INTER-UNIVERSITY CENTRE FOR ASTRONOMY AND ASTROPHYSICS

(An Autonomous Institution of the University Grants Commission)

Annual Report

(April 1, 2006 - March 31, 2007)

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HIGHLIGHTS OF 2006- 2007

This annual report covers the activities of IUCAA during its nineteenth year, April 2006-March 2007. 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 16 core faculty members (academic), 15 post-doctoral fellows and 20 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, active galactic nuclei, quasar absorption system, high energy astrophysics, galaxy and interstellar medium, stellar physics, solar physics, and instrumentation. These research activities are summarised in pages 17-53. The publications of the IUCAA members, numbering to about 76 in the current year are listed in pages 77-80. IUCAA members also take part in pedagogical activities like lectures, seminars, popularisation of science, etc., the details of which are given in pages 85-86 of this Report.

The extended academic family of IUCAA consists of about 85 Visiting Associates, who have been active in several different fields of research. Pages 54-73 of this report highlight their research contributions The resulting publications, numbering to about 88 are listed in pages 81-84 of this report. A total of about 1265 person-days were spent by Visiting Associates at IUCAA during this year. In addition, IUCAA was acting as host to about 495 visitors through the year. During the current year the Visiting Associates were drawn from over 60 universities and colleges from all over India. The Visitors to IUCAA came from over 100 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, one student has successfully defended her thesis and obtained Ph.D. degree from the University of Pune during the year 2006-2007. Summary of her thesis appears in pages 74 - 76.

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 7 such events in IUCAA and 6 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 6000 people visited IUCAA.

These activities were ably supported by the scientific and technical, and administrative staff (21 and 32 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, and instrumentation lab. A brief update on these facilities is given on pages 112-119 of this Report.

The IUCAA Girawali Observatory was dedicated to astronomy research and education by Professor Yash Pal on May 13, 2006. The Optical Astronomy activity is poised for further strengthening in another front. IUCAA has taken partnership in Southern African Large Telescope (SALT) paying for about 6% of the observing time which translates to about 15 nights a year. This 10 metre class telescope, run by a Consortium of universities and institutes, will help IUCAA to do cutting-edge research in this field.

T. Padmanabhan
Editor

The Council and the Governing Board

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(As on March 31, 2007)

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University Grants Commission, New Delhi.

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Member Secretary

Naresh Dadhich,
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The following members have served in the Council for part of the year

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A.N. Basu,
Vice-Chancellor,
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North Bengal University, Siliguri.

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(As on March 31, 2007)

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T.R. Kem
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K. Ramamurthy Naidu
Rajaram Nityananda
Amitava Raychaudhuri
R.C. Sobti
Ajay K. Sood

Member Secretary

Naresh Dadhich

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

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A. Hewish,
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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,
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North Bengal University, Siliguri.

Anvar Shukurov,
University of Newcastle, UK

Alexei Starobinsky,
Landau Institute for Theoretical Physics, Russia.

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Ashoke Sen,
Harish-Chandra Research Institute, Allahabad.

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Assam University, Silchar.

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

T. Padmanabhan,
IUCAA, Pune.

Shantanu Rastogi,
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H.P. Singh,
Department of Physics and Astrophysics,
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Anwar Jahan Zuberi,
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Ranjan Gupta
A. K. Kembhavi
Ranjeev Misra
M. Parikh (from 17.11. 2006)
A.N. Ramaprakash
S. Ravindranath
Varun Sahni
Tarun Souradeep
R. Srianand

K. Subramanian
S. N. Tandon

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

The Finance Committee

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

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T. Padmanabhan (Dean, Core Academic Programmes)
A.K. Kembhavi (Dean, Visitor Academic Programmes)
J. Bagchi
S.V. Dhurandhar
R. Gupta
R. Misra
M. Parikh (from 17.11. 2006)
A.N. Ramaprakash
S. Ravindranath
V. Sahni
Tarun Souradeep
R. Srianand
K. Subramanian
S. N. Tandon

Emeritus Professor

J.V. Narlikar

Scientific and Technical

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S.S. Bhujbal
M.P. Burse
S.B. Chavan
V. Chellathurai
K.S. Chillal
P.A. Chordia
H.K. Das
S. Dhurde
S. Engineer (till 15.11.2006)
G.B. Gaikwad
S.U. Ingale
A.A. Kohok
V.B. Mestry
V. Mohan
N. Nageswaran
A. Paranjpye
S. Ponrathnam
V.K. Rai
H.K. Sahu
Y. R. Thakare

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K. C. Nair (Senior Administrative Officer)
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V.P. Barve
S.K. Dalvi
S.L. Gaikwad
B.R. Gorkha
B S. Goswami
S.B. Gujar
R.S. Jadhav
B.B. Jagade
S.M. Jogalekar
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S.B. Kuriakose
N.S. Magdum
M.A. Mahabal
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R.D. Pardeshi
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M.S. Sahasrabudhe
V.A. Samak
S.S. Samuel
B.V. Sawant
S. Shankar
D.R. Shinde
V. R. Surve
D.M. Susainathan
S.R. Tarphe
S.K. Waghole
K.P. Wavhal

Post-doctoral Fellows

Vivek Kumar Agrawal (till 07.04.06)
S. Barway
S. Basak
R. Gopal (from 21.08.06)
S. Joshi
M. Joy
R. Koley (from 20.11.06)
S. Pal (from 09.01.07)
B. Pandey (from 11.10.06)
A.K. Ray (from 03.08.06)
Subharthi Ray
Suryadeep Ray (till 10.07.06)
S. Roychoudhury (till 17.04.2006)
P. Subramanian (till 21.04.2006)

Post-doctoral Fellows (Project)

P. Hasan (Indo-French Project) (till 31.07.2006)
R. Sinha (Virtual Observatory Project)

Research Scholars

M. Aich (from 07.08.06)
A. Bora
S. Chakravorty
H. Chand (till 31.07.2006)
S Chatterjee (from 04.08.06)
A. Deep
T. Ghosh (from 01.06.06)
D. Kothawala

S. Kumar (from 07.08.06)
G. Mahajan
S. Mitra (till 29.12.2006)
H. Mukhopadhyay
T. Naskar
A. Rawat
P. K. Samantray (from 13.10.06)
S. Samui
S. Sarkar
A. Shafieloo
M.K. Srivastava
S. Sur

Temporary/Project/Contractual Appointments

M. S. Kharade (Project Officer , ERNET Project)
S.B. Koshti (Project Scientist, DST WOS -A Project) (till 14.12.2006)
P.L. Shekade (System Engineer)
P. Barathe
A. Durgade
P. Gaware (from 17.11.06)
A.P. Kadam
V.P. Kulkarni
V. Mhaiskar
D. Nandrekar
S. Panchal (from 21.02.07)
S.M. Prabhudesai
A. Rupner
S. Sagar
M. Shaikh

Part time Consultant

V. S. Savaskar (Medical Services)

Long Term Visitor

Arvind Gupta

Visiting Associates of IUCAA

G. Ambika,
Department of Physics,
Maharaja's College, Kochi.

Bindu A. Bambah,
School of Physics,
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N. Banerjee,
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Jadavpur University, Kolkata.

