophysics

Participants and Lecturers of the Introductory Summer School on Astronomy and Astrophysics

The Introductory Summer School on Astronomy and Astrophysics, funded by the Department of Science and Technology, New Delhi, was conducted jointly by IUCAA and NCRA, during May 12 - June 13, 2008. Thirty eight students, who were in their final year of BSc, or first year of MSc, as well as third year of engineering participated in the school.

The programme consisted of a series of lectures, special evening lectures, data analysis and problem solving sessions. Facilities like library access, internet access, etc. were provided to the students during their stay.

The main areas on which the lectures were given include, Astrophysical Processes, Stars and Stellar Systems, Gravitation and Cosmology, Telescopes, Instruments, and Data Analysis. The lectures were given by IUCAA and NCRA faculty, and visiting associates of IUCAA. Several special lectures were also given by the IUCAA and NCRA faculty, which incorporated the range of research interests at the institute. The graduate students and post-doctoral fellows from IUCAA delivered lectures, which exposed the participants to the doctoral research work, and other active research areas being pursued by the youngest researchers in the institute. The IUCAA graduate students and post-doctoral fellows also helped with the problem solving sessions and data analysis sessions.

The participants were taken for a visit to the IUCAA Girawali Observatory to see the 2m optical and infrared telescope. They also visited the GMRT, operated by NCRA. The faculty coordinators for this Summer School were Swara Ravindranath from IUCAA, and D. J. Saikia from NCRA.

Vacation Students' Programme

Participants and Lecturers of the VSP

The Vacation Students' Programme (VSP), for students in their penultimate year of their M.Sc. (Physics) or Engineering degree course, was held during May 12 - June 27, 2008. Eight students participated in this programme. The participants attended about 50 lectures dealing with wide variety of topics in Astronomy and Astrophysics, given by the members of IUCAA and NCRA, and demonstrations and practical sessions. They also did a project with one of the faculty members of IUCAA during this period. R. Srianand and K. Subramanian were the faculty coordinators of this programme.

Meeting of IGO Users

Participants of the IGO Users' Meeting

IUCAA Girawali Observatory (IGO) operates a 2 metre optical telescope, which was opened to scientific community for use in October 2006. Based on the recommendation from IGO Time Allocation Committee (TAC), a two day meeting of IGO users was held at IUCAA during July 22 - 23, 2008. The aim of this meeting was to bring together the Principal Investigators (PIs) of different observing programmes undertaken with IGO in the past three cycles (October 2006 to May 2008), to review the progress made so far. PIs presented their observing programmes, progress made in data analysis, etc. An update on IGO status, some peculiarities of the data taken with IGO and ways to deal with these, and future developments at IGO were also presented. The meeting helped to gather valuable feedback regarding the operations at IGO and provided better insight into the capabilities of the IGO. About 20 observers participated in the meeting including IGO TAC members.

ICTS – IUCAA Programme on Cosmology with CMB and LSS

A group photo with the programme coordinators and small representative set of speakers and participants from India and abroad.

Recent advances in exquisite measurements of subtle fluctuations in Cosmic Microwave Background (CMB), the relic radiation from Big Bang, coupled with increasingly extensive maps of the distribution of galaxies spread over billions of light years around us, have refined cosmology into a precision science. An extremely successful six weeks long international programme of schools and workshops on this frontline research area in cosmology was held at IUCAA during July 21 – August 31, 2008. This was a first partnership venture between the newly set up *International Centre for Theoretical Sciences* (ICTS) of the Tata Institute of Fndamental Research (TIFR), Mumbai, and IUCAA. The grand vision and scope of ICTS programmes allowed, what is arguably, the largest international cosmology programme organized in India. The programme coordinators, Tarun Souradeep (IUCAA) and Subhabrata Majumdar (TIFR) are among the increasingly visible younger generation of Indian cosmologists. The scientific organization committee comprised largely of established young international cosmologists – Asantha Cooray (UC, Irvine), Bhuvnesh Jain (U. Penn), Simon Prunet (IAP), Subir Sarkar (Oxford), Sandip Trivedi (TIFR), and the programme coordinators. Besides renowned senior researchers such as, Marc Davis (Berkeley), Joe Silk (Oxford), Lyman Page (Princeton), Francois Bouchet (IAP), Subir Sarkar (Oxford), Ruth Durrer (Univ. Geneva) and Lev Kofman (CITA), most other lecturers were young achievers in their field of research. The median age of lecturers being about forty brought in a youthful flavour that does justice to the new dawn of the precision era in cosmology.

The programmes featured a unique blend of experts teaching young researchers in the schools, as well as, engage in heady scientific deliberations in the workshops. The programme was divided into three sessions – Cosmic Microwave Background Anisotropy and Polarization, Probes of Large Scale Structures, and Link to the Early Universe. Each two weeks long session had nine days of pedagogical lectures followed by a workshop. The unique format of the meeting attracted lecturers from top research institutions worldwide. Other than young Ph.D. students from Indian institutes and universities, the programme had a very sizable fraction of international students from across the globe — US, UK, France, Germany, Japan, Italy and even as far as Argentina and Brazil. The strong response reflects the global recognition of cosmology, and IUCAA has always enjoyed the increasing recognition of science in India. The programme exposed Indian young researchers to the forefront of research in this remarkably successful area of contemporary science. All the lecture courses, workshop talks and public talks were video recorded. This excellent resource has been made available for free download from the conference website (given at the end of this report).

The programme also reached out to the public through a series of four public lectures delivered by eminent cosmologists, Francois Bouchet (IAP), Marc Kamionkowski (Caltech), Joseph Silk (Oxford), and Lyman Page (Princeton, USA). The lectures on exciting topics from the frontiers of theoretical and observational cosmology were all well attended.

The long duration of the programme also gave time for the participants to enjoy the cultural and social ambience, and to develop strong bonds between the Indian and international students. The Lalit Kala Kendra, Pune University, advised and assisted the LOC in organizing six high quality cultural programmes during each week. The programmes by the established and emerging talents of culturally rich city of Pune provided the international participants a glimpse of the rich heritage of Indian music and dance forms. Three weekend, day excursions to nearby scenic spots were also organized during the programme. To coincide with each workshop, a special dinner was organized for the participants and the school banquet on August 5, 2008 was sponsored by Scopus (Elsevier). The success of the ambitious programme owes to the unfettered support from ICTS and the excellent organizational capability of the IUCAA staff.

The video and electronic files of lectures and other details are available online at

http://iucaa.ernet.in/Events.html, and http://icts.tifr.res.in/sites/cmb/Index.

Glimpses of the ICTS-IUCAA Programme

The Workshop on Open Source Standards and Software in Libraries: Spotlight on NewGenLib

Participants of the Workshop on Open Source Standards and Software in Libraries: Spotlight on NewGenLib

The Workshop on Open Source Standards and Software in Libraries: Spotlight on NewGenLib was held at IUCAA during September 17-19, 2008. NewGenLib, an integrated library automation software has been developed by J. Haravu, Trustee, Kesavan Institute of Information and Knowledge Management (KIIKM), in collaboration with Verus Solutions Pvt. Ltd, Hyderabad. In January 2008, the software was declared to be open source under GNU GPL. The primary objective behind organizing the workshop was to spread awareness about NewGenLib among the library professionals in Pune. For the same reason, preference was given to participants, who were keen to automate their libraries and were on the lookout for a good library software.

Eighteen participants representing government organizations, private academic institutions including a non-governmental organization registered for the workshop, which was inaugurated by Naresh Dadhich, Director, IUCAA. M.P. Chirmule, Scientist In-charge, Library, Information Division, National Chemical Laboratory, Pune, delivered the key note address on "*Towards Open Source Library Software Movement*".

The workshop was highly interactive and focused primarily on hands-on exposure, wherein each participant was provided an opportunity to install the software and explore the different modules. Speakers included Bighnaraj Swain (NewGenLib Foundation) and Shubhada Nagarkar, Department of Library and Information Science, Jayakar Library, University of Pune.

The workshop was organized by the IUCAA library in association with the NewGenLib Foundation, Hyderabad. The Coordinator was Nirupama Bawdekar, IUCAA.

Technology Workshop on Performance Enhancement on Emerging Parallel Processing Platforms (PEEP-2008)

Centre for Development of Advanced Computing (C-DAC), Pune, and IUCAA, jointly conducted the Technology workshop on Performance Enhancement on Emerging Parallel Processing Platforms (PEEP-2008) during September 23-27, 2008 at IUCAA. The first objective was to understand performance issues for applications on Multi-Core Processors, GPU Computing using CUDA Programming, GPU- Stream Accelerators, Cell Processors-Cell programming, and Clusters with Multi-Core Processors. The second objective was to make aware of Performance Optimization Tech-

Participants of the Technology Workshop Performance Enhancement on emerging Parallel Processing Platforms (PEEP-2008)

niques and Programming Paradigms on Multi-Core Processors, GPU Computing, GPGPU - Stream Computing and Cell Processor Technology for solving large-scale problems in science/engineering and commercial domains. It provided an opportunity for interaction among the various participants from different academic institutes and research organizations in the country and leading IT company experts, who are working in the area of emerging parallel processing platforms.

PEEP-2008 proceedings, and hands-on (softcopy) document with software were written in order to impart a sense of unity to this expanding and exciting field of parallel computing for this workshop. By understanding the presentation material covered and the programmes in the hands-on softcopy CD as building blocks, scientists and engineers could piece together more complicated software tools that were tailored specifically for their needs in emerging parallel processing platforms using Multi-Cores, GPU Computing, CPU-Stream Computing, and Cell Processors. The PEEP-2008 workshop proceedings covered trends in Multi-Core Processors, Performance enhancement through software multi-threading, Performance analysis tools, Keynote address as of persons from academic institutes and IT company sponsors such as AMD, Intel, HP, IBM, and NVIIDA on Multi-Cores, Application perspective using Multi-Cores, GPU computing, GPGPU, GPU-stream computing and Cell processors technology. Special sessions have been arranged to demonstrate emerging parallel processing technology, such as performance analysis tools on Multi-Cores, Intel Thread Building Blocks (TBB), GPU computing-CUDA, GPGPU Stream Computing and Cell Processors, in which IT company experts actively participated.

The workshop was inagugurated by *Naresh Dadhich*, Director, IUCAA and *S.P. Dixit*, Director, C-DAC. In their message to the participants, *Naresh Dadhich* said that this workshop was beneficial for students, research scholars and industry participants to use emerging parallel processing platforms. Director of C-DAC said that C-DAC was continuously pursuing number of High Performance Computing projects focusing on applications to further achieve a leadership position in emerging parallel processing technology platforms. Interactions with experts from IT company, who partially sponsored this workshop, and participants of this workshop can bring about a lot of new ideas and opportunities for the researchers to start meaningful collaborative activities in this area.

C-DAC and IUCAA view the PEEP-2008 workshop (CD proceedings) and the hands-on sessions document presentation notes as a continuously evolving resource on parallel computing. The concluding session and feedback was conducted by V.C.V. Rao, the workshop Co-coordinator from C-DAC. Sarah Ponrathnam was the coordinator from IUCAA.

C-DAC and IUCAA would like to put on record their sincere thanks to the sponsors, Information Technology companies, Indian Space Research Organisation

(ISRO), Department of Information Technology (DIT), collaborators and associates from various institutions for their continuous support, guidance and cooperation. Without their support, the organization of PEEP-2008 would not have been possible.

Workshop on X-ray Timing with ASTROSAT: Science, Techniques and Tools.

Participants and lecturers of the workshop on X-ray Timing with ASTROSAT: Science, Techniques and Tools

A workshop on X-ray Timing with ASTROSAT: Science, Techniques and Tools was held at IUCAA during October 13-15, 2008. The Indian Multiwavelength Astronomy Satellite ASTROSAT is due to be launched in about a year's time, and one of the prime areas of interest to be pursued with it will be accurate and sensitive timing of variable X-ray sources, ranging from stellar mass objects, like isolated pulsars and x-ray binaries to accreting supermassive black holes in galactic nuclei. The emphasis of this workshop was on discussing the new areas in X-ray timing science that ASTROSAT will open up, and the software and data analysis tools that will be required to pursue them.

The workshop was attended by nineteen participants, including two from abroad. There was a mix of senior researchers, young faculty members, post-doctoral fellows and graduate students, representing various national research institutions and universities. During the workshop, there was a series of presentations, software demonstrations and extended discussions. Equal amounts of time was devoted to presentations and discussions. A set of requirements for new data analysis tools to address emerging science areas with ASTROSAT was drawn up at the conclusion of the workshop. Dipankar Bhattacharya was the coordinator of this workshop.

Workshop on Light Scattering: Its Applications in Astrophysics and other Fields

IUCAA sponsored workshop was organised by Gujarat Arts and Science College, Ahmedabad, during November 7-8, 2008. The workshop was held to mark the centenary year of Mie Scattering theory (1908); and Gujarat College being pioneer in research in light scattering. The topics covered at the workshop were light scattering theories, dust models, cometary dust, dust in novae, circumstellar dust, interstellar dust, and intergalactic dust. About thirty five university and college students/teachers participated in the workshop. Scientists, Abhijit Sen (IPR, Ahmedabad); Ajit Kembhavi, R. Srianand, Ranjan Gupta, (IUCAA, Pune); B.G. Anandarao, U. C. Joshi, D. P. K. Banerjee (PRL, Ahmedabad); S. K. Sharma (S.N. Bose Institute, Kolkata), R. V. Mehta (Bhavnagar Univ.), J. N. Desai

Participants and Lecturers of the Workshop on Light Scattering: Its Applications in Astrophysics and other Fields

(Ex-PRL), H. S. Shah (Ex-S.V.R. Engg., Surat) and D. B. Vaidya (Ex-Gujarat College) were invited to give talks at the workshop. Ranjan Gupta (IUCAA) and K. G. Chhaya (Gujarat College) were the conveners for the workshop. Partial financial support for the workshop was also provided by Gujarat Council for Science and Technology (GUJCOST).