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Suresh Chandra,
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Asis Kumar Chattopadhyay,
Department of Statistics,
Calcutta University.

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

Sarbeswar Chaudhuri,
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Gushkara Mahavidyalaya, Burdwan.

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

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

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D.V. Gadre,
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BITS, Pilani.

P.S. Goraya,
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Ashok Goyal,
Department of Physics,
Hansraj College, Delhi.

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

N. Ibohal,
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S.S.R. Inbanathan,
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Naseer Iqbal Bhat,
PG Department of Physics,
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S. Mukherjee,
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Anirudh Pradhan,
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M.B. Govt. P.G. College, Haldwani.

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Cochin University of Science and Technology, Kochi.

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Saibal Ray,
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Punjab University, Chandigarh.

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

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

T.R. Seshadri,
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University of Delhi.

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

Pankaj Kumar Shrivastava,
Department of Physics,
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G.P. Singh,
Department of Mathematics,
Visvesvaraya National Institute of Tech., Nagpur.

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

Yugindro Singh,
Department of Physics,
Manipur University, Imphal.

D.C. Srivastava,
Department of Physics,
D.D.U. Gorakhpur University.

Pradeep K. Srivastava,
Department of Physics,
DAV PG College, Kanpur.

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

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

J.P. Vishwakarma,
Department of Mathematics and Statistics,
D.D.U. Gorakhpur University.

Till July 31, 2006

Badruddin,
Department of Physics,
Aligarh Muslim University.

Siddhartha Bhowmick,
Department of Physics,
Barasat Government College,Kolkata.

Umesh Dodia,
Department of Physics,
Sir P.P. Institute of Science, Bhavnagar.

Abhinav Gupta,
Department of Physics,
St. Stephen's College, Delhi.

Manoranjan Khan,
Centre for Plasma Studies,
Jadavpur University, Kolkata.

Ashok Mittal,
Department of Physics,
University of Allahabad.

Udit Narain,
Astrophysics Research Group,
Meerut College.

Santokh Singh,
Department of Physics,
Deshbandhu College, New Delhi.

P.K. Suresh,
School of Physics,
Universtiy of Hyderabad.

From August 1, 2006

B.R.S. Babu,
Department of Physics,
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Sukanta Dutta,
Department of Physics and Electronics,
Sri Guru Tegh Bahadur Khalsa College, Delhi.

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

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

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

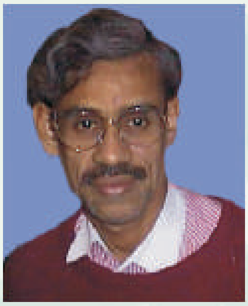
C.D. Ravikumar,
Department of Physics,
University of Calicut.

Sanjay Kumar Sahay,
Department of Physics,
Birla Institute of Technology and Science,
Pilani, Goa Campus.

M. Sami,
Department of Physics,
Jamia Millia Islamia, New Delhi.

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

The seventeenth batch of Visiting Associates, who were selected for a tenure of three years, beginning August 1, 2006.



B.R.S. Babu

Sarbari Guha

Joe Jacob

C.D. Ravikumar

Sanjay Kumar Sahay

The photographs of the following Visiting Associates from the seventeenth batch are not available: Sukanta Dutta, Avinash Khare, M. Sami, and M. Sivakumar.

Appointments of the following Visiting Associates from the fourteenth batch were extended for three years : Shyamal Kumar Banerjee, Dhananjay V. Gadre, Ngangbam Ibohal, Deepak Jain, Moncy V. John, Bikash Chandra Paul, Sandeep Sahijpal, Asoke Kumar Sen, K. Shanthi, and Gyan Prakash Singh.

Organizational Structure of IUCAA's Academic Programmes

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N.K. Dadhich

Dean, Core Academic Programmes
(T. Padmanabhan)

Head, Pedagogical Programmes
(K. Subramanian)

Head, Computer Centre
(A.K. Kembhavi)

Head, Library
(V. Sahni)

Head, Publications
(T. Padmanabhan)

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

Head, Telescope and Observational Programmes
(R. Srianand)

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, Recreation Centre
(P. Chordia)

Head, Guest Observer Programmes
(R. Srianand)

Director's Report

This year opened with an important event, the inauguration of IUCAA Girawali Observatory (IGO) on May 13, 2006 and the dedication of the IUCAA 2-metre Telescope to astronomy research and education in the country by Professor Yash Pal. It was he who envisioned that world class facilities should be accessible to faculty and students for revamping and strengthening academic environment in the universities. It is hoped that IGO will give a new boost to observational astronomy and many young students will take up careers in this exciting field.

This was followed by yet another important development. IUCAA can now boast of one of the most enthusiastic and vibrant observational groups in optical astronomy and it is, therefore, natural to look for bigger and more challenging avenues. This came in the form of Southern African Large Telescope (SALT) seeking partnership. It is a 10-metre class telescope, which is run by a consortium of universities and institutes, each having a share in the observing time according to the contribution one makes. IUCAA has bought 6% of observing time, which translates to about 15 nights a year. It is indeed exciting as well as challenging to do cutting edge astronomy with such a frontline instrument.

IUCAA believes in taking up challenges and I am confident that IUCAA and university colleagues will measure up to this one. I envisage a new band of young and highly motivated students coming forward to use SALT and other facilities. This will indeed bring astronomy to the centre stage in higher education and research. That was what precisely IUCAA was meant to achieve; so we are on the right track.

I am very happy to say that international collaborations are building up, and IUCAA-MPA (Max Planck Institute for Astrophysics, Garching, Germany) workshop on Astrophysics and Cosmology in March 2007 was a concrete example of this. The workshop was very successful in which, besides universities, scientists from other institutes also participated. This series of workshops is supposed to alternate between IUCAA and MPA. It has been envisaged that there would be exchange of students, post-docs and faculty members between the two institutes based on the collaborative research projects. One of the IUCAA students is already on a visit to MPA under this informal arrangement. I see many more such informal collaborations on the anvil with various other centres of excellence.

In my first Director’s report in 2004, I had said to the IUCAA Visiting Associates from universities that it was now the time for consolidation and orientation to relevant and interesting studies in the mainstream astronomy and astrophysics. This still has a long way to go. I would once again like to reiterate this sentiment in all earnestness and would appeal to my university colleagues to take it in the right spirit.

I am particularly grateful to Dr. Anil Kakodkar for accepting to be the Chairman of the Governing Board of IUCAA. His guidance and support in all our programmes have been most invaluable. In particular, his enthusiastic support to IUCAA’s participation in SALT project was not only helpful but was indeed inspiring enough for us to think of even bigger and more challenging projects. His wisdom and sagacity on the one hand and friendliness and camaraderie on the other are indeed most cherished and enlightening.

I have been very lucky in having matching appreciation and understanding of our projects, and support in particular SALT, from Professor Sukhdeo Thorat, President, Council of IUCAA and Chairman, UGC. For that, I am grateful to him and thank him very warmly. I would also like to appreciate the understanding and consideration shown by UGC officers, in particular for the expeditious processing of the SALT project.

Naresh Dadhich

Congratulations to ...

Hum Chand

R.K. Bhalla Award of Indian Physics Association (Pune Chapter), 2006.

Dawood A. Kothawala

Shyama Prasad Mukherjee Fellowship of CSIR, 2006.

Ranjan Gupta

Elected as the Secretary for ASI for the triennium 2007-2009.

Jayant Narlikar

Sohrab Godrej Memorial Oration Award from the Rotary Club of Bombay, Mumbai, 2006.

Vocational Excellence Award from the Rotary Club of Thane Hills, Thane, 2006.

H.K. Firodia Award from the H.K. Firodia Memorial Foundation, Pune, 2006.

T. Padmanabhan

Padma Shri from the President of India, 2007.

Third Prize in the Gravity Research Foundation Essay contest, 2006 .

Elected as the Vice-President (2006-09) and the President-Elect (2009-2012), Commission 47 on Cosmology of the International Astronomical Union.

Tarun Souradeep

Swarnajayanti Fellowship of DST, 2006.

SCOPUS Young Scientist Award for Physics of Elsevier, India, 2006.

Buti Foundation Award of Indian Physics Association, 2006.

R. Srianand

Vainu Bappu Gold Medal of the Astronomical Society of India, 2004.

T. Padmanabhan receiving the *Padma Shri* from Dr. A.P.J. Abdul Kalam, the President of India.

Welcome and Farewell

Welcome to...

Russell Cannon, from Anglo-Australian Observatory, Australia, as an Honorary Fellow of IUCAA.

Maulik Parikh, who is the new addition to IUCAA Faculty.

V. Mohan, who is the new addition to Scientific and Technical staff.

Rajesh Gopal, **Ratna Koley**, **Supratik Pal**, **Biswajit Pandey** and **Arnab Kumar Ray**, who have joined IUCAA as Post-doctoral Fellows.

Moumita Aich, Archana Bora, Saugata Chatterjee, Tuhin Ghosh, Sandeep Kumar and **Prasant Kumar Samantray**, who have joined IUCAA as Research Scholars.

… Farewell to

Vivek Kumar Agrawal, who has joined the Indian Space Research Organisation (ISRO) as a Scientist.

Amrit Lal Ahuja, who has joined the Indian Institute of Information Technology, Hinjewadi, Pune.

Hum Chand, who has joined as a Post-doctoral Fellow at Institut d'Astrophysique de Paris (IAP), France.

Priya Hasan, who left at the conclusion of the project.

Sanjit Mitra, who has joined as a Post-doctoral Fellow at Observatoire de la Cote d'Azur, Nice, France.

Suryadeep Ray, who has joined at CGG India Pvt. Ltd., Mumbai.

Suparna Roychowdhury, who has joined Raman Research Institute, Bangalore, as a visiting fellow.

Prasad Subramanian, who has joined Indian Institute of Astrophysics, Bangalore.

Calendar of Events

2006

April 17-May 26	**School Students' Summer Programme** at IUCAA, Pune
May 5	**IUCAA-NCRA Graduate School** Second semester ends
May 13 -14	**IUCAA Girawali Observatory Inauguration, Dedication, and Symposium** at IUCAA, Pune
May 15-June 16	**Introductory Summer School on Astronomy and Astrophysics** for College/University students at IUCAA, Pune
May 15-June 30	**Vacation Students' Programme** at IUCAA, Pune
August 7	**IUCAA-NCRA Graduate School** First semester begins
September 10-12	**Workshop on Astronomy for Engineers** at Siliguri Institute of Technology, Sukna
September 12-15	**Workshop on Stars and Galaxies: Observational Techniques and Data Analysis** at North Bengal University, Siliguri and Sikkim Govt. College, Gangtok
October 4-14	**Workshop on Advanced Topics in Data Analysis in Cosmology and Gravitational Wave Astronomy** at IRC, Delhi University
November 2-4	**Discussion Meeting on Nonlinear Phenomena and Techniques** at IUCAA
December 8	**IUCAA-NCRA Graduate School** First semester ends
December 20-24	**Introductory Workshop on Astrophysics** at Mohanlal Sukhadia University, Udaipur
December 29	**Foundation Day**

2007

January 8	**IUCAA-NCRA Graduate School** Second semester begins
January 8-10	**Workshop on Understanding the Universe** at Utkal University, Bhubaneswar
January 17-18	**Introductory Workshop on Astronomy and Astrophysics** at K.T.H.M. College, Nashik
February 12-26	**Indo-French Training School in Optical Astronomical Observations** at IUCAA
February 28	**National Science Day**
March 5 - 9	**IUCAA-MPA Workshop on Astrophysics and Cosmology** at IUCAA

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 italics.

Quantum Theory and Gravity

Gravity as an emergent phenomenon

T. Padmanabhan is continuing his programme of investigating the thermodynamic, continuum, limit of quantum gravity, which is expected to be reasonably independent of the detailed microstructure of spacetime. This leads to a very novel perspective on quantum — and even classical — gravity. Details of this formalism have been reported in the annual reports of previous years and the progress during the current year is highlighted below.

The null surfaces of a spacetime act as one-way membranes and can block information for a corresponding family of observers (timelike curves). Since lack of information can be related to entropy, this suggests the possibility of assigning an entropy to the null surfaces of a spacetime. *Padmanabhan* (in collaboration with A.Paranjape) has motivated and introduced such an entropy functional for any vector field in terms of a fourth-rank divergence free tensor P_{ab}^{cd} with the symmetries of the curvature tensor. Extremising this entropy for all the null vectors then leads to equations for the *background metric* of the spacetime. When P_{ab}^{cd} is constructed from the metric alone, these equations are identical to Einstein's equations with an undetermined cosmological constant (which arises as an integration constant). More generally, if P_{ab}^{cd} is allowed to depend on both metric and curvature in a polynomial form, one recovers the Lanczos-Lovelock gravity. In all these cases: (a) It is only necessary to extremise the entropy associated with the null surfaces; the metric is *not* a dynamical variable in this approach. (b) The extremal value of the entropy agrees with standard results, when evaluated on-shell for a solution admitting a horizon. The role of full quantum theory of gravity will be to provide the specific form of P_{ab}^{cd} which should be used in the entropy functional. With such an interpretation, it seems reasonable to interpret the Lanczos-Lovelock type terms as quantum corrections to classical gravity.