Science with SALT

Recently, IUCAA has joined the Southern African Large Telescope (SALT) consortium. IUCAA members will be entitled for approximately 6% observing time (equivalent of 16 nights per year) in SALT for the next several years. The telescope is expected to go into regular operations soon. IUCAA has organised the SALT Science working group and Board meeting during November 4-7, 2008. In order to initiate scientific collaboration between partner institutions and introduce the science capabilities of SALT to the user community in IUCAA and Indian universities, a two day meeting on "Science with SALT" was organized during November 3 - 4 2008. This was attended by SALT partners from all over the world. In addition to IUCAA members, about 20 participants from the university sector also took part in the meeting. There were about 20 scientific presentations covering various possible science projects that will be undertaken with SALT. The meeting also provided a platform for the members from the university sector to interact with the SALT partners to discuss various possible scientific collaborations. R. Srianand was the coordinator of this meeting.

Participants of the SALT Meeting

IUCAA-NCRA Radio Astronomy Winter School for College and University Students

Participants of the IUCAA-NCRA Radio Astronomy Winter School for College and University Students

The first 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 15 - 23, 2008, at Pune. The winter school was attended by about 30 graduate and undergraduate students of Science and Engineering. The participants comprised of about 20 outstation students from different parts of the country and 10 local participants.

Following the goals envisaged for the Radio Physics Laboratory, a major emphasis was placed on a practical 'hands-on' approach for teaching radio astronomy. For understanding the practical/instrumental aspects of radio astronomy, the students conducted instructive observations of Sun and 21cm spectral line from neutral Hydrogen gas of Milkyway using two radio telescopes of 3 m and 4 m diameter, located at the NCRA east campus. They also performed an Optical Faraday Rotation experiment in IUCAA's Radio Physics Laboratory for studying the interaction of polarized light with magnetized matter and understanding its application 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 drawn from IUCAA, NCRA/TIFR and IISER Pune, and a IUCAA Visiting Associate. The subject matter ranged from Radio Telescopes, Astronomical Coordinate Systems, Great Discoveries, the Sun, Milkyway, Pulsars, Darkmatter, Radio Galaxies, Astrobiology - to Quasars, Cosmic Microwave Radiation, Cosmology and Bigbang theory.

During the winter school, the participants visited the Giant Metrewave Radio Telescope Facility (GMRT) operated by NCRA/TIFR and IUCAA's 2mt optical telescope facility at the Girawali Observatory near Pune. The programme exposed the young students to the excitement of observations 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 the Faculty Members in several well-planned informal discussion sessions (the 'Kattas'). They prepared and presented their own colourful posters on various interesting topics in Physics and Astronomy. The best teams received handsome prizes. This School was coordinated by Joydeep Bagchi (IUCAA), and Bhal Chandra Joshi (NCRA/TIFR).

X-ray Astronomy School and Workshop on Broadband X-ray Spectroscopy with ASTROSAT

Participants and Lecturers of the X-ray Astronomy School

Participants and Lecturers of the Workshop on Broadband X-ray Spectroscopy with ASTROSAT

A well focussed school on X-ray Astronomy was conducted at IUCAA from February 02 to March 20, 2009. The main purpose of the school was to enable Ph. D. students from universities and their advisors to get a good command of X-ray data analysis techniques and the interpretation of the data. The school was divided into two parts. The first part, which ran for a week, had introductory lectures on X-ray astronomy during the first 3 days. The emphasis was on foundations of X-ray astronomy. In the next three days, technical lectures and data analysis sessions were organized. The first week of the school was designed to provide a broad exposure to X-ray astronomy and the associated data analysis techniques. Thirty participants from all over India, two from Egypt and one from Indonesia attended the school.

The second part of the school during the next six weeks was designed for serious research work. A small group of participants and experienced researchers worked together on carefully chosen research projects. There were also a series of lectures, about one or two per day, on time series analysis, radiation and accretion processes, statistics, X-ray binaries, active galactic nuclei, etc. Twenty participants worked on the projects under the supervision of experienced scientists from India and abroad. The main emphasis of the school was on teaching and learning by interaction, either on one-to-one basis or in small groups. Most of the participants have completed substantial part of their projects, and will continue working at their universities in collaboration with project advisors. There were 20 scientists from India and abroad who have delivered lectures, supervised projects and closely interacted with participants during the long school.

About midway through the school, a three day advanced workshop was organized on *Broadband X-ray Spectroscopy with ASTROSAT* during February 23 – 25, 2009. In addition to the participants of the school, this workshop was attended by about a dozen experts from India and abroad. The spectral characteristics of the ASTROSAT instruments were discussed in detail and some of the key science areas to be addressed using broadband spectroscopy from ASTROSAT were highlighted. Extensive discussions were held on instrument details, science priorities, as well as the techniques and tools to be employed for spectroscopy with ASTROSAT.

Workshop on Machine Learning Methods in Astronomy

Participants and Lecturers of the workshop on Machine Learning Methods in Astronomy

The IUCAA workshop on *Machine Learning Methods in Astronomy* was held at Mar Athanasios College for Advanced Studies (macfast.org), Tiruvalla, on the banks of the backwaters in Kerala State during January 19 – 23, 2009. Thirty-one selected researchers from various universities participated in the workshop. Excellent lectures covering topics from astronomy, bioinformatics and cosmology were included. The discussions and lectures were focused on Virtual Observatory and Data Mining Challenges in Astronomy, that can be extended to other areas like bioinformatics or cosmology. Indepth analysis and use of different machine learning tools and methods such as Support Vector Machines, Perceptrons, Artificial Neural Networks, Gaussian Process Regression, Bayesian Neural Networks, Hidden Markov Models and various issues such as Anomaly Detection, Clustering of Streaming Data in Astronomy and Bioinformatics, Bayesian Inference for Cosmological Model Comparison Problems were some of the main topics discussed at the workshop. Besides, special sessions on Virtual Observatory and tools like VOStat, VOPlot were demonstrated. The workshop was inaugurated by Naresh Dadhich (Director, IUCAA) and the lectures were given by Ajit Kembhavi (IUCAA), Ashish Mahabal (Caltech), Asis Kumar Chattopadhyay (Calcutta University), Shirish Shevade(IISc, Bangalore), Giuseppe Longo (University of Napoli Federico II, Italy), Yogesh Wadadekar (NCRA), Vasudha Bhatnagar (Delhi University), Moncy V. John (St. Thomas College), and Ninan Sajeeth Philip (St. Thomas College). The objective of the workshop was to initiate interactions and research collaborations between isolated researchers in the country, so that more focussed and fruitful collaborations can be established. Apart from our own Chandrayan mission, the many huge data archives such as SDSS, GOODS and new ones like LSST require lot of expertise in machine learning and data mining for its processing. The workshop was the first step in the direction to generate such expertise and awareness.

Public Outreach Programmes

Based on the initiatives by the International Astronomical Union (IAU) and UNESCO, to commemorate the 400th anniversary of the first use of an astronomical telescope by Galileo Galilei, United Nations (UN) 62nd General Assembly proclaimed that the year 2009 is to be celebrated as the International Year of Astronomy (IYA-2009). Ranjeev Misra, Head, Public Outreach Programme has been appointed as the Single Point of Contact in India. The Public Outreach Programme has planned a series of activities, with setting up national web pages for the information exchange.

IYA Astronomical Diary

The IYA Astronomical Diary was conceived and directed by J. V. Narlikar and T. Padmanabhan, and was designed by Samir Dhurde. It was produced on behalf of the Inter-University Centre for Astronomy and Astrophysics (IUCAA), as a part of its public outreach programme, for the International Year of Astronomy.

The diary contains 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, are also provided, along with a list of important events, at the beginning of every quarter of the year to promote interest in skywatching amongst readers.

Even though the diary is dated 2009, it contains wealth of information and is a collectors' item. The diary is also available on line at http://www.iucaa.ernet.in/~scipop/Literature/iyadiary.html, for free download.

Telescope making workshops for school students

School students making the telescopes

As a part of activities related to the International Year of Astronomy (IYA-2009), IUCAA has been conducting a number of telescope making workshops in various institutions, university departments and colleges in India. During these workshops, high school and college students make one-inch refracting telescopes using kits provided by IUCAA. Up to 20 telescopes have been made by participants of each workshop, working in teams of two students each. These 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.

Students at the Visvesvaraya National Institute of Technology (VNIT), Nagpur, workshop had a wonderful view of the crescent of Venus in February this year, which was both exhilarating and surprising for them.

These workshops have been conducted at DDU Gorakhpur University; VNIT, Nagpur; and Osmania University, Hyderabad. For the rest of the year, several more workshops have been planned. These will take place at IISER

Kolkata; Utkal University, Bhubaneswar; CUSAT, Kochi; North Bengal University, Darjeeling; University of Kashmir, Srinagar; M. L. Sukhadia University, Udaipur; and others.

T. Padmanabhan delivering the IYA inaugural workshop lecture at Osmania University, Hyderabad.

School Students' Summer Programme

Students engaged in various activities.

The School Students' Summer Programme was held during April 14 - May 23, 2008. Following the long tradition of the Public Outreach Programme, IUCAA hosted about 80 students, for a period of six weeks, a set of students attending a five days programme, (one working week) during this summer. The participants were invited from amongst the high scorers in the Science Quiz held during the National Science Day celebrations. Thus, we had three students from each school.

Over a period of 5 days, the students interacted with one of the members of IUCAA. The academic guides included Moumita Aich, Sudhanshu Barway, Saugata Chatterjee, Samir Dhurde, Ranjan Gupta, Sandeep Kumar, Gaurang Mahajan, Jayant Narlikar, Arvind Paranjpye and Mudit Srivastava. The innovative topics chosen included, *Finding Exoplanets, Making Sundials, Combining Electricity and Magnetism, Geological History of Pune*, etc.

Some special events for the students included visits to the science park and appreciation of the films like "Powers of Ten". All students presented their work in seminars and a report at the end of each week.

Telescope Making Workshops held at different Universities in India

January 18 - 19
Department of Physics,
DDU Gorakhpur University,
Coordinated by Shantanu Rastogi

February 14 - 15
Department of Mathematics
Visvesvaraya National Institute of Technology
Deemed University, Nagpur
Coordinated by G. P. Singh
Ajit Kembhavi delivered a public lecture on "*Galileo after 400 years*".

March 16 - 17
Department of Astronomy
Osmania University, Hyderabad
Coordinated by Vivekananda Rao
T. Padmanabhan delivered a public lectuer on "The Many Faces of Gravity".

Inaugural Meeting on IYA-2009

Nationwide activities in India

IUCAA organized a half day inaugural meeting on nationwide activities in India in connection with the International Year of Astronomy (IYA-2009) on Saturday, January 10, 2009. T. Padmanabhan, Chairman, INSA-IAU National Committee welcomed the delegates and summarized IYA related activities that would be carried out by various institutions in India. In particular, he mentioned the role of NGOs such as Akashmitra of Pune and Academy of Physics Teachers (APT), Kochi, which have planned year long activities. In his brief speech, Jayant Narlikar shared his personal views about what one might do to celebrate the IYA-2009. Firstly, he said that the historical background, not just of Galileo and his work, but also that of his contemporaries and others who contributed to the development of astronomy, such as Kepler and Newton, should be highlighted. He then said that though the simple sky watching programmes were important, the other scientific information about the astronomical objects must also be highlighted. The general public should be made aware of the technological innovations and achievements including those in application of software in astronomy.

Next, he pointed out that the study of asteroids and comets was quite important. He reminded the audience that the chance of threat to the life on earth due to collision of a comet could be, if detected early enough, be averted. He also talked about writing good science fiction stories and novels to take science of astronomy to general public. He then touched upon the importance of eradication of astrology from the mindset of people. He said giving rational arguments about why astrology was not a science, could be an important IYA activity. He pointed out the importance of giving career guidance to the school students, particularly to those doing secondary and higher secondary. Last point on his list was what an astronomer should not do. He said that as a part of IYA activities, astronomy should be communicated in simple language to general public and highly technical talks should be avoided.

Scientists from various institutions attended the meeting and talked about the special programmes and initiatives being undertaken on the occasion of IYA-2009. The list of speakers included S. Seetha, ISRO; Ranjan Gupta, Secretary, Astronomical Society of India (ASI); S. Chatteejee, Indian Institute of Astrophysics (IIA); Vinod Kamble, Director, Vigyan Prasar; A. S. Manekar, Director, Nehru Science Centre, Mumbai; Aniket Sule, of Homi Bhaba Centre for Science Education, Mumbai; Piyush Pande, Director, Nehru Planetarium, Mumbai; and Pushpa Khare, Utkal University, Bhubaneswar.

In addition to the half day programme, IUCAA organized a series of lectures for the school and college students, and for general public as follows:

Why Study Astronomy? (J. V. Narlikar).

X-ray astronomy and ASTROSAT (S. Seetha, Indian Space Research Organization, Bangalore).

Frontiers of Radio Astronomy (Yashwant Gupta, National Centre for Radio Astrophysics, Pune).

Chandrayaan-1 - Public Lecture (P. Sreekumar, Head of Space Astronomy and Instrumentation at the ISRO Satellite Centre, Bangalore).

Basic Astronomy Workshop for Primary School Teachers

A Basic Astronomy Workshop for Primary School Teachers from Ambegaon Taluka was conducted during May 3-4, 2008. The workshop was planned to be interactive, and various basic concepts, such as phases of the Moon, why we see only one side of the Moon, eclipses, measuring the diameter of the Sun, were discussed using hand-on activities. For this workshop, fifteen teachers were invited. The workshop was part of IUCAA's on going Public Outreach Programme in this region.

Estimating Earth-Sun distance

Phases of moon demonstration

Public visit to Girawali

From time to time, IUCAA receives requests to visit IUCAA Girawali Observatory (IGO) from citizens of Pune and a few from those not residing in Pune. To honour their request, IUCAA has started I Go to IGO programme.

These visits are coordinated with the IGO staff handled through the Public Outreach Programme. Every visit consists of about 25 people. Visitors are introduced to the state-of-the-art telescope and its functions. The first visit was conducted on May 08, 2008.