In a recent work, *Padmanabhan* has further generalised this approach, interpreting the entropy as an action functional and generalising it to any vector field of fixed norm. This is particularly important in describing the formalism in the Euclidean sector in which there is no concept of null, spacelike and timelike vectors.

Emergent gravity and the cosmological constant problem

The approach to gravity described above has important implications for the cosmological constant problem. In conventional approach to gravity, one derives the equations of motion from a Lagrangian $\mathcal{L}_{\rm tot} = \mathcal{L}_{\rm grav}(g) + \mathcal{L}_{\rm matt}(g, \phi)$ where $\mathcal{L}_{\rm grav}$ is the gravitational Lagrangian dependent on the metric and its derivatives and $\mathcal{L}_{\rm matt}$ is the matter Lagrangian which depends on both the metric and the matter fields, symbolically denoted as ϕ. This total Lagrangian is integrated over the spacetime volume with the covariant measure $\sqrt{-g}d^4x$ to obtain the action. In such an approach, the cosmological constant can be introduced via two different routes which are conceptually different but operationally the same.

First, one may decide to take the gravitational Lagrangian to be $\mathcal{L}_{\rm grav} = (2\kappa)^{-1}(R - 2\Lambda_g)$ where Λ_g is a parameter in the (low energy effective) action just like the Newtonian gravitational constant κ. This is equivalent to assuming that, even in the absence of matter, flat spacetime is *not* a solution to the field equations. The second route through which the cosmological constant can be introduced is by shifting the matter Lagrangian by $\mathcal{L}_{\rm matt} \to \mathcal{L}_{\rm matt} - 2\lambda_m$. The equations of motion for matter are invariant under such a transformation which implies that — in the absence of gravity — we cannot determine the value of λ_m. But such a shift is clearly equivalent to adding a cosmological constant $2\kappa\lambda_m$ to the $\mathcal{L}_{\rm grav}$. In general, what can be observed through gravitational interaction is the combination $\Lambda_{\rm tot} = \Lambda_g + 2\kappa\lambda_m$.

It is clear that there are two distinct aspects to the so called cosmological constant problem. The first question is why $\Lambda_{\rm tot}$ is very small when expressed in natural units. Second, since $\Lambda_{\rm tot}$ could have had two separate contributions from the gravitational and matter sectors, why does the *sum* remain so fine tuned? This question is particularly relevant because it is believed that our universe went through several phase transitions in the course of its evolution, each of which shifts the energy momentum tensor of matter by $T^a_b \to T^a_b + L^{-4}\delta^a_b$ where L is the length scale characterizing the transition. For example, the GUT and Weak Interaction scales are $L_{GUT} \approx 10^{-29}$ cm, $L_{SW} \approx 10^{-16}$ cm respectively which are tiny compared to L_Λ. Even if we take a more pragmatic approach, the observation of Casimir effect in the lab sets a bound that $L < \mathcal{O}(1)$ nanometer, leading to a ρ which is about 10^{12} times the observed value. Given all these, it seems reasonable to assume that gravity is quite successful in ignoring most of the energy density in the vacuum.

The transformation $\mathcal{L} \to \mathcal{L}_{\rm matt} - 2\lambda_m$ is a symmetry of the matter sector (at least at scales below the scale of supersymmetry breaking; we shall ignore supersymmetry in what follows). The matter equations of motion do not care about constant λ_m. In the conventional approach, gravity breaks this symmetry. *This is the root cause of the so called cosmological constant problem.* As long as gravitational field equations are of the form $E_{ab} = \kappa T_{ab}$ where E_{ab} is some geometrical quantity (which is G_{ab} in Einstein's theory) the theory cannot be invariant under the shifts of the form $T^a_b \to T^a_b + \rho\delta^a_b$. Since such shifts are allowed by the matter sector, it is very difficult to imagine a definitive solution to cosmological constant problem within the conventional approach to gravity.

If metric represents the gravitational degree of freedom that is varied in the action and we demand full general covariance (unlike in the unimodular theory of gravity), we cannot avoid $\mathcal{L}_{matter}\sqrt{-g}$ coupling and cannot obtain of the equations of motion which are invariant under the shift $T_{ab} \to T_{ab} + \Lambda g_{ab}$. Clearly a new, drastically different, approach to gravity is required.

This is precisely how *Padmanabhan's* work on the emergent gravity approach tackles this problem. In this case, the gravitational action is invariant under the shift $T_{ab} \to T_{ab} + \Lambda g_{ab}$ making gravity is decouple from the bulk vacuum energy. While this is considerable progress, there still remains the second issue of explaining the observed value of the cosmological constant. Once the bulk value of the cosmological constant (or vacuum energy) decouples from gravity, classical gravity becomes immune to cosmological constant; that is, the bulk classical cosmological constant can be gauged away. Any observed value of the cosmological constant has to be necessarily a quantum phenomenon arising as a relic of microscopic spacetime fluctuations. In this approach in which the surface degrees of freedom play the dominant role, rather than bulk degrees of freedom, *Padmanabhan* argues that there is a possibility of obtaining the correct value for the cosmological constant.

Thermodynamic route to dynamics of gravity

The classical general relativity as it stands today is an elegant description of gravity in terms of geometrical structure of spacetime. Specific solutions of general relativity allow the existence of spacetime horizon which act as a casual boundary and block the propagation of any information to an outside observer. This led Bekenstein in 1973 to argue that black holes must posses a non-zero entropy since they hide information from the outside observer. This is not possible classically because of the very definition of black holes in general relativity as the objects from which nothing comes out. Then in 1975, Hawking showed that a black hole of mass M does emit a thermal radiation with a temperature $k_B T = \hbar c/8\pi M$ when quantum effects are taken into consideration and this led to the understanding that the black holes behave like thermal systems and the laws of black hole mechanics are basically same as the laws of thermodynamics.

This analogy between gravity and thermodynamics is not yet understood at a deeper level. It is quite possible that the spacetime horizons act as the link between the microscopic degrees of freedom of the gravitational field with the bulk dynamics just as thermodynamics can provide a link between statistical mechanics and the (zero temperature) dynamics of the solids. If this picture is correct, one should be able to connect the field equations describing the dynamics of gravity with the horizon thermodynamics. *Padmanabhan* has earlier shown that this is indeed the case for spherically symmetric solutions in Einstein's theory.

Recently Aseem Paranjape, *Sudipta Sarkar* and *T. Padmanabhan* have carried out detailed analysis in this direction and their work reveals that the near horizon structure of the field equations in a D-dimensional spherically symmetric Lovelock gravity can also be interpreted as a thermodynamic identity $TdS = dE + PdV$ under the virtual displacement of the horizon with S and E being given by expressions of entropy and energy of the horizon. One can think of the Lovelock action as describing the low energy effective theory of the underlying quantum picture where the successive terms of the Lovelock series represent the possible quantum corrections. Then this result indicates a deep connection between the thermodynamics of horizons and the allowed quantum corrections to standard Einstein gravity, and shows that the relation $TdS = dE + PdV$ has a greater domain of validity that Einstein's field equation.

One possible limitation of this work is assumption of spherical symmetry and time independence. *Dawood Kothawala, Sudipta Sarkar* and *T. Padmanabhan* have tried to eliminate this by further generalising this approach to two more generic cases within the context of general relativity: (i) stationary axis-symmetric horizons and (ii) time dependent evolving horizons. In both the cases, the near horizon structure of Einstein equations can be expressed as a thermodynamic identity under the virtual displacement of the horizon. This result demonstrates the fact that the thermodynamic interpretation of gravitational dynamics is not restricted to spherically symmetric or static horizons but is quite generic in nature and indicates a deeper connection between gravity and thermodynamics.

Thermodynamics of horizons from a dual quantum system

Spacetimes with horizons show an interesting resemblance to thermodynamic systems with well defined notions of temperature and entropy. In conventional systems, one can derive the laws of thermodynamics from a more fundamental theory — statistical mechanics. In such systems, entropy can be defined as the logarithm of total number of accessible microstates corresponding to the same macrostate. The existence of an entropy associated with any horizon provides a strong motivation to look for certain microstates of the underlying quantum theory. Although there have been several attempts to derive black hole entropy formula from counting the possible microstates in both string and loop formalisms, a comprehensive understanding of this issue remain elusive. Recently, Balazs et. al. has proposed an intriguing model in which they have considered a "dual thermodynamics" corresponding to isolated Schwarzschild black hole and have tried to obtain the entropy from a dual theory, to which standard statistical mechanics is applicable. They show that the standard (black hole) thermodynamic relations are invariant under the transformations $E' \to A/4$, $S' \to M$, and $T' \to T^{-1}$ where A, M and T are the horizon area, mass and Hawking temperature of a black hole and E', S' and T' are the energy, entropy and temperature of the corresponding dual quantum system. After working out the standard thermodynamics of the dual system, they apply the inverse transformations to get standard horizon thermodynamics as well as the logarithmic corrections to the original Bekenstein-Hawking entropy formula.

The result is sufficiently intriguing that one would like to understand its origin and domain of applicability. In particular one would like to know whether it generalizes for an arbitrary horizon (like e.g., De-Sitter horizon, which will play an important role in the study of cosmological constant). *Sudipta Sarkar* and *T. Padmanabhan* investigated these issues and show that the idea works for a general case only if we define the entropy S as a congruence ("observer") dependent quantity and the energy E as the integral over the source of the gravitational acceleration for the congruence. In fact, in this case, one recovers the relation $S = E/2T$ between entropy, energy and temperature previously proposed by *T. Padmanabhan*. This approach also enables one to calculate the quantum corrections of the Bekenstein-Hawking entropy formula for all spherically symmetric horizons and seems to provide a description of a strongly interacting gravitational system like black hole in terms of a weakly interacting quantum mechanical dual system. This also suggest that the approach of understanding the horizon thermodynamics based of a duality transformation is possibly quite generic and therefore may be important for the understanding of the underlying quantum theory.

Quantum theory in an external background

The quantum theory of a harmonic oscillator with a time dependent frequency appears in different important physical problems, especially in QFT while studying particle production in an external background. While the mathematics of this system is straightforward, several conceptual issues arise in such a study:
If a quantized degree of freedom q is evolving in a time-dependent classical background C, the quantum theory of q will be based on a time dependent Hamiltonian and q particles will be generated by the interaction. If the classical system reaches an adiabatic state asymptotically, it is straightforward to define the notion of particles based on the *in* and *out* vacuum states and also obtain an expression for the total number of particles produced. But many physically relevant problems (like cosmological particle production) will not give us this luxury of well defined in and out states, and this brings up the question of defining the notion of a particle in a time dependent background. Moreover, the production of the quanta of q will modify the evolution of the classical background, and it will be important to obtain the equations of motion for C with this backreaction incorporated as the particle production progresses. This is not an asymptotic notion and one would like to have a way of accounting for back reaction which does not use the out vacuum state etc.

Such a back reaction and semiclassical evolution can be meaningful only if we have at least an approximate notion of 'classicality' for the q mode. Our intuitive idea of a particle which is produced (that has drained away energy from C) is classical and one assumes that a particle which is produced 'stays produced'. This is of course not in general true and no sensible, time dependent definition of particle exists which will obey this criterion. One, however, expects the notion of particles to be reasonably well defined if the quantum state is 'quasi-classical'. This raises the question of defining the notion of classicality of the state in some precise sense and relating it to particle production.

As an attempt towards addressing these conceptual issues, *T. Padmanabhan* and *Gaurang Mahajan* have worked out a general formalism to analyze the dynamics of a time-dependent oscillator in the Schrodinger picture. In particular, they introduce a particular parametrization of the wave functional in terms of a complex number and express all physically relevant quantities in terms it. They also generalize the notions of particle number density, effective Lagrangian etc., which are usually defined using asymptotic states, as time dependent concepts, showing that reasonable results can be obtained. The formalism is then applied to address the specific question of relating particle production with classicality of the quantum state in terms of the phase space distribution of its Wigner function, $\mathcal{W}(q,p)$, which involves considering two possible criteria: peaking on the corresponding classical phase space trajectory and emergence of correlations. An analysis of toy models as well as examples of quantum fields in cosmological and electric field backgrounds has been carried out, which reveals that an interpretation of classicality based solely on the requirement of peaking on the classical trajectory can lead to ambiguities. An example of this occurs in the cosmological context: when evolution of scalar field modes in a de Sitter universe is considered, the Wigner function can be shown to get peaked on the classical trajectory not just at late times, *but also* in the asymptotic past when the modes are started off in the Bunch-Davies vacuum state. This suggests that peaking of the Wigner function on the classical trajectory *alone* is *not* tantamount to having classical behavior, and one needs to *also* look at some additional measure of correlations to get rid of this ambiguity. The phase space average of qp [weighted by the Wigner function] has been suggested as such an alternative, and its reasonableness as a measure of classicality has been demonstrated with the help of the examples. It has further been shown that once one chooses to concentrate on the variation of this correlation measure, two possible asymptotic limits can be identified. When the oscillator evolves adiabatically ($|\epsilon| = |\dot{\omega}/\omega^2| \ll 1$), particle creation is suppressed and the classicality measure maintains an oscillatory profile (and in fact averages out to zero), suggesting the *necessity* of continuing particle creation for monotonic growth of correlations. In contrast, whenever the evolution violates adiabaticity ($|\epsilon| \gg 1$), large particle production occurs and this is shown to be accompanied by sharp growth in the correlation measure. This is in agreement with, and to some extent a generalization of, previous analyses in the literature associating the notion of classicality with particle creation in the context of inflationary cosmology.