Public Visit

Career Mahotsav

A **Career Mahotsav** (festival) was hosted by the University of Pune from June 11 to 13, 2008. IUCAA had also put up a stall at this exhibition. This was done with the intention of publicising Astronomy, and to encourage its study amongst students. The exhibition was focussed mainly at class 12 students, who had recently passed their board exams. Pamphlets explaining the frequently asked question "How to become a professional astronomer?" were distributed amongst youngsters and parents. Samir Dhurde was present in person everyday to explain the details of the career choices leading to a research position in Astronomy and Astrophysics. Many people were also made aware of amateur astronomy and concerned groups in Pune. He was helped in this by Vidula Mhaiskar , Ashok Rupner, and Sushrut Bhanushali.

The IUCAA Stall at the University of Pune Career Mahotsav

Mobile Planetarium Tour

Narendra Dabholkar, President, Maharashtra Andhashradha Nirmulan Samiti (M-ANIS) (an organization of rational thinkers, that works towards the eradication of superstitions among common public) made a request to IUCAA for short term loan of its mobile planetarium to be taken to different talukas of the state, which was accepted.

The programme will be conducted in two or three phases. In the first phase (July to begining October 2008), the planetarium has been taken to districts of Pune, Solapur, Latur and Usmanabad. It was also taken to Beed and Aurangabad, before coming to Pune in the first week of October. The second phase will be in the second half of 2009.

M-ANIS made prior arrangements with various schools for conducting the planetarium shows. A full time 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 Narlikar and Chala Karuya Akashdarshan (Let us observe the sky) by Arvind Paranjpye have also been made available for the students visiting the planetarium.

The programme started with a planetarium show by the volunteers of M-ANIS for school students on July 16, 2008. Naresh Dadhich flagged off the van.

Naresh Dadhich gives his best wishes to the Touring Mobile Planetarium Programme in the presence of N. Dabholkar. Members of IUCAA, and M-ANIS family were also present

(i) IUCAA Promoted Khagol Vidnyan Manch Astro-Science Platform for school students and teachers of Ambegaon Taluka

IUCAA has been promoting Khagol Vidnyan Manch (KVM) in Ambegaon Taluka. Very close to the taluka headquarters at Ghodegaon, IUCAA's two metre telescope is located on Girawali mountain.

KVM is an ambitious project of IUCAA, aimed at the students of rural India to enrich them in quality learning, deriving pleasure of learning and inculcating scientific temperament. Khagol (astronomy) and Vidnyan (science) are used as separate words for this precise reason.

It has been envisaged that through this project, habit of scientific thinking would be cultivated among the students in their tender age, that is, asking questions about the nature around us and finding answers objectively. The hope is that after the initial efforts by IUCAA in setting up these KVMs, they would be independent science centres. They are named after Nakshatras (the lunar station of Indian Calendar). The first Manch, to start the activity is given the name as Ashwini, the first Nakshatra, and so on. IUCAA will provide certain basic facilities to kick start, such as books, star maps, a small telescope, etc. IUCAA officials, graduate students and scientists would visit these schools on regular basis.

On September 22, 2008, Naresh Dadhich has initiated KVMs in nine (8 secondary and 1 primary) schools in a simple ceremony that was held at the Panchayat Samiti office in Ghodegaon, organized by P. Mahajan, the Block Education Officer of Ambegaon Taluka. He handed over KVM banners and a set of books to the headmasters of these schools. About 70 headmasters of secondary schools and science/ geography teachers of the taluka and the Block Development Officer, K. K. Kohinkar were also present.

Prior to the ceremony, three hour session on astronomical telescopes and small telescope making programme was conducted by Vijay Mohan and Arvind Paranjpye. Nine telescopes (with 40 mm achromatic lens) were made by the science teachers of KVMs. About 30 science teachers participated in this workshop.

Sakaal NIE (Newspaper In Education) sponsored 5 inch reflecting telescopes to all the nine Vidnyan Manchs. The initiative was taken by Uday Jadhav, Chief Operating Officer and Vinayak Joshi of Sakaal Media Group group in Pune.

(ii) *Programme for school teachers*

To extend its regular programme for the school students every second Saturday, a regular monthly programme for the teachers has been initiated from August 9, 2008. For the first programme, heads of schools in Pune were invited to discuss the programme planned by IUCAA. It was agreed that most of the programme would be related to the curriculum taught to secondary or higher secondary schools. It was further decided that teachers would also give presentations.

On August 23, in the first session, Arvind Paranjpye talked on the solar system and Pluto. It was followed by Samir Dhurde conducting demonstrations on electricity and magnetism.

|On September 27, Samir Dhurde discussed atom and its structure. This was followed by presentation by Neha Abhyankar of Jnana Prabodhini on how to do the science projects.

Participants observing the Sunspots

Outreach Telescopes for IRCs

On the occasion of IYA - 2009, IUCAA made available three telescopes with 150 mm (6 inch) primary mirror. The telescopes are on equatorial mount with sidereal clock drive that runs on 6 volts power supply. The telescopes were sent in March to the following IRCs:

Department of Physics,
College of Science,
M. L. Sukhadia University,
Udaipur.

Department of Physics Cochin University of Science and Technology, Kochi.

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

The telescopes are suited for the purpose of general sky watching and simple observational exercises for undergraduate students.

NATIONAL SCIENCE DAY CELEBRATIONS - 2009

As every year, the National Science Day was celebrated by having a special programme of Essay, Drawing and Quiz competitions and a lecture for the secondary school students and open day for the public.

The school student's programme was held on February 21, 2009. A. S. Padmavathi of ISRO gave a lecture on Chandrayaan I and showed the first videos from the spacecraft data.

In competitions, IUCAA has always put a very high standard of judging and there have been occasions that either no prizes were given or only first or second prize was given. This year the standard of students was exceptionally high in all the three events.

Varun Sahni, who chaired the panel of judges for essay competition could not help but recommend two first and two second prizes in English essay competitions. Similarly, it was a narrow margin between first and second prizes in Marathi essay competitions. T. Padmanabhan chaired the panel of judges for drawing competitions and after much debate, the two drawings were selected for the first and second prizes, and one prize was given as honourable mention.

The quiz programme was conducted by Gaurang Mahajan.

Naresh Dadhich, Director, IUCAA gave away the prizes.

The list of winners in various categories is given in the adjoining box.

Results of various competitions

Quiz Competition

1st Prize: Jnana Prabodhini Prashala, represented by Aditya Sunil Joshi, Harshwardhan Prasad Jog, and Eeshan Gunesh Dhekane.

2nd Prize: Loyola High School, represented by Aakash Atul Kalwint, and Vinit Ravishankar.

3rd Prize (jointly) : St. Joseph's High School represented by Sanskriti Atul Dawle, Leena Hemant Damle, and Shreejita Pinaki Sengupta ***and*** Vidya Bhavan High School represented by Manish Suresh Advani, Vinit Kundan Gela, and Soham Rajesh Phade.

Essay (English)

1st Prize: Spruha Advait Kurlekar, Jnana Prabodhini Prashala, Pune, ***and*** Rutuja Surve, St. Joseph High School.

2nd Prize: Abhiram P Bhalerao, Abhinava Vidyalaya High School, ***and*** Asawari A Ambike, Jnana Pabodhini Prashala, Nigadi.

Essay (Marathi)

1st prize: Arati Ajai Bhattu, Jnana Prabodhini Prashala, Nigadi.

2nd Prize: Sonal Mangesh Pawar, Huzurpaga School, Katraj.

Drawing

1st Prize: Manorama Londhe, Vidya Pratishthan's English Medium School.

2nd Prize: Sameer P. Khare, Vidya Bhavan High School.

Honourable mention: Snehal Ingale, Kendriya Vidyalaya 2, AFS.

Open Day at IUCAA

The Open Day for public was observed on Saturday, February 28, 2009. On this day there were many events, which ran continuously and concurrently.

In Bhaskara complex, IUCAA academic members displayed the latest trends in astronomy and astrophysics research in a poster session. Many faculty members were present to answer questions. The instrumentation department displayed astronomy related instrumentation and demonstrations on astronomical seeing. Astronomy films were screened in Chandrasekhar Auditorium. In the foyer of Chandrasekhar Auditorium, SciToys demonstrations were arranged by the students of Loyola School. Deoyani Nandrekar gave demonstrations on Virtual Observatory and Hubble data analysis. On the grounds of Muktangan Vidnyan Shodhika (MVS), students of Loyola School gave demonstrations on water rocket and Venus at it's crescent phase was shown live.

Workshop on making of a simple CD/DVD spectroscope was conducted for the school students at MVS. Fergusson College students helped in making about 250 such spectroscopes.

A poster exhibition on ***Chandrayaan*** from ISRO was also arranged. IUCAA science park was kept open with volunteers to explain various exhibits.

Gulab Dewangan and Samir Dhurde gave short 30 minutes talks titled ,“The Universe in X-rays”, and “Galaxies” respectively. In a programme titled “Meet the Scientists and Ask Questions” Jayant Narlikar and T. Padmanabhan answered the questions asked by the audience.

Popular Talks and Articles by IUCAA Members

(a) Talks

Joydeep Bagchi

Amateur Radio Astronomy in IYA-2009, ASI sponsored `Pro-Am Collaboration' meeting, Jawaharlal Nehru Planetarium, Bangalore, February 17.

Dipankar Bhattacharya

Gamma Ray Bursts, Nehru Planetarium, Mumbai, August 9.

Radiation-matter Interaction in Exploding Supernovae, Workshop on Radiation Matter Interaction Under Extreme Conditions, Banaras Hindu University, Varanasi, December 20.

Naresh Dadhich

Gravity (to students during the Summer School Programme), IUCAA, Pune, June 5, 6.

Sustainability of Faith, (during the inaugural address at the National Symposium on “Intersecting Science, Philosophy and Religion - An Indian Perspective” organized jointly by the Indian Institute of Science and Religion, Pune and the Indian Council of Philosophical Research, New Delhi), Kochi, June 14.

Newton Se Einstein aur Us Se Aage (in Hindi) [From Newton to Einstein and Beyond] (to the school students during the Second Saturday School Students Programme) IUCAA, Pune, July 12.

Making Teaching Creative, (to the faculty of All India Shri Shivaji Memorial Society’s College of Engineering) Pune, August 27.

Why Einstein (to the students of Indian Institute of Technology, Madras during the technical festival “SHAASTRA”), Chennai, September 30.

Gravity (to the students of Presidency College, Kolkata) IUCAA, October 14 and 16.

Why Einstein? (to the faculty and students of Regional Institute of Education), Mysore, October 21.

Next Five Years in Indian Astronomy (at the inauguration of IUCAA workshop on “Machine Learning Methods in Astronomy”) Mar Althanasios College, Tiruvalla, Kerala, January 19.

Why Do We Live in Four Dimensions? (V.V. Narlikar Memorial lecture organized by Centre for Theoretical Physics), Jamia Millia Islamia, Delhi, January 23.

Basic Forces of Nature (during the inaugural function of the IUCAA Reference Centre at the University of Calcutta, April 21.

Gulab Chand Dewangan

Seeing Heavens in X-Rays, (at Akashmitra Association), Pune, October 23.

The Universe in X-rays, (in Hindi) National Science Day, IUCAA, Februare 28.

Ranjan Gupta

Astronomy Related Research in India, (Rupnarayanpur Cine Club, Rupnarayanpur), Burdwan, West Bengal, April 6.

ASI2009 Activities and IUCAA Astronomical Observational Activities in General, Conference on IYA-2009 -- Role of Planetarium, Goa, January 22 - 25.

ASTRONOMICAL TELESCOPES from GALILEO till TODAY, Subodh School, Jaipur, March, 25 (as a part of IYA-2009 Activity).

Ajit Kembhavi

Discovering Planets, School Students Lecture Demonstration Programme, IUCAA, Pune, December 13.

Grahancha Shodh, (Marathi), School Students Lecture Demonstration Programme, IUCAA, Pune, December 13.

Galileo for the 21st Century, (IYA-2009 Celebrations, Breakthrough Science Society Kerala Chapter), Kozhencheri, Kerala, January 20.

Galileo – Astronomer and Physicist, Akashmitra, National Institute of Opthalmology, Pune, February 12.

Galileo after 400 years, Visvesvaraya National Institute of Technology, Nagpur, February 15.

Galileo to Einstein – A Journey Over 400 years, Pt. Ravishankar Shukla University, Raipur, March 21.

Ranjeev Misra

Black Holes in the Universe, Frontiers of Physics, Fergusson College, Pune, February 2009.

J.V. Narlikar

Vishwat jeevasrushticha shodh (Search for extra-terrestrial life) (in Marathi) (a lecture organized by Maharashtra Mandal, Gandhinagar), Bangalore, April 6.

Why study astronomy, to the students of Astronomy Olympiad Camp, IUCAA, Pune, May 11.

Anomalous Redshifts in Astronomy, Nehru Centre, Mumbai, May 31.

Searches for Life in the Universe, a lecture organized by the Academy of Science of South Africa in conjunction with the Astrophysics and Cosmology Research Unit of University of KwaZulu-Natal, Durban, South Africa, June 10.

Mathematics : Key to All Scientific Research, M.C.E. Society's Abeda Inamdar Senior College, Pune, October 6.

India in Space, Sixth Prof. G.S. Diwan Memorial Lecture, Mumbai, October 11.

Cosmic Illusion, to the members of the Aundh-Baner Senior Citizen Assocation, Pune, November 11.

Searches for Life in the Universe, Central Water & Power Research Station [CWPRS], Pune, November 14.

Searches for Life in the Universe, 14th Sir J.C. Bose Memorial Lecture organized by The Institution of Electronics and Telecommunication Engineers, Pune, Yashada, Pune, November 28.

Astronomical Significance of Galileo, a talk organized by Akashmitra, Pune, January 1.

Why Study Astronomy, Second Saturday Lecture and Demonstration Programme, IUCAA, Pune, January 10.

Khagol shastrachya abhyasachi aavashakta (Why study astronomy) (in Marathi) a lecture organized by the Marathi Vidnyan Parishad, Thane Vibhag delivered at the Gadkari Rangayatan, Thane, January 11.