Classical Gravity

Matter without matter

Einstein's theory of gravitation is characterized by the distinctive feature of gravity being described by curvature of spacetime. Matter thus produces curvature of the spacetime. On the other way round, reciprocity of action between matter and curvature (gravity) will demand that the latter should also produce the former. However, there is no direct demonstration of this feature.

The nearest one has come in the string theoretic formulation is what is known as AdS/CFT correspondence. In this case, at the boundary of anti-deSitter spacetime there resides conformal field theory (quantum chromodynamics) of matter. AdS is pure curvature while CFT is a matter field and there exists a dual correspondence between them. This is indeed the first example of spacetime curvature manifesting itself as matter in a dual spacetime.

H. Maeda and *N. Dadhich* obtained an interesting $n(\geq 6)$-dimensional vacuum black-hole solution of Einstein-Gauss-Bonnet gravity in Kaluza-Klein spacetime (a product of the usual 4-dimensional spacetime with a space of constant curvature) with extra dimensional space having negative constant curvature. The black hole fully resides in 4-dimensional spacetime which asymptotically resembles Reissner-Nortström black hole in anti-de Sitter spacetime in spite of the absence of the Maxwell field. The black hole is entirely created by coupling of extra-dimensional curvature to Λ and Gauss-Bonnet coupling constant. The presence of any matter including a mass point is prohibited by the gravitational equation. This is therefore a pure curvature creation. Indeed, this offers a first direct (and purely classical) example of curvature manifesting as matter, i.e., "matter without matter". The key ingradient of this remarkable result is the Kaluza-Klein decomposition which also brings Gauss-Bonnet contribution down to four dimensions. It has been further shown by Maeda and *Dadhich* that the black hole could be envisioned as being formed from AdS spacetime by the collapse of Vaidya-like null dust.

Higher dimensions ($n > 4$) is the natural playground for superstring/M-theory. Since gravity is to be described by curvature of spacetime, that means its Lagrangian should be an invariant function of Riemann curvature and its contractions. The second requirement is that we should get the second order quasi-linear (highest order of derivative to be linear) equation. This leads to the Lovelock polynomial Lagrangian of which $L_0 = -2\Lambda, L_1 = R, L_2 = R^2 - 4R_{\mu\nu}R^{\mu\nu} + R_{\mu\nu\rho\sigma}R^{\mu\nu\rho\sigma} = L_{GB}, ...$ The first two are the familiar cosmological constant and Einstein-Hilbert while the quadratic is known as Gauss-Bonnet term. For $n \leq 4$, the first two suffice as higher order terms make no contribution to the equation of motion. This means the order of Lagrangian to be included for description of classical gravity depends upon spacetime dimension. It is however true that our experience is restricted to 4 dimensions and from where all the experimental support emanates. At the level of principle, if $n \geq 4$, higher order terms in the Lovelock polynomial are also equally valid and they must be taken into account for full description of gravitational field.

It turns out that the low-energy limit of heterotic superstring theory as the higher curvature correction to general relativity indeed gives rise to the second-order Gauss-Bonnet Lagrangian. On the other hand *Dadhich* has pointed out that there are strong physical arguments for higher dimensions for description of classical dynamics of gravity. Confining gravity to 4 dimensions is equivalent to containing curvature entirely to 4 dimensions. That is, no curvature information is transmitted to extra dimension. That would perhaps require isometric embedding of 4-spacetime into 5-dimensional flat spacetime. It is well known that an arbitrarily curved 4-spacetime requires 6 extra dimensions for its flat embedding. Gravity could thus in general penetrate down to 10 dimensions! Secondly gravity is a self interactive force and self interaction can be evaluated in an iterative process. The first iteration is already included in Einstein equation as indicated by the presence of square of the first derivative. However how can we stop at the first iteration? For that we have to square the Riemann curvature and yet the equation should remain quasi-linear. So we are led to inclusion of the quadratic Gauss-Bonnet term which makes non-zero contribution in dimensions higher than 4. Hence for physical realization of second iteration of self interaction of gravity, we have to go to 5 or higher dimension. These are purely classical arguments and thus higher dimensions are required for description of even classical dynamics of gravity.

It is well known that 2 and 3 dimensions are not big enough for free propagation of gravity, similarly 4 dimension is not big eneough to fully describe self interaction of gravity. Interestingly higher dimension and Kaluza-Klein split up of spacetime play an important role in the construction of the new black hole spacetime exhibiting manifestation of curvature as matter.

Testing extra dimensions using an artificial planetary system in space

The idea that the universe may have more than 3 spatial dimensions is not new but goes back to the seminal work of Kaluza (1921) and Klein (1926) who suggested the presence of a fifth spatial dimension in their attempts to unify gravity with the electromagnetic force. More recently, extra dimensions have been invoked to make the universe accelerate at late times and thus obviate the need for dark energy. Such possibilities have been examined by *Varun Sahni* and Shtanov in the context of higher dimensional theories in which the universe is a 3+1 dimensional 'brane' embedded in a higher dimensional 'bulk' space time.

Most papers on Kaluza-Klein geometry however assume that the radius of the compact extra dimensions $\mathcal{R}$ is very small $\mathcal{R} \simeq 10^{-33}$ cm. In a significantly different approach, Arkani-Hamed, Divopolous and Dvali suggested that extra dimensions may be macroscopic, $\mathcal{R} \sim 1$ mm, while our space-time is described as a lower-dimensional domain wall (brane) where all the matter is concentrated. Within this setting, the fundamental higher-dimensional Planck scale could become as small as ~ 1 TeV, thus getting rid of the hierarchy problem. (The hierarchy problem arises because the Planck scale is so much higher than the known scales in physics, for instance $M_P/M_W \sim 10^{17}$, where M_W is the mass of the vector boson which mediates the electroweak force and M_P is the Planck scale.)

Within this setting one expects the familiar Newton's law of gravitation to be modified on small scales so that

$$V(r) \sim \frac{m_1\, m_2}{M^{n+2}}\, \frac{1}{r^{n+1}}\,, (\quad r \ll \mathcal{R})\,,$$

where M is the $(4+n)$-dimensional Planck mass. On scales much larger than $\mathcal{R}$ the familiar inverse-square law $V(r) \propto 1/r$ is recovered. Similar predictions also arise in the so-called 'braneworld' models which are inspired by string/M-theory. The presence of macroscopic extra dimensions in these models can be probed either via accelerator experiments or by checking whether Newton's law holds on small scales. Traditional tests of the inverse square law include table top Cavendish type experiments. However on very small scales the Casimir force needs to be modelled accurately and subtracted out which can pose difficulties for table top experiments. *Sahni* and Shtanov have proposed a new means of testing the inverse-square law (and hence the presence of extra dimensions) through a space experiment which does not encounter such problems.

Sahni and Shtanov propose an *Artificial Planetary System In Space* (APSIS) which will operate in a drag-free environment with controlled experimental conditions and minimal interference from terrestrial sources of contamination. According to their experimental setup, one (or more) test bodies (planets) will orbit a more massive central ~ 5 kg mass at a distance of ~ 10 cm.

The science behind APSIS is simple. It is well known that a test particle orbiting a larger mass has a closed orbit only for the inverse square law. For all other types of interactions the orbit of the test particle will show a *perihilion shift*. For instance consider the potential

$$U(r) = -\frac{\alpha}{r}\left[1 \pm \left(\frac{r_0}{r}\right)^n\right], \quad r \gg r_0, \quad n \geq 1$$

where r_0 is the relevant scale below which gravity becomes non-Newtonian, and '$\pm$' determines the attractive or repulsive character of the additional potential. The power n depends on a particular model; for instance, $n = 2$ in the five-dimensional Randall–Sundrum model. In this case the perihelion shift in the orbit of two masses is given by $\delta\phi = \pm 2\pi(2n-1)\left(\frac{r_0}{r}\right)^n$

Since the orbital period of a test body around a more massive central mass is proportional to $r^{3/2}$ one gets more orbits (and a larger cumulative perihilion shift) by decreasing the separation between the two bodies. For instance, for a test body at a distance of ~ 10 cm from a central mass of about 5 kg, the net perihilion shift in a year will be $\delta\phi_{\text{one year}} \simeq 1$ arc sec if the universe is five dimensional and departures from Newton's law occur at the scale $r_0 = 10^{-4}$ cm.

A space experiment can therefore probe the presence of a 'hidden' fifth dimension on the scale of a micron, if the perihelion shift of a 'planet' can be measured to sub-arc-second accuracy.

The payload of APSIS will include, in addition to the test masses, a tracking camera which will monitor the motion of the *miniature planetary system* floating within the spacecraft.

Since the masses involved should be in free fall, it is essential that all non-gravitational forces are minimized and the test bodies be allowed to execute their motion in a drag-free environment. For this purpose, the spacecraft will play the role of a Faraday cage and screen the experiment from any external electric field as well as cosmic rays. In addition, any residual gas present within the spacecraft can easily be released by means of a small opening.

Sahni and Shtanov are of the view that a miniature planetary system placed in free fall within a spacecraft located at the L2 Lagrange point of the Earth–Sun system, will provide an ideal testing ground for possible departures of Newtonian gravity from the familiar inverse-square law. The small accelerations prevalent in such systems ($\sim 10^{-8}$ cm/s^2) may also be useful for probing the MOND hypothesis, which has been suggested as an alternative to dark matter to explain the rotation curves of galaxies.

Mach's principle revisited

Mach's principle is the vague but attractive idea that inertial frames are uniquely determined by matter. Despite numerous attempts, no precise statement of Machs principle has been successfully implemented, until now. Along with Justin Khoury, *Maulik Parikh* proposed a formulation of Mach's principle in which matter and geometry are in one-to-one correspondence. Einstein's equations are not modified and no selection principle is applied to their solutions. Rather, Mach's principle is realized wholly within Einstein's general theory of relativity, an achievement that has often been thought to be impossible. The key insight was the observation that, in addition to bulk matter, one can also have boundary matter. Specification of both boundary and bulk stress tensors determines the geometry and thereby the inertial frames.

Gravitational Waves

Background

The existence of gravitational waves (GW), as predicted by Einstein's theory of relativity, has been established *indirectly* through the expert observations of Hulse and Taylor. So far direct observation of such waves has eluded experimentalists. Never the less, in recent years, the laser interferometric detectors have achieved sensitivities close to that required for detecting such waves from astrophysical sources. The space mission LISA is also planned by the NASA and ESA to detect low frequency GW. The significance of the direct detection of GW lies, not only in the opening of an entirely new window into observational astronomy by probing phenomena in the strong regime of gravitation; it further promises to place our present theories of gravitation on an entirely different foundation from that which currently exists.

GW sources that may be detected by ground-based detectors can be broadly classified into three categories: (i) Burst sources – such as binary systems of neutron stars (NS) and/or black holes (BH) in their in-spiral phase, BH/BH and/or BH/NS mergers, and supernovae explosions, whose signals last for a time much shorter, typically between a few milli-seconds and a few minutes, than the planned observational time; (ii) Stochastic GW backgrounds (SGWB) of radiation, either of primordial or astrophysical origin, and (iii) Continuous wave sources – e.g. rapidly rotating neutron stars, where a weak deterministic signal is continuously emitted.

The proposed space mission - the Laser Interferometric Space Antenna (LISA) - of the space agencies NASA and ESA envisages detecting low frequency GW in the range 10^{-4} Hz to 1 Hz. LISA consists of three spacecraft located 5 million kilometres apart forming an equilateral triangle. The spacecraft are maintained drag-free by a complex system of accelerometers and micro-propellers. Each spacecraft revolves in its own heliocentric orbit. The centre of the equilateral triangle is located on the ecliptic and lags 20 degrees behind the Earth. The spacecraft rotate in a circle drawn through the vertices of the triangle and the LISA constellation as a whole revolves around the Sun. The astrophysical sources that LISA could observe include galactic binaries, extra-galactic super-massive black-hole binaries and coalescences, and stochastic GW background from the early universe. Coalescing binaries are one of the important sources in the LISA frequency band. These include galactic and extra galactic stellar mass binaries, and massive and super massive black-hole binaries.