Searches for life in the universe, Indian Institute of Science Education and Research (IISER), Kolkata, January 27.

Khagol shastracha abhyas karane garjeche ka aahe? (Why Study Astronomy) (in Marathi), a lecture organized by the Andhashraddha Nirmulan Samiti at IUCAA, January 31.

Searches for Life in the Universe, a public lecture at the Institute of Physics, Bhubaneshwar, February 2.

Why Astronomy is Important?, National Institute of Technology, Rourkela, February 6.

Brahmand mein jeevan ki utpatti (Origin of life in the universe) (in Hindi) at Pandit Ravishankar Shukla University, Raipur, February 11.

Ya vishwat aapan ektech ka? (Are we alone in the Universe?) a lecture organized by Khagol Club, at the One Life Club, Pune, February 28.

T. Padmanabhan

The Enigma of Gravity, Indian Institute of Technology, Mumbai, May 20.

Astronomy as a Physical Science, Public Talk in Trivandrum Book Fair , December 21.

Excitement of Pure Science, Trivandrum Book Fair, December 22.

The Many Faces of Gravity, Frontiers in Astronomy, Fergusson College, Pune, February 6.

Universe: Our Changing Perceptions, 46th Kerala Sasthra Sahithya Parishad , Annual Conference, February 13.

The Many Faces of Gravity, IYA Inaugural workshop, Osmania University, March 16.

Gravity: The Last Frontier, S.S.G.M. College, Kopargaon, March 23.

Maulik Parikh

The Greatest Experiment in History: The Large Hadron Collider, IUCAA, Pune, October 2008.

Left-Right, Past-Future, Matter-Antimatter, IUCAA, Pune, February 2009.

A.N. Ramaprakash

Future Large Telescopes, Mindspark, College of Engineering, Pune, October 03.

A Giant Leap in Astronomy, BITS Alumni Meet, IUCAA, February 01.

Four Blind Men and an Elephant, Frontiers in Astronomy, Fergusson College, Pune, February 05.

An Astronomical Future for Astronomy, North Bengal University, Darjeeling, March 17.

Tarun Souradeep

The Cosmos Unraveled, Frontiers of Astronomy, Fergusson College, Pune, February 6.

(b) Articles

Kuntal Misra (co-authored with Ram Sagar)

An Insight into the Progenitors of Gamma Ray Bursts from the Optical Afterglow Observations, Current Science, Vol. 96, No. 3, February 10.

Narlikar, J.V.

Scientific Research: What it Means to Me, Mens Sana Monographs, **6**, 1, 135.

By Jupiter, It's Not In Your Stars, Financial Chronicle, April 22.

Eclipse of Reason : Superstition Continues to Thrive in India, Via Lactea, May 4.

IISER, NISER, Are We Any Wiser?, Financial Chronicle, May 8.

Infinite Human Quest, Financial Chronicle, May 12.

The Science Behind God, Financial Chronicle, June 4.

Science vs Religion, Financial Chronicle, June 23.

It's All About Thinking Fresh, Financial Chronicle, July 21.

Necessity Invents Science, Financial Chronicle, August 25.

Science Journalism in India and Abroad, NCSTC Communications, August.

Gravity Can Create Illusions, Financial Chronicle, September 28.

Traveller's tales : I posed with Einstein, Reader's Digest, October.

Space and the Common Man, Financial Chronicle, October 26.

Effective Funding for Research, Financial Chronicle, December 7.

Superstitions of Space Age, Financial Chronicle, January 4.

400 years of Astronomical Discoveries, Co-authored with T. Padmanabhan, DNA, January 5.

Sunspots Revealed, Co-authored with T. Padmanabhan, DNA, January 13.

Sankranti's Solar Connection, Co-authored with T. Padmanabhan, DNA, January 21.

Virtues of Studying Astronomy, Financial Chronicle, January 25.

Distance Units in Astronomy, Co-authored with T. Padmanabhan, DNA, January 28.

The Golden Age of Indian Astronomy, Heritage India, **2**, 1, 22.

Landings on Mars, Co-authored with T. Padmanabhan, DNA, February 2.

Strange Visitors to Our Skies, Co-authored with T. Padmanabhan, DNA, February 9.

The Rise and Fall of Pluto, Co-authored with T. Padmanabhan, DNA, February 16.

The Message of Science Fiction, Financial Chronicle, February 22.

Uranus Has Rings Too, Co-authored with T. Padmanabhan, DNA, February 23.

The Different Views of Saturn, Co-authored with T. Padmanabhan, DNA, March 2.

The Scientific Temper, Dream 2047, **11**, 6, 35.

Here Comes the Sun's Eleven-year Cycle, Co-authored with T. Padmanabhan, DNA, March 10.

The Best Clocks in the Cosmos, Co-authored with T. Padmanabhan, DNA, March 16.

Catching Uranus : Saga of Missed Opportunities, Co-authored with T. Padmanabhan, DNA, March 23.

Hazards of Observing the Sky, Financial Chronicle, March 29.

Seeing the Earth Spin, Co-authored with T. Padmanabhan, DNA, March 30.

Bharat aur videsho mein vidnyan patrakarita (in Hindi) [Science journalism in India and abroad], NCSTC Communications, August.

Vaidnyanik manovruti (in Hindi) [The Scientific Temper], Dream 2047, **11**, 6, 6.

Newton ka bagicha aur seb ka pedh (in Hindi) [The Apple Tree in Newton's Garden], Chakmak, February.

Mazi shala (in Marathi) [My School], Jeevan Shikshan, July, 6.

Mazi shala (in Marathi) [My School], Panchavati Patrika, May.

Maze vadil (in Marathi) [My Father], Sakal, October 26.

Newtonchya bagetale safarchandache zad (in Marathi) [Apple Tree in Newton's Garden], Marathi Vidnyan Parishad Patrika, Diwali Issue, November, 10.

Wrangleriche diwas (in Marathi) [Working for Wranglership], Mouj, Diwali Issue.

Makar Sankranti (in Marathi) [Makar Sankranti], Loksatta, January 1.

Khagol varsha (in Marathi) [International Year of Astronomy], Loksatta, January 2.

Prithvi phirte ka surya? (in Marathi) [Which Moves, the Sun or the Earth?], Loksatta, January 3.

Chandravarun akashdarshan (in Marathi) [The Sky Seen from the Moon], Friend, 8.

(c) Radio/TV Programmes

Ajit Kembhavi

Galileo – the Astronomer, (Hindi) for Edusat., March 21 at Raipur.

J. V. Narlikar

Participation in a special programme on History of Space Technology in India, BBC London.

Hamare Beech : Bhetvarta (in Hindi), All India Radio, October 11.

Maulik Parikh

One-hour appearance on STAR India on LHC, November 2008.

Two-hours appearance on STAR India on LHC, November 2008.

FACILITIES

(I) Computer Centre

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.

Green computing is the environmentally responsible way of using computers and related resources such as energy-efficient central processing units (CPUs), servers and peripherals, as well as reduced resource consumption and proper disposal of electronic waste (e-waste). IUCAA has taken the green computing seriously and has opted for VMWARE desktop virtualization which is in the final stage of implementation. This virtualization approach has helped to consolidate desktops onto fewer pieces of power efficient blade servers and thin clients at user end, which would result in sizable energy savings.

In November 2008, Zimbra Collaboration Suite (ZCS) was deployed, as it has many features compared to Squirrelmail webmail that was in use earlier at IUCAA. It is a server-based groupware commercial product that provides web-based enterprise e-mail, calendaring, and contact sharing.

Wireless networks have evolved into more affordable and logistically acceptable alternatives to wired LANs. In February 2009, IUCAA wireless network was secured from being an open wireless network by following the best practices recommended by Department of Telecommunication.

(II) Library and Publications

In the period under review, the IUCAA library has added 200 books and 250 bound volumes to its existing collection, thereby taking the total collection to 22433. 127 journals were subscribed by the library. 330 books were added to the collection of the Muktangan Science Exploratory library.

The library has received 312 full-text article requests from 63 academics (including students), through e-mail/post/in person, interlibrary loan requests for 5 books from 5 libraries and requests for 11 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.

A workshop on Open Source Standards and Software in Libraries: Spotlight on NewGenLib was organized by the IUCAA library during September 17-19, 2008.

The IUCAA library is an active member of the Forum for Resource Sharing in Astronomy (FORSA), which comprises twelve institutes in which Astronomy and Astrophysics is a major research area. Efficient and speedy service to users has been possible due to the excellent rapport shared by each member. The members of FORSA will be jointly organizing the sixth International Conference on Library and Information Services in Astronomy (LISA) scheduled to be held during February 14-17, 2010 and co-hosted by National Centre for Radio Astrophysics (NCRA) and IUCAA, Pune. The logistics of the conference will be handled using the Open Conference Systems (OCS), developed by the Public Knowledge Project (PKP), which operates through a partnership among the Faculty of Education at the University of British Columbia, the Simon Fraser University Library, the School of Education at Stanford University, and the Canadian Centre for Studies in Publishing at Simon Fraser University. The conference website is available at http://libibm.iucaa.ernet.in/conf/index.html.

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.

(III) Instrumentation Laboratory

Ensuring the smooth operation of IUCAA Girawali Observatory and providing maintenance and upgradation support occupies the largest chunk of laboratory staff time. Observatory downtime due to back end instrument failures or auxiliary support issues, have been reduced to be less than 1% of the total scheduled time over the past year also. This was achieved as the result of sustained efforts of the IUCAA laboratory and observatory staff. Having reached this milestone, the primary thrust over the last year has been to minimize downtime due to telescope related technical issues. As part of this, a proactive effort was undertaken to identify and procure both strategic as well as routine spares for components of the telescope. The goal was to locate Indian suppliers for as many of the OEM components as is possible. A team from the laboratory visited the Astrophysics Research Institute (ARI), Liverpool, UK, who operated the Liverpool telescope on La Palma, Spain. Extended discussions were carried out about problems that have been faced by the two groups with their respective (almost identical) telescopes and the merit of IUCAA and ARI working together in resolving these issues.

The basic system of operational control and safety interlocks for the telescope is built using Allen-Bradley (Rockwell Automation) industrial control and automation components. Laboratory staff (M. Burse, K. Chillal, and A. Kohok) have taken specific training for dealing with these components. These steps have become particularly important as the original manufacturer of the telescope (Telescope Technologies Ltd., UK) has been taken over by a new managment, which has declined to renew technical support contract since the end of 2008.

A new E2V CCD based detector system for use with IFOSC was developed in the laboratory as replacement for the currently used ageing EEV CCD detector system. Subsequent to some initial tests on the telescope, the new system was found to have some performance issues (such as channel to channel coupling leading to faint negative ghosts etc.). P. Chordia, H. K. Das, M. P. Burse, and others have been working on diagnosing these issues and the resolutions are currently being implemented. It is expected that the new CCD system can be released for use at IGO from the next observational cycle (2009B) onwards.

With the completion of twenty years of IUCAA, a series of intense discussions as to its future directions of growth were carried out within IUCAA and through its Scientific Advisory Council. One of the key recommendations which came out of this process was a paradigm shift in the scope of IUCAA's experimental programme. Worldwide giant leaps being currently made in ground-based observational astronomy. In view of these developments, a vision document was prepared to guide the future development of IUCAA's instrumentation laboratory among other things. Three key technology areas, which the laboratory will develop expertise with a view to be competent at a global level over the next decade are (i) adaptive optics, (ii) astronomical detector control and data acquisition systems, and (iii) optical fibre applications in astronomy.

Work has started in the laboratory for developing the next generation focal plane array controller system. This system is specified to handle upto sixteen data streams simultaneously either in groups or individually. Each data stream may be associated with a detector output and can handle pixel rates of at least 1Mbytes per second. Adequate provisions are made to allow this system to handle a wide variety of detectors such as L3CCDs, IR-detectors, CMOS arrays, etc. Based on Xilinx-family FPGA devices, the system can be easily configured to handle any of these detectors. Experiments in the laboratory has already achieved data rates of 16 Mbytes second through a single USB connection to a standard Core2 Duo computer running Linux OS.

Initiatives are being made to set up collaborations with other institutes within and outside the country to kick start the AO programme. Work which is already underway in the laboratory to build a fibre-based integral field unit has already been described elsewhere in this report.

Keeping with the above vision, work on adding a new facility to the laboratory has been initiated. This facility will have a class 10000 clean room, where an adaptive optics test bench will be created to address specific AO-related R & D issues. In addition, this room will be utilized for handling astronomical detectors. The laboratory will also house a design centre, where workstations for AutoCAD, OrCAD, Zemax, RSLogix, PanelBuilder, etc. will be set up. A third section of the laboratory will have facilities for handling and polishing optical fibres, small filters, etc.

(IV) IUCAA Girawali Observatory (IGO)

A major revamp of the instrument control hardware at IGO was getting ready in the laboratory almost exactly a year ago. Along with the hardware, it was reported that the operational and engineering control software also was to be replaced with a new integrated system. These upgrades were implemented on the telescope during the monsoon break of 2008 and this new control system has worked very well during the 2008B and 2009A observational cycles. With this success, the previous control system has since been decommissioned. Mudit Srivastava, M. Burse, K. Chillal, V.Mestry, and S. Punnadi worked along with other laboratory staff in developing this Unified Instrument Control System (UNICS). Figure 22 shows UNICS mounted on the telescope.

Subsequently, another major effort was undertaken under the responsibility of K. Chillal to replace the power supply and control system at the Cassegrain instrument cluster of the telescope. A new power control panel with built in safety and remote control provisions was developed in the laboratory and deployed on the telescope in early 2009. Along with the release of this hardware, the instrument control software was also updated to provide facilities for power supply control and remote initialization of all the individual instrument components from the control room. Figure 23 shows the power house panel mounted on the telescope.

Last year also saw a few episodes of critical component failures. The detector assembly of the autoguider had to be replaced after a failure of the detector control circuit. A design bug in the CCD temperature controller was fixed primarily through the efforts of P. Chordia,and M. P. Burse. It was noticed that the encoder tape of the altitude control system was developing rust spots leading to noticeable deterioration of the servo control of the axis. Once the cause of the problem was diagnosed, a replacement encoder tape was procured

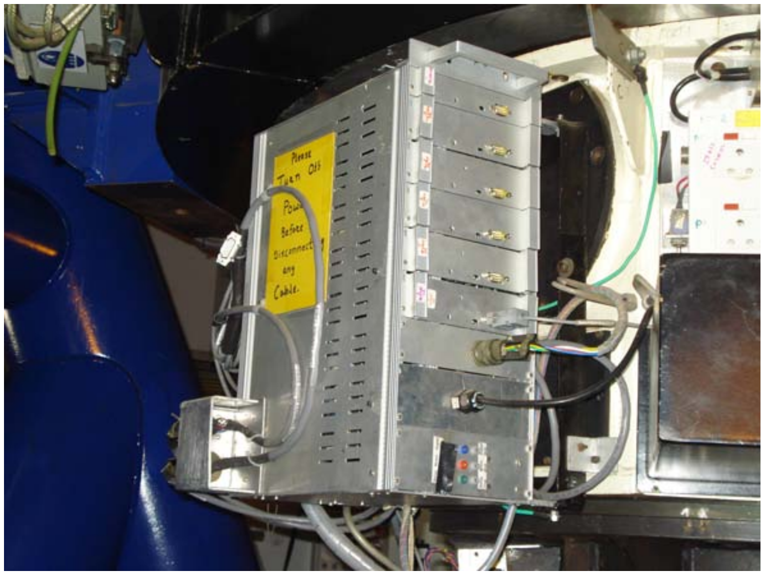


Figure 22: The UNICS hardware, named Common Control Unit (CCU), mounted on IUCAA telescope

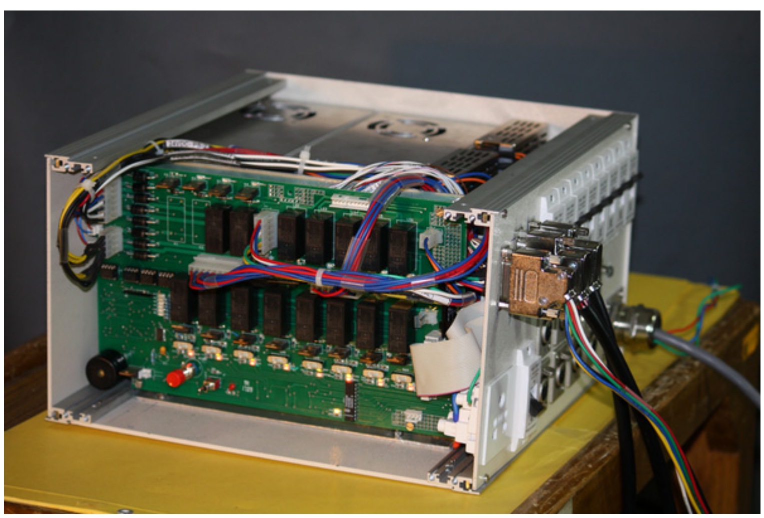


Figure 23: Powerhouse Hardware

from Heidenhain, Germany. It was installed on the telescope immediately after the monsoon break of 2008, and the system was re-calibrated and tested largely through the efforts of M. P. Burse, P. Chordia, H. K. Das, A. Kohok, and V. Mohan. There was also an incidence of lightning strike affecting some of the power cables in the main services control panel. Failure of a memory module of the services PLC required re-programming of the device using external Allen-Bradley software packages. Other critical failures included a large leak in the radiators of the main oil tank and a breakdown of the water-glycol circuit in the oil chiller plant.

A Fabry-Perot etalon based spectrograph is being developed in the laboratory for use at one of the Cassegrain side ports of the telescope. This project is undertaken in collaboration with the astronomy group at Physical Research Laboratory, Ahmedabad. The spectrograph will be used to study H alpha (656.3nm) NII (648.6 and 658.3 nm) lines, AGNs and star, kinematics of gaseous nebulae, interacting Galaxies.

The optical design of the insrument is nearing completion and the optical layout and performance results can be seen in Figures 24, 25 and 26. It essentially is a collimator-camera design with the collimated beam width being about 28 mm. The total working field of view is about 1.6 arc. min. and is optimized to work over a wavelength range of 600 to 700 nm. The angle between the collimated beam (for the maximum field radius of 0.8 arc. min.) and the optic axis is about 1 degree. Its 80% encircled energy also falls within 1 pixel of the detector. An etalon ET28 of IC opticals will be used for the spectrograph. It has a working range of 600-700 nm and finesse of 20. The reflectivity of each plate is about 90% and FSR (free spectral range) is 2.15 nm, spectral element 0.108 and resolution about 6000; the two etalon plates are separated by about 100 microns. R. Gupta, H. K. Das, C. Rajarshi, and B. G. Anandrao (PRL) are directly involved in this programme.

The primary mirror of the telescope was re-aluminized in November 2008 using the coating plant at IGO. As seen in Figure 27 this led to a substantial improvement in the reflectivity of the mirror. It is also clear from Figure 27 that the monthly CO2 dust cleaning is helping in keeping the reflectivity deterioration under check. Our experience is that about 5-10% reflectivity can be recovered during a cleaning cycle, unless there has been a prolonged (few days) high humidity period in the intervening gap.

Steps being initiated to curtail the high attrition among operational support staff at the observatory was mentioned in the last annual report. As part of this effort, three regular scientific staff have been appointed in the laboratory, each of whom spends approximately a week at IGO per month. The rest of the time they work on various developmental projects which are undertaken in the laboratory. R. Bhandare has been working on data analysis of laboratory test data using IRAF. C. Rajarshi is involved in the optical design of the Fabry-Perot spectrograph using Zemax, and S. Prabhudesai works on developing a data reduction pipeline for IGO data.

(V) Virtual Observatory India - The Next Generation (VOI-TNG)

VOI-TNG is the second generation of VOI project hosted at IUCAA in collaboration with Persistent Systems Ltd (PSL). PSL is a Pune based leading software development company, which has significant expertise in databases. The project is partially funded by Ministry of Communication and Information Technology of Government of India, IUCAA and PSL. VOI is a part of the International Virtual Observatory Alliance (IVOA) and works in collaboration with other virtual observatories in the world as the framework of the IVOA.

The aim of VOI is to provide sophisticated software tools along with astronomical data for analysis and study to the astronomical community in India and other countries. Tools are developed in conformity with the VO standards for interoperability. The tools are available in two versions- web based and stand alone. Web based tools are hosted on VOI servers and can be accessed from any machine having internet connectivity. Stand alone tools can be installed on users machines and can be accessed locally. VOI provides software services to the astronomical community, which includes development of sophisticated codes for specific applications for data archiving, management, analysis and visaualization.

As a part of the VOI initiative several data archive mirrors are hosted on IUCAA servers. These include the Chandra data archive, various data releases (DR) of the Sloan Digital Sky Survey (SDSS), Vizier and some other smaller datasets. Mirrors of these archives are available at some limited centers in the world. VOI plans to archive large image databases in the near future.

VOI improves performance and functionalities of its tools using feedback from users. A new SAMP compatible version of VOPlot (plotting and visualization tool) has been released, which has important added functionalities like density plot. SAMP, Simple Application Messaging Protocol , is a direct descendent of the PLASTIC protocol. All VOI tools are PLASTIC compatible . A modified version of VOStat, a statistical analysis tool (web based version developed in jsp/servlets) has been released recently, which has some modified statis-

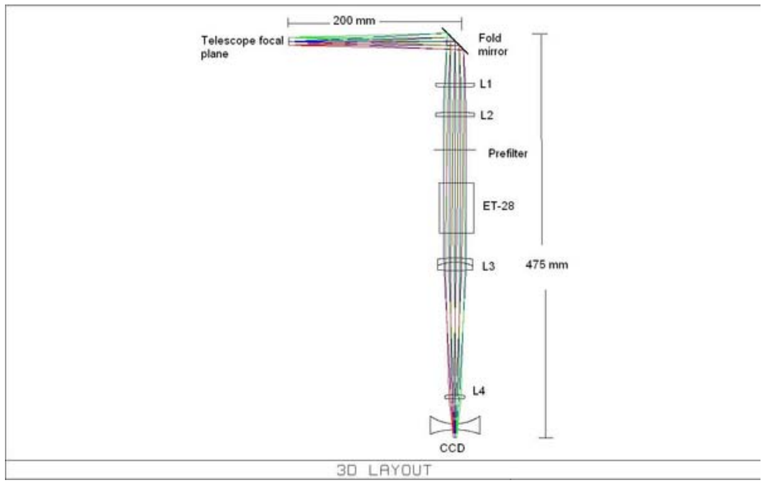


Figure 24: Optical layout of the Fabry Perot Spectrometer

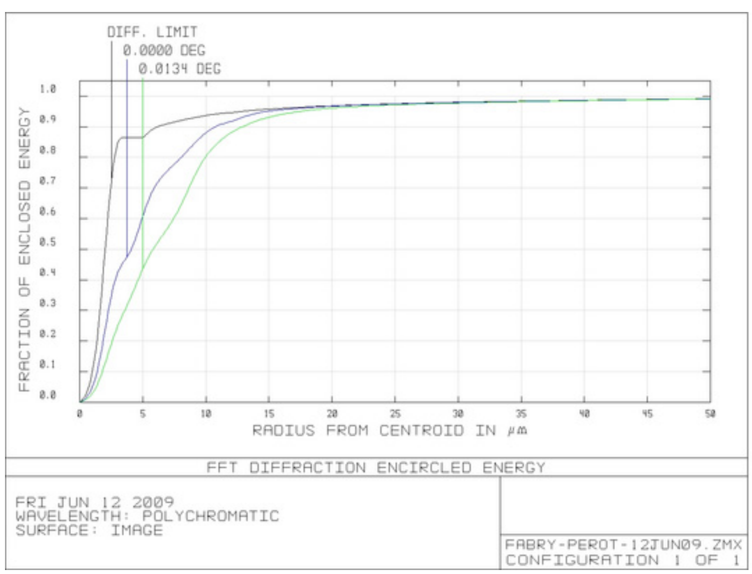


Figure 25: 80% fraction of the energy is falling within one pixel of the CCD (1 pixel = 13.5 microns)

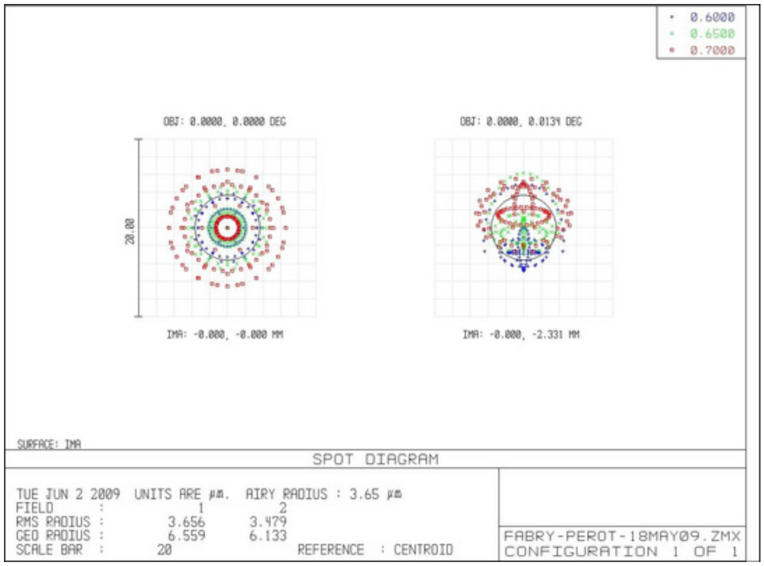


Figure 26: Spot Diagram

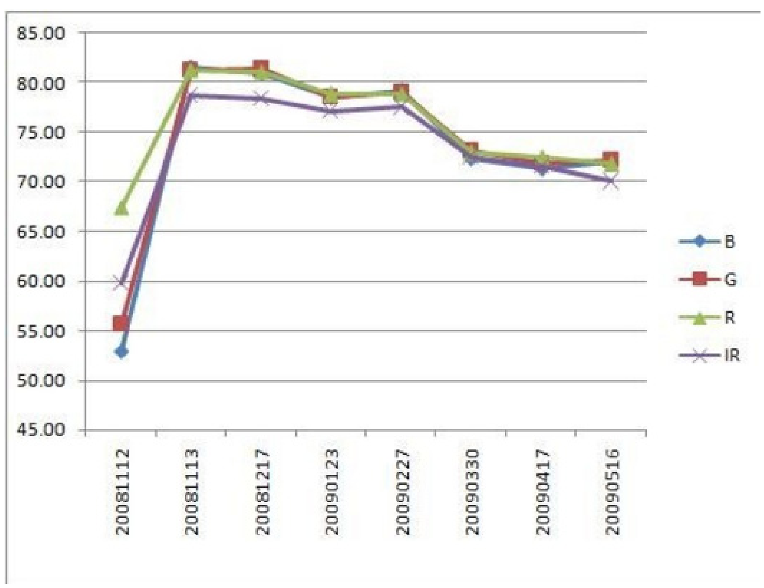


Figure 27: Mirror Reflectivity over 6 months

tical tests routines.

During the 2008-2009 period, VOI has developed a Data Archive and a Proposal Management System (PMS) for the Giant Metrewave Radio Telescope (GMRT), in collaboration with National Center for Radio Astrophysics (NCRA). The proposal management system was released in December 2008 and astronomers from all over the world have started using this online system for proposal submission. The system is customized variously to the roles of proposer, reviewer, Time Allocation Committee (TAC) member and TAC chair. The data archive system is expected to be released soon. The GMRT data archive system is being developed to VO standards. Development of the proposal management system for the IUCAA Girawali Observatory (IGO) is completed and is ready for release.

VOI-TNG is a good example of collaboration between academic institutes and software industry for development of highly sophisticated scientific software tools .

(VI) IUCAA-NCRA Radio Physics Laboratory Facility (RPL)

During last year the IUCAA - NCRA Radio Physics Laboratory, which is a joint facility of IUCAA and the National Centre for Radio Astrophysics (NCRA) took further significant steps toward achieving the goals envisaged for this facility. The RPL started to function in all earnest both at NCRA (East campus, where the radio telescopes have been set up) and IUCAA (where the physics and radio lab experiments were put together). The RPL facility continued to be at the hub of activities connected with major academic programmes designed for imparting training in the field of radio astronomy. Two small radio telescopes of 3 and 4 metre diameter have been commissioned and fully functional, which are currently serving as the main workhorse facilities of the RPL. During previous year, these telescopes were extensively deployed for conducting practical training sessions; first during the Radio Astronomy Summer School (RAS - 2008), conducted by NCRA, and second during the First IUCAA-NCRA Radio Astronomy Winter School (RAWS - 2008), jointly conducted by IUCAA and NCRA in Pune. These telescopes are also used for joint IUCAA-NCRA graduate school experiments, and for Pune University MSc teaching. More than 50 students who participated in the two above mentioned schools conducted Radio Astronomy experiments, which included determination of telescope beam width, calculating pointing offsets, understanding astronomical co-ordinate systems and rising and setting of sources, solar radio astronomy, and measurement of 21 cm line of neutral Hydrogen (HI) from our galaxy. In addition, students also conducted an optical Faraday Rotation experiment, set up in the IUCAA RPL laboratory. The small radio telescope facilities of RPL proved to be excellent pedagogical tools for introducing students to the field of radio astronomy and also gave them a practical, human-scale 'hands-on' feel for radio telescopes and observations, not provided by very large radio telescopes. Below is a brief report on the instrumentation and facilities available on these telescopes and shows some astronomical data obtained with them.

The 3 m Radio Telescope Facility

The 3 m Small Radio Telescope (SRT) antenna is a dedicated radio telescope developed by MIT Haystack Observatory (USA) for student training and is a part of RPL since 2008. The antenna is located in the north end of the NCRA East campus. and mounted on the roof of the control-room housing the 4 m antenna receiver (see Figure 28). The telescope can observe approximately 70% of the sky above horizon. The 3m dish is mounted on top of a fully motorized AZ-AL mount, designed by CASSI Corp. The antenna is equipped with a superheterodyne receiver, which uses digital technology with a 8-bit analog to digital down converter (AD9283), GC1011A and Motorola 56F803 digital signal processor (DSP). The receiver and the low noise amplifier are mounted at the feed of the antenna and it is controlled remotely using a STAMP microprocessor and RS-232 communications.

A Software has been provided for controlling the antenna (both AZ and AL motion) and selection of sources and also allowing the observer to observe in two modes: continuum and spectral line mode in the L-band (1.42 GHz), and to perform total power measurements and contour mapping. The further data reduction can be performed using existing radio astronomy software packages. The SRT is used routinely for many simple radio astronomy experiments involving system temperature calibration, solar flux observations and galactic 21cm Hydrogen line observations. A plot of complex 21cm Hydrogen line profile observed by the 3m telescope from the IAU calibrator source S7 in our galaxy (looking towards the Perseus - Cassiopeia boundary) in shown in Figure 28. The dual peaked Hydrogen line profile comes from Doppler shift of frequency of Hydrogen line emitted by two different spiral arms of the galaxy, which are at different distances from the galactic centre and thus, have different rotation speeds relative to the local arm containing the Sun and earth.

The 4-m Radio Telescope Facility:

The Small Metrewave Radio Telescope antenna is locally fabricated, with good quality drive systems and receivers and has been the main workhorse of RPL since 2006. This antenna is located in the north end of NCRA East campus with the control-room just in front of the antenna (see Figure 28). The telescope can look approximately 70% of the sky above horizon. The antenna can rotate in two directions - azimuth (AZ) and altitude (AL). Both the rotation axes are controlled by two BALDOR brushless DC motors driven using Delta-tau drives, which are operated through a programme running on a local PC. Both the motions can be achieved by giving precise position and velocity commands. Both axes are equipped with incremental encoders, which provide the position information. The receiver consists of a 21 cm horn, mounted on a quadripod above the dish. The RF signal is amplified using a 35 K noise temperature LNA and is fed to a RAS Spectra-Cyber 21 cm receiver (superheterodyne swept local oscillator receiver). The receiver can be operated in two modes - continuum and spectral line mode. The former is used for experiments with the Sun and for observing strong radio sources. The latter mode is used for 21 cm HI observations of our galaxy. The 4 m telescope is used routinely for simple radio astronomy experiments involving observations of Sun and the galaxy.

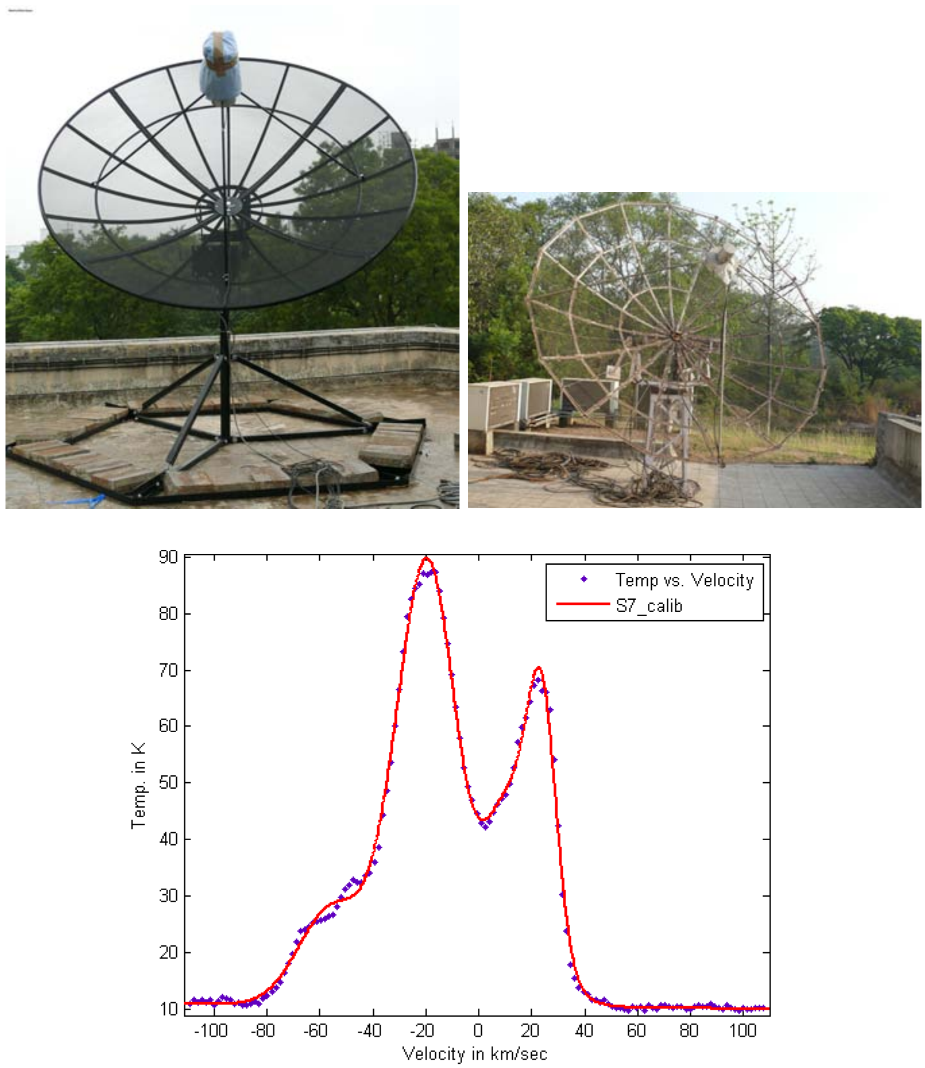


Figure 28: Radio Telescope Facilities (SRT) presently available at the IUCAA-NCRA Radio-Physics Laboratory. Top left photograph: The 3 m Radio Telescope, and the top right photograph: The 4 m Radio Telescope facility. A plot of complex 21 cm Hydrogen line profile observed by the 3-m telescope from the IAU calibrator source S7 in our galaxy (looking towards the Perseus - Cassiopeia boundary) in shown in the plot below. The dual peaked Hydrogen line profile comes from Doppler shift of rest frequencies of Hydrogen line emissions from two different spiral arms of the galaxy, which are at different distances from the galactic centre and thus, have different rotation speeds relative to the local arm containing the Sun and earth.

IUCAA REFERENCE CENTRES (IRCs)

[1] Cochin University of Science and Technology, Kochi (Coordinator: V.C. Kuriakose, Jt. Coordinator: Ramesh Babu T.)

The facilities at the IRC have been regularly used by M.Sc. and M.Phil. students for their project works, 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 the IRC facility.

Talks/seminars

N. Dadhich, *Why Einstein?(Had I been born in 1844)*, June.

Gangan Prathap, *Knowledge and Deep Knowledge*, August.

M. Lakshmanan, *Nonlinear Dynamics: An Introduction*, August.

P. P. Divakaran, *Quantum Mechanics of Magnetic Field*, September.

V. C. Kuriakose, *The Physics of Large Hadron Collision*, October.

Ramesh Babu T., *Nature Works in Strange Ways*, December.

R. Raja, *Opening up the Neutrino Physics Frontier*, January.

V. C. Kuriakose: *The Impact of Astronomy in Society*, February

P. Sreekumar: *Chandrayan I- Scientific Investigations and Initial Results*, March.

IRC Seminar on Astronomy, Gravity and Beyond Einstein March 6-7, 2009

A. Kembhavi, *Very Large Telescopes*.

R. Misra, *Black Holes in the Universe*.

T. R. Govindarajan, *Geometry and Gravity Beyond Einstein*.

C. D. Ravikumar, *The Sky Above*.

V. C. Kuriakose, *Black Hole Stability*.

Visitors

N. Dadhich (IUCAA, Pune), A. Kembhavi (IUCAA, Pune), R. Misra (IUCAA, Pune), P. P. Divakaran (CMI,Chennai), M. Lakshmanan (Bharathidasan University, Tiruchirappalli), Moncy V. John (St.Thomas College, Kozhencherri), Ninan Sajeeth Philip (St. Thomas College, Kozhencherri), C. D. Ravikumar (Calicut University), K. P. Harikrishnan (The Cochin College).

Other activities:

Workshops

a) Summer School Programme

In collaboration with the Department of Physics and SPIE CUSAT Chapter, the IRC has organized a workshop during April 16 - 26, 2008 for High School students, who completed IXth Standard. There were 30 school students, who attended the programme. They were introduced to the basic concepts in Physics and they were able to do some fascinating experiments in the laboratories of the Physics Department. They were also given training to construct small telescopes. The students enjoyed this programme.

b) Workshop at M. G. University, Kottayam

IRC, Kochi has sponsored the Workshop held at M.G. University, Kottayam, during December 1-3, 2008.

IYA Programme.

(a) Public lectures:

In the department, one seminar and two public lectures were conducted, and the Coordinator gave public lectures at other places:

1) Radio talk on Galileo, Feb. 22, AIR, Thrissur.
2) Astronomy – Why ?, Carmel College, Mala, Feb. 24.
3) What do we gain by learning Astronomy, NGM College, Pollachi, March 17, 2009.
4) Why do we need to study Astronomy, Department of Physics, Pondicherry University, March 20, 2009.

(b) Sky watching:

Using the 6" telescope given by IUCAA, sky watching has been started in the Department students could photograph the images of moon, Saturn with ring and satellites. Research Scholars of the Astrophysics group: Vivek M., Nijo Varghese, R. Tharanath, and Sanish Sebastian, have organized the sky watching sessions.

[2] North Bengal University, Siliguri
(Coordinator : B. C. Paul)

The faculty members, research scholars and M.Sc. students of the department, as well as visitors from different colleges and neighbouring universities used the facilities available at IRC, Physics Department, N.B.U. The college teachers have visited the centre for carrying out collaborative research work on Cosmology and Astrophysics. IRC, N.B.U. has organized several seminar talks at different times of the year and a seminar on "Recent Advance in Physics and Astrophysics" during this period. About 101 participants from different colleges and universities including P.G. students, research scholars and faculty members of Physics Department, N.B.U., have participated in this seminar. The centre has been organizing group discussions and seminars by the local resource persons regularly.

Talks :

S. Ananthakrishnan : *Introduction to Astronomy, Radio-Astronomy, the Giant Metrewave Radio Telescope of India,* April 01.

A.Bandyopadhyay : *A New Kind of Science*, December 12.

S. Mukherjee : *Boson Star and the Dark Matter,* December 22.

G.Majumder : *Large Hadron Collider,* February 24.

Visitors:

P. K. Chattopadhyay (Alipurduar College), S. Mukherjee (Kolkata), N.K. Dadhich (IUCAA, Pune), A.N. Ramaprakash (IUCAA, Pune), A. S. Majumdar (SNBNCBS, Kolkata), S. Pal (ISI, Kolkata), R. Koley (IACS, Kolkata), S. Karmakar (Jalpaiguri), S. K. Nath (B. H. College, Assam), P. K. Halder (Dinhata College), S. Tamang (Sikkim Govt. College), P. Sarker (Alipurduar College), B. Raychaudhuri (Surya Sen College, Siliguri), K. C. Dey (A. B. N. Seal College, Cochbehar), C. L. Bhutia (Darjeeling Govt. College), A. Tamang (Kurseong College), I. D. Lepcha (Sikkim Govt. College), P. Thakur (Alipurduar College), D.Ghosh (St. Joseph's College), A. Saha (Darjeeling Govt. College), S. K. Gupta (Darjeeling Govt. College), G. Majumder (TIFR).

Other Activities :

Seminar/Workshop Organized:

The IRC and Physics Department, N.B.U. jointly have organized a seminar on advance in Physics and Astrophysics (March 16-17).

The Speakers were :

N. K. Dadhich: Universal Velocity and Universal Force.

R. N. P. Choudhury : Advances on Multifunctional Materials.

R. Paul: An Introduction to Liquid Crystal.

S. Mukherjee: Concept that Inspired Modern Cosmology.

A. N. Ramaprakash: Adaptive Optics Techniques in Astronomy.

Archan S. Majumdar: Cosmology with Black holes - Probe of new Physics ?

S. K. Bhadra: Recent Advances in Fibre Optics : Optical Communication to Fibre Laser.

S. M. Bhattacharjee: DNA Phase Transitions: Melting Vs. Unzipping.

S. Pal: Cosmology with Higher Dimensions : Why anyway?

R. Koley: Standard Model Fields and Gravity in Warped Spacetime.

Public Outreach :

B. C. Paul has given popular lectures on

Mystery of the Universe and LHC, North Bengal Science Centre, Siliguri, Dec. 21.

Viswa Bramhander Rahasya O LHC, Surya Sen Mahavidyalaya, Siliguri, Dec. 19.

On Non-conventional Sources of Energy, ABN Seal College, Coochbehar, Feb 27 (sponsored by West Bengal Govt.).

No.of Publications : 07

[3] Delhi University
(Coordinator : T. R. Seshadri)

Talks :

Shruti Thakur: *Review of Singularity Problem with f(R) Dark Energy, by Froloy,* March 5.

Jasjeet Singh Bagla (HRI, Allahabad): *Hyperfine Transition of Helium-3: A Probe of the High Redshift Universe,*
March 12.

Somasri Sen (CTP, Jamia Milia Islamia): *Randall-Sundrum Scenario with Bulk Torsion and Bulk Dilaton,*
March 19.

Visitors:

Madhavan Varadharajan (RRI, Bangalore), Jasjeet Singh Bagla (HRI, Allahabad).

[4] Pt. Ravishankar Shukla University, Raipur
(Coordinator: S. K. Pandey)

Astronomy and Astrophysics has been one of the major areas of research activity in the School of Studies in Physics since inception. It is worth mentioning that Pt. Ravishankar Shukla University is among a few universities in India, and the only one in the new state of Chhattisgarh, where teaching and research is carried out in the School of Studies in Physics. The year 2009 is declared as the International Year of Astronomy and the IRC, Raipur has been actively engaged in arranging many seminars by visiting members from different institutes of India notably J. V. Narlikar, Ajit K. Kembhavi, and N. K. Dadhich, D. K. Shrivastava, and also by S. K. Pandey.

It is a matter of great joy and pleasure for all of those who are involved in the activities of IRC for the past 10 years, that the coordinator S. K. Pandey has now assumed the charge as the Vice Chancellor of Pt. Ravishankar Shukla University, Raipur. It is needless to say that this will be a great boost towards the future activities of IRC, Raipur.

Research : The research interests of the faculty members and the research students are:

(i) D. K. Chakraborti, with his research students Firdous, Arun Singh and Arun Diwakar has actively engaged in the estimates of the intrinsic shapes of the light distribution of the triaxial galaxies. They found that using photometric data and models, flattening at inner and outer radii and the absolute value of the triaxiality difference could be constrained by using the methodology of Bayesian statistics. A paper "Distribution of Intrinsic Shapes of Elliptical Galaxies" was presented by Arun Singh at the IIIrd International Meeting on Fronties of Physics, 2009, held at Ku alampore, and this paper will appear soon in American Journal of Physics.

Recently the group (Arun Diwakar and D. K. Chakraborti) is engaged in constraining the viewing angles of the elliptical galaxies. This will exhibit the relationship between the photometric shape and the intrinsic shapes of ellipticals.

(ii) S. K. Pandey, along with his collaborators has continued research work on multiband surface photometry of galaxies. Faint outermost region of the galaxies from the Large Format Camera (LFC) field is currently under investigation. A sample of 266 galaxies was selected from the LFC field SDSS 1208, with sufficient brightness and size to ensure reliable morphological study. A sub-sample of 180 early-type galaxies was chosen for isophotal study using the value of bulge-to-total luminosity ratio obtained from the 2-dimensional bulge-disk decomposition.

(iii) Newly appointed lecturer, Nand Kumar Chakradhari has been also continuing his work, which he was doing at ISRO-ISAC, Bangalore, as a JRF. His work consists of study of short period chemically peculiar variable stars.

Lectures/Talks :

N. K. Dadhich: Relativity: *A Common Sense Perspective, and Science and Society*, at School of Studies in Physics, March 20. (2 lectures)

Ajit K. Kembhavi: *Large and Extremely Large Telescopes*, at School of Studies in Physics, March 20, and Galileo to Einstein: a journey over 400 years at Govt. B. Ed. College, Raipur, March 21.

A live interaction programme on IYA-2009 by N.K. Dadhich, A. K. Kembhavi, S. K. Pandey was organized at SCERT, Raipur using EDUSAT.

Series of lectures and public talks were given by J.V. Narlikar, on his 7- day visit to Raipur during February 8-16. It includes

(i) February 09 : Live Interaction with School Children and Teachers, Venue: Govt. Higher Secondary School, Raipur.

(ii) February 10 : A Critique of the Big Bang Cosmology, Venue : School of Studies in Physics, Pt. Ravishankar Shukla University, Raipur.

(iii) February 11: (a) Lecture cum interaction programme with school students and teachers, Venue : Kala Mandir, Bhilai, (b)Public Lecture on the topic : Origin of Life in the Universe, at Universtiy Auditorium, Raipur

iv) Chhattisgarh Vigyan Sabha and IRC, Raipur, organized informal interaction programme of J. V. Narlikar and Mangala Narlikar with School/College students and teachers on his way to Jagdalpur, in Bastar region as well on way back to Raipur during February 12-15.

S. K. Pandey, Chhattisgarh Vigyan Sabha, Raipur on the occasion of International Year of Astronomy–2009, January 01.

S. K. Pandey, Chhattisgarh College, Raipur on the occasion of International Year of Astronomy -2009, January 27.

D. K. Shrivastava, from Variable Energy Cyclotron Centre, Kolkata, gave a series of three lectures on his 3- days visit to Raipur. The topics of his talks were : Physics questions at Large Hadron Collider, Physics of Relativistic Heavy Ion Collision, and Nuclear Physics and Our Planet, November 17-19, 2008.

Visitors

Vijay Mohan, (IUCAA, Pune.), Arvind Paranjpye, (IUCAA, Pune.), Manoj Patel and Vinod Prasad, (Gorakhpur University), T. Padmanabhan, (IUCAA, Pune), D. K. Shrivastava (VECC, Kolkata), J. V. Narlikar, (IUCAA, Pune), N. K. Dadhich, (IUCAA, Pune) and Ajit Kembhavi, (IUCAA, Pune).

Other activities

Sky Gazing Programme : Regular sky gazing programme for students of the Department/University, students from local Schools/Colleges as well as for the general public. IRC, Raipur has procured a 6", Sky Watcher Telescope, from IUCAA.

Project work in Astronomy :

During the year, Eight final year students of the Department, who had offered A & A as the specialization for their M.Sc. course used IRC facilities (INTERNET and library) in carrying out their project work; this includes observational exercises using the observing facility (8" CGE series telescopes from Celestron with photometer, CCD camera and CCD spectrograph) as well as data analysis using archival data. One of the M. Phill. students also has done his dissertation in A & A.

Student's seminar :

M. Sc., M. Phill. students of the department make use of IRC facilities for the preparation/presentation of weekly seminars organized in the department.

Workshop/Conferences attended

Laxmikant Chaware attended COSPAR meeting held at Kuala Lumpur, Malaysia during June 1-14, 2008.

Arun Singh presented a paper at IIIrd International Meeting on Frontiers of Physics, 2009, held at Kuala Lumpur

A Failed World View
by
Professor Amit Bhaduri

Twentieth IUCAA Foundation Day Lecture delivered on December 29, 2008

A badly kept secret among economists should be shared with non-economists on this occasion. Economic theory, in so far as it consists of results derived logically from clearly stated premises, is mostly precautionary knowledge which warns against unfounded economic propositions. Very rarely, it is positive knowledge for guiding policies. There is even more fuzzy area of economic knowledge, which infers from quantitative data through statistical techniques and historical analogies. Such knowledge is even more tentative, yet essential in a subject like economics, where controlled experiments are impossible. With data generated over time subject to observational error, bias, and random shocks, we would do well to remember the saying of the Greek philosopher Heraclitus, a rough contemporary of Buddha, “It is never possible to step twice into the same river.”

As a body of inexact knowledge economics requires us to be intellectually modest, and that leaves little room for inflexible views. And yet, exactly the opposite happens. Driven by ideology or vested interests, politicians, captains on industry, media men, spokespersons of the chambers of commerce, labour unions and even academic economists posture with absolute confidence, often to mislead the public for their own interest, and conveniently change suddenly, again to suit their interest in a changed situation. Flexibility in views is necessary in economic policy making, but only if one is willing to learn honestly also from one’s past mistakes. The problem with most politicians changing suddenly their views is that they change only their posture, but not their ideology. Their interests remain the same. Otherwise, how can we explain our Prime Minister on his recent return flight from China telling his captive audience on board that, he foresaw the current financial crisis 18 months ago, while on March 18, 2006 he told a global audience that the Reserve Bank of India would prepare a road map on full capital account

Professor Amit Bhaduri delivering the twentieth IUCAA Foundation Day Lecture

convertibility to integrate the Indian financial system completely with the global capital market, but now he talks of insulating India. And even now he talks of the rescuing role of the IMF and the World Bank (Times of India, October 26, 2008), while these two institutions with their continuous support for financial liberalization has all along been part of the problem. As a matter of fact, until the global financial crisis gripped the world, our ‘dream team’ of policy makers including the current Prime Minister, Deputy Chairman of the Planning Commission and the then Finance Minister insisted on speedier liberalization of the financial sector, with measures like capital account convertibility, greater presence of foreign banks and insurance companies with freedom to shift funds. Now they want to take credit for being prudent and slow in introducing reforms, making the nationalised banks safer, etc. Politicians may be right in believing that public memory is short, but perhaps would find that it was not that short! Women and men in practical affairs pretend to know and change posture to suit the situation, but it should be the job of economists to call the bluff. We have not done too well on that count. As a well-known economist once said, “Some knowledge of economics is useful, if only to guard against being fooled by other economists.” Amidst the global financial crisis and the quick u-turn taken by our so-called economic technocrats in the government, I am often reminded of the intrinsic wisdom of this statement.

It is remarkable that despite the inexactitude of economics as a body of knowledge, which should have left enough space for some if not several contesting economic ideologies, over the last twenty years or so, all the major political parties in India cutting across the spectrum from the Left to the Right largely converged to a very similar point of view on economic management. While differentiating themselves mostly by rhetoric, they came to subscribe to the view that globalization, market based liberalization and corporate led industrialization were inevitable compulsions for economic development in India. Consequently, they all sought foreign investments and funds on whatever terms, accepted World Bank-IMF views of growth and equity, and engaged in a race to the bottom by offering competitively favourable terms to attract large corporate houses in the states, where they were in power. In short the TINA syndrome that, There Is No Alternative, gripped economic action as well as imagination. For the traditional Left, recent history explains part of it. The failure of Soviet style bureaucratic central planning, u-turn of officially socialist China and Vietnam in embracing capitalist style policies, undermined confidence in old fashioned socialist ideas. Economic success stories of countries like South Korea, Singapore, Taiwan, Malaysia, and Hong Kong pointed to attractive possibilities. Nevertheless, in the orchestrated celebration of the market economy, one tends to forget this story is one-sided. It is inconvenient for a pro-market economist to remember that most countries of sub-Saharan Africa, of Latin America, of central Asia underwent dramatic economic stagnation or decline for several years by embracing the same principle of market based liberalization (Maddison, 2001).

With economic history seldom giving unambiguous answers, economic theory has to play a critical role in making our inexact knowledge appear more plausible in the service of economic ideology. The ideology of the self regulating free market that came to rule the world and is commonly known as neo-liberalism has its origin in the idea of perfect competition as the prototype market form. We all know markets involve buying and selling, activities which are organized under certain rules that vary enormously, say from the weekly village market to the Stock Exchanges in Dalal Street or Wall Street. Economists study the properties of the market organization by taking a perfectly competitive market as their point of reference. Under highly unrealistic assumptions, which rules out for instance all forms of uncertainty and banishes the unknown future from the analysis, some results are obtained. It is shown that an equilibrium set of prices exist, which simultaneously clears all markets by equating demand and supply. The prices in equilibrium correspond to an efficient arrangement in the sense that the production of no commodity can be increased further without decreasing the production of some other, and no participant in the market can do better either as a producer or consumer, without someone else becoming worse off. The powerful ideological metaphor is that of the invisible hand of the self regulating market leading the society of selfish individuals to an optimum. This is indeed a most spectacular case of self organization, where neither any intervention of the state nor any concern for the collective expressed in social norms like trust and fellow feeling is needed to reach the optimum economic state. Margaret Thatcher, the former Prime Minister of Britain and a main architect of the neo-liberal world view famously echoed this sentiment by claiming that there was no society, only individuals.

However, even this mythical land of perfection, competition is flawed on its own terms. The optimum equilibrium that is shown to exist under idealized conditions does not guarantee that the distribution of income in the society would be tolerably good. To appreciate its practical implications, remember demand depends on the purchasing power of individuals, so a grotesquely unequal distribution of income under competitive conditions might mean millions of children dying from easily treatable diseases like malaria and T.B., while most expensive hospitals in the metropolis provide state-of-the-art treatment at a price which only the rich can afford. Villages go without sanitation and drinkable water, but selected areas of cities might pride themselves with world class luxury apartments and glittering malls. And yet, by the logic of the market, any such equilibrium would still be considered optimum, because it allocates resources efficiently, and the poor in the city slums or in the villages cannot be made better off without hurting the rich in the cities.

A deeper logical flaw is that the stability of the equilibrium in a competitive market is not guaranteed without imposing further stringent conditions, and it remains unspecified how long it would take to converge to it. This is a political catch. A decision maker in a democracy, say a Prime Minister, can always say that economic reforms are about to produce results without specifying the time horizon. Like a dictator, the competitive market can go on promising without delivering, as it is without accountability within any specified time period. In this sense the market as an institution has no accountability except for the largely make belief ideology of self regulation. This is the fundamental difference between the market and democracy in so far as in a democracy, there is some reckoning at the time of elections. I need only to remind you that market based reforms did badly in India on that count. The slogan of “Shining India” crashed in the last general election, and the present Prime Minister, widely considered the guru of India’s market oriented reforms, could not personally win an election.

Enthusiastic reliance on the market mechanism as the main driving force of efficient resource allocation and growth by the government accentuated poverty to create rumblings outside the electoral process in the countryside which often spills over into desperate fury and despair. Over hundred thousand farmers have committed suicide over the last decade or so. According to government estimates, some 125 districts, spread over 12 states, and covering more than a quarter of the land mass mostly in the central part of India, is affected by extremist Naxalite activities. The Dalits (16 percent) and the Adivasis (8 per cent), approximately one quarter of the population provide the main support to these movements, suggesting a combination of economic and socially oppressive factors as a major cause. Despite near double digit growth for more than a decade and a half, available estimates suggest that more than one third of the Indian population live in sub-human poverty (a recent World Bank estimate puts nearly 42 per cent as absolutely poor by international standard), more than three fourths of the population has a daily purchasing power of less than Rs. 20 a day, nearly half the children are undernourished and many crippled by undernourishment, anemia is on the increase among women, and food deprivation in the countryside has not decreased in the last two decades. And all along the logic of the market has been encouraged by government policies to work relentlessly against the poor majority through three major routes.

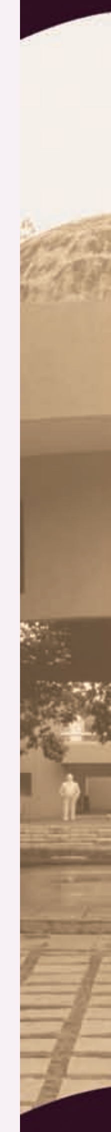
First, is the extraordinarily slow growth in regular employment. Regular employment in the organised sector over the last decade or so grew at only about 1 percent, while the rest of the average 6- 7 percent growth in GDP came from the growth in output per worker or labour productivity. In contrast, during the earlier decades, when GDP grew on an average at less than 4 percent, regular employment grew at the annual rate of 2 per cent. The recent drive to increase labour productivity is related to globalisation. International trade means increasing the importance of the external compared to the internal market, while corporations compete in the export market, mostly by cutting costs to increase their international competitiveness. This usually means shedding labour force through mechanisation. For instance, if the labour force in a corporation is downsized to half at the same wage, labour cost per unit of output would be also be halved. Let one example suffice to illustrate how this process is working in practice. Tata Motors in Pune reduced the number of workers from 35 to 21 thousand, but increased the production of vehicles from 129 to almost 312 thousand between 1999 and 2004, implying labour productivity increase by a factor of 4. The aggregate picture broadly conforms to this. According to the Economic Survey of the Government of India (2006-07), total employment in the organised sector declined from 28.2 million in1977 to 26.4 million in 2004, because the much talked about growth of the private organised sector under the reform policies of the government hardly compensated for the decline employment by the public sector. Another telling piece of evidence against the belief that, corporate-led industrialisation and greater direct foreign investment would promote more employment came from the headlines of The Times of India (July 7, 2008). Long hailed as most dynamic in these respects, a recent comparison of the various states of India suggested Gujarat and Maharashtra, have been among the slowest growing states in terms of creating either non-agricultural or manufacturing jobs.

With regular employment opportunities growing far too slowly compared to the number of job seekers, more and more people are being pushed to the unorganised sector. Agriculture, in particular, has become even more over-crowded. According to the

National Sample Survey (61st round), approximately 110 million agricultural workers (out of a total work force of 400 million) found employment for 209 days in 2004-05 compared to 220 days in 1999-2000. People desperate for a livelihood join the rank of the so called self-employed in the unorganised sector, the fastest growing category, marked by long hours of work with negligible earning, lack of any social security or labour protection and extensive use of child labour. More than half the hawkers of Kolkata, and more than one third the hawkers of Amhedabad belonging to this category of self employed are retrenched industrial workers, now threatened once more with the corporatisation of retail trade in this era of globalisation in the name of economic efficiency. This vast informal sector is increasingly becoming a refuge for people devoid of all hopes, and reminds one of the hell imagined by the great Italian poet Dante. On its gate is written, “You enter this land after abandoning all hopes”.

The **second** reason for growing inequality lies in the style of economic management pursued by the government. While opportunity for regular work is growing at a grossly insufficient pace despite a high growth rate of output, the government has become increasingly weary of spending more for social welfare like health, education, public distribution, and social security for the poor. Government expenditure remained more or less steady around 22 per cent of GDP throughout 2000-2007, with health receiving 1.4, and education receiving 2.9 percent of GDP on the average. The apparent reasons given are lack of ‘money’ and poor public delivery system for social services. However, these are superficial justifications, and there is a more compelling reason. which has come out into the open due to the financial crisis. Globalisation of finance made the government highly sensitive to the moods of the stock market and the financial sentiments of major players in that market. India has a relatively large foreign exchange reserve (283 billion U.S. dollars in February 2008), but unlike China, which has been enjoying export surplus for several years, our reserve comes mostly from capital inflows exceeding balance of payments deficits, like deposits from NRIs, and portfolio investments by various international financial institutions. These are far more fickle in nature and can be withdrawn at relatively short notice if the mood of the financial market turns sour. A main thrust of the pro-market government policy has been to keep the financial market happy by being on the right side of the IMF and the World Bank in so far as they have a central role in shaping international financial opinion for banks, credit-rating agencies, and other financial institutions. This means, following their economic guidelines in formulating policies. As a result, the government minimised its welfare spending by letting it stagnate as percentage of GPD even during the years of high growth. The cost of this squeeze of expenditure on social security, education, and health falls mainly on the poor, who cannot turn to the market due to lack of purchasing power and job opportunities.

The **third** route is paved by the style of industrialisation the government has increasingly adopted. It amounts to extending various privileges to the large corporations by the federal and state governments irrespective of their professed political colour as incentives for promoting corporate-led industrialisation. Land acquisition by the states (land is a state subject under the constitution) for ‘public purpose’ has become its politically most visible aspect. The central government all along has provided the legal and logistical support for land acquisition, and the original 1894 Land Acquisition Act proclaiming the ‘eminent domain’ status for the state, was significantly revised successively in 1952, 1963, and 1984, to give greater power to the government to acquire land for the defence sector, companies, cooperatives, and public sector companies. The present government has brought two related bills (of land acquisition amendment act, and rehabilitation and resettlement act, both under consideration of parliamentary standing committees) to extend in many ways further the reach of the government. They are all linked directly or indirectly to a view of the model of development for three major purposes, namely (a) mining, (b) land for industrial sites, and (c) Special Economic Zones, SEZ. First, consider the mineral rich usually forested land acquired mostly from the tribal populations, concentrated heavily in the states of Jharkhand, Bihar, Chhattisgarh, and Orissa. As has often been pointed out, these are some of the richest lands in the country where the poorest live. A piece of revealing statistics shows, mining displaces typically the poorest in the country, the adivasis or tribals, who constitute some 8 per cent of the population but account for nearly half of the people displaced in the name of development. The state apparatus takes recourse to silent violence in various ways. Forcible acquisition of land and dispossession is



obtained often through manufactured consent of the Gram Sabhas at gunpoint to comply formally with the legal requirements of the PESA Act (1996) relating to tribal areas. The public purpose is granting possession to private corporations of the iron ore rich land in Chhasttisgarh, Jharkhand, Madhya Pradesh, bauxite rich land of Orissa, prospect of diamond mine in Bastar, etc. MOUs (Memorandum of Understanding) between the large private corporations and the concerned state governments are seldom revealed despite applications under RTI (Right to Information) Act. The mining land taken from the locals at unilaterally announced low compensation price (that are frequently not paid) is handed over to large corporations and industrial houses often with supporting infrastructure provided by the government at public cost by displacing more people. A telling instance of public private partnership is the proposed SEZ comprising of 45 villages in Raigad district of Maharastra, which has been recently rejected almost unanimously in a referendum held in 22 villages. While the government had the area under notification for acquisition for a ‘public purpose’, in that very same area Ambani’s agents were privately trying to acquire land illegally with direct help from the Maharastra government.

It must be left for you to infer whether this is done only to pursue a model of industrialisation, or large money also changes hand benefiting our political class and many bureaucrats in this process. This is at least a part of the story behind the phenomenal growth in corporate wealth and dollar billionares in the country in recent years. Available statistics show that in hardly 4 years, between 2003-04 and 2006-07, the market value of capital of the companies listed on Bombay Stock Exchange grew almost three hundred percent, while until the recent stock market crash (October, 2008) India with the majority of its population desperately poor could perversely boast of the highest number of dollar billionares after the United States. The logic of a liberalised market mechanism buttressed further by state power to help the private corporations is relentlessly creating unprecedented inequality in India along with high growth. Sub-human poverty for millions, and billions of dollars for a handful of citizens has become the name of this game called development.

For this growth process to remain economically viable over time, slow growth of domestic purchasing power of the majority of the population must be countered by a compensating expansion either of our exports or expenditure by the rich. However, because our export exceeds import and we buy more from the foreigners than we sell to them, the net contribution of the foreign trade sector to the expansion of demand in our economy is negative. As a result, this anti-poor pattern of growth is being sustained by a rapid expansion of income and expenditure by the richer groups in the society (a maximum of top 20-25 per cent). The increasing inequality entailed in such a process of high growth means that the corporations sell their products and realise handsome profits by concentrating mostly on the production of goods consumed by the richer sections of the population. As a result, some 75 per cent of Indians with a daily per capita purchasing power of less than Rs. 20 have virtually no place in this corporate led modern economy as consumers. Their space as small rural producers or as small businesses in the unorganised sector also shrinks, as the goods produced for the high end of the market can mostly be produced only by corporations (e.g., cars, refrigerators, air conditioned malls, state-of-the-art hospitals, etc). Thus, growing inequality and lack of employment opportunities are coupled, and an output composition oriented towards a rich minority of this country, tend to exclude the majority of our fellow citizens and often destroy their livelihoods. Thus, the big dams that we build, the electricity that we generate, the world class cities that we strive for divert even non-reproducible natural resources. The large corporate houses use them efficiently to produce and sell to the rich profitable products, but their efficient utilization of natural resources imply the exclusion of the poor both as producers and as consumers. The process of growth is sustained by growing inequality, and inequality reinforces growth in a mutually supportive manner. The Swedish economist Gunner Myrdal had called it “cumulative causation”, somewhat similar to the engineer’s system of strong positive feedbacks, the evolutionary biologist’s symbiosis between two species, and perhaps the notion of autocatalysis in chemical reactions.

While all this has been happening around us for quite some time, most of us refused to see it. The main stream English language media, largely owned and controlled by large corporate houses, condition us continuously to turn a blind eye and believe that the virtual economy of the hourly fluctuations in the stock market is far more news worthy than the growing inequality, despair and fury engulfing gradually the countryside. Most economists who should have known better fuelled this perception, and cheered politicians in power for the rapid emergence of India as a global economic power; and of course, politicians in power never tire of congratulating themselves for their own achievements. When the market boomed they took credit for liberalising the market, then as the market crashed they took credit for not liberalising the market! They took credit for forcing labour market flexibity of ‘hire and fire’ rule, when the market crashed the Prime Minister begged with the captains of industry in a specially called meeting not to fire workers near the time of election! This hypocritical politics have been going on as business as usual until the recent global financial crisis shook deeply the confidence in self-regulating free market capitalism with its global reach. The comfortable thought that more economic reform to deregulate the market and speedier integration with global market would lead us rapidly towards an optimal economic state is no longer fashionable. Like their counterparts in the U.S and Europe, pro-market reformers of yesterday are now looking for cover; they who had opposed now want more supervision and regulation of the market in India. However, this is only passing, because as an old English rhyme says: “Those who are convinced against their will, Are of the same opinion still.”

Neo-liberalism has merely gone out of sight, but not out of mind. Vested interests cryslallised around corporations are merely on the defensive at the moment.

We are still being misled to support a model of corporate led industrialisation financially helped by the state in difficult times as the way to our economic development, without questioning its relevance in the Indian context. A deep seated habit of thinking inculcated by the globalisation, privatisation and liberalisation rhetoric still wants us to believe that this market fundamentalism, practising developmental terrorism selectively on the poor, will ultimately help them as high corporate growth trickles down. To keep our conscience comfortable, it claims that the market can substitute for social ethics by deciding what is profitable to produce, and who should be in charge of production. So we no longer question how without extensive public action and state intervention in favour of the poor, in this country of overwhelming poverty the logic of political democracy of one adult one vote can be compatible with the logic of the market dictated by the rich with many more votes with their higher purchasing power than the poor. These are almost subversive questions; and yet, the ability to pose them is the first step to liberate ourselves from the ruling system of conventional economic wisdom that has failed us so badly despite the big show of producing precise technocratic economic knowledge, helped by various vested interests including the distribution of a disproportionately large number of Nobel Prizes to make market-oriented economic conservatism academically respectable. Long ago, in the introduction of his famous allegorical novel, The Animal Farm George Orwell had warned us that British democracy is not very different from the totalitarian monster he was describing in his book. Unpopular ideas, he said, can be suppressed without the use of force with two methods. First, the press is owned by wealthy men (read corporations these days!) who have every reason not to want certain ideas to be expressed. And the second reason, Orwell said, is a good education. If you have gone to the best schools (read specially the top management and economics schools), it has been instilled in you that, there are certain things it would not do to express or even to think. Aided by the media, our educated middle class showed its excellent education until recently by banishing all skeptical thoughts about the efficiency and intrinsic wisdom of the market, and the virtues of corporate led high growth under financial globalization. Would this global financial crisis give us the courage necessary to reeducate ourselves to view the ‘logic of the market’ more logically? For, at times the unintended effects of history can be beneficial.