The IUCAA gravitational wave group has focussed on the data analysis aspects of GW observation by both ground-based as well as space-based detectors. It has had in the past collaborations with all the major gravitational wave groups around the world. Currently the IUCAA group has formal collaborations with US, Japan and France and informal collaborations with other important gravitational wave groups around the world. With US the IUCAA group has a MOU on data analysis of stochastic GW background with the Ligo Science Collaboration (LSC). With Japan the collaboration is with the TAMA data analysis group and research visits between the two groups have been funded by DST and IJSPS. With France, the collaboration is with the Nice group working on LISA data analysis and is funded by the Indo-French Centre for the Promotion of Advanced Research (IFCPAR). Following are the three main activities the IUCAA GW group has focussed on:

Obtaining the gravitational wave sky map of the stochastic background

Some of the background related to this work has been described in the last Annual Report. The new developments are as follows:

The formulation of the problem of mapping the gravitational-wave sky has three critical elements: (a) Measuring the excess power per pixel, (b) estimating the GW background per pixel after deconvolution of the synthesized network antenna-pattern from the data, and (c) Testing the "search and map" algorithm on simulations. The raw sky map of the GW background is the signal convolved with the antennae pattern. In order to obtain the sky map it must be deconvolved from the observed data. A data analysis method has been developed that measures and maps the power in the SGWB from a specific location in the sky - GW radiometry using a network of detectors. This work by *S. Mitra*, *S. Dhurandhar*, *T. Souradeep*, A. Lazzarini, M. Vuk and S. Bose is nearing completion. It is found that the angular resolution essentially depends on the effective GW bandwidth and the linear size of the network. The initial work is restricted to a single baseline, namely, the one connecting two 4km LIGO detectors at Hanford (LHO) and Livingston(LLO). The noise curves are assumed to be identical with the LIGO-I design power spectral density. The future plan is to extend this analysis to include VIRGO and other detectors around the world.

The basic statistic is the cross-correlation between the data from a pair of detectors. In order to 'point' the pair of detectors at different locations the signal must be suitably delayed by the amount it takes for the GW to travel to both detectors corresponding to the source direction. This delay will be a function of the source position and will vary as the Earth rotates. Using the delay allows the detectors to sample the same wavefront from the source. Here the focus is on the targeted search with the final goal of making a GW sky map.

The advantage of a targeted search is seen immediately by examining the so called overlap reduction factor normally denoted by $\gamma(f)$ in the literature for isotropic, unpolarized background. This becomes a time-dependent factor $\gamma(f, t)$ for the targeted search. For the LIGO detectors $\gamma(f)$ quickly reduces to zero beyond few tens of Hz, while the targeted factor has bandwidth of few hundreds of Hz. This is typically valid for a network of detectors and therefore important from the point of view of the sensitivity regime of GW detectors which lies in this region.

As in radio-interferometry, the correlation statistic so constructed produces a 'dirty' map where a point source does not produce a point image, but one that is smeared by a beam response function (beam, for brevity). The 'cleaned' GW sky map is obtained from the measured cross-correlation statistic by deconvolving the beam. In other words, to obtain the GW power from each

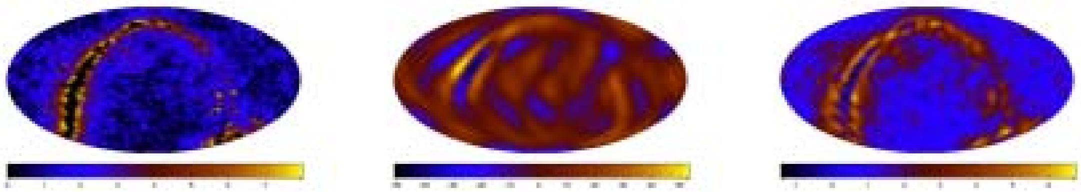

Figure 1: The Figure shows the injected, the dirty and the cleaned maps of GW background

direction in the sky one needs to solve an integral equation where the measured power (data) is a convolution of the actual power with a kernel (beam). In order to understand the structure of beam, analytical study in the stationary phase approximation (SPA) is carried out. It is found that at low latitudes of the point source, the kernel essentially has the shape of an 'eight' with a bright spot at the intersection. The bright spot is at the location of the pointing direction. The 'eight' continuously changes and bifurcates into a 'tear drop' as the pointing direction moves to higher latitudes. The latitude at which this bifurcation occurs is determined by the half-angle of the cone traced out by the vector joining the two detectors. For the LIGO detectors this latitude is about $26°$. The size of the bright spot or effective sky patch, defined by a certain percentage of drop in brightness, say 50%, is determined by the inverse of the band-width divided by the light (GW) travel time between the detectors. Considering a broadband source and LIGO detectors having kHz bandwidth with 10 ms light travel distance between them, the angular size is about $5°$ in radius. It is found that these results agree very well with those obtained by applying singular value decomposition to the kernel matrix; the eigenvalues fall off steeply after a certain point which determines essentially the number of 'degrees of freedom' of the kernel matrix and thereby the size of the sky patch.

The maximum likelihood (ML) approach for deconvolving the sky map is employed. The integral equation for a discrete pixelised sky leads to a set of linear algebraic equations. Several deconvolution algorithms exist in literature for solving such a problem. However, because of the broad similarity of the given problem with the cosmic microwave background (CMB) analysis, techniques that have been successfully applied to deconvolve CMB sky maps have been chosen. The ML estimate is found by employing the conjugate gradient method. The method is verified on simulated sky maps mapped by a GW radiometer consisting of LIGO pair of detectors LHO and LLO. Various sky maps are embedded into 'realistic' coloured Gaussian noise corresponding to LIGO-I design sensitivity curve. By the method of deconvolution used, the true sky maps can be recovered satisfactorily. The figures below show the extraction of the GW map from a noisy background. The source map of the CMB like GW background is inserted in the noise. Then the dirty map of the statistic is shown. In the final figure the dirty map is deconvolved and a cleaned map obtained.

Coherent versus coincidence search for inspiraling binaries

Because several detectors will take data simultaneously, it is advantageous to perform a multi-detector search for GW signals. A multi-detector search would (i) improve our confidence in detection of a GW event if a candidate event is registered; (ii) provide useful directional information on the GW event if the detectors are sufficiently separated in location, that is, at large geographical separations; (iii) provide polarization information if they are differently oriented. The information mentioned in (ii) and (iii) is degenerate in a single detector.

The response of a network to a GW is phase coherent. By 'correcting' for the phase from the data of different detectors, and the time-delay between detectors (this amounts to bringing the detectors to the same site and with the same orientation), one can combine the data phase coherently. *H. Mukhopadhyay*, H. Tagoshi, *S. Dhurandhar*, N. Sago, H. Takahashi and N. Kanda compare two different multi-detector detection strategies the coherent versus the coincident. The GW source chosen is the inspiraling binary because the phase of the wave can be sufficiently accurately computed; the phase of the wave has been modeled to the 3.5 post-Newtonian order which means that the phase of the wave is accurate to about a cycle in a wave train of $\sim 10^4$ cycles for typical stellar mass binary inspirals. Secondly, in the context of GW detectors, it is of great astrophysical significance; a GW signal of astrophysical importance is considered and for the first time the analysis uses template banks of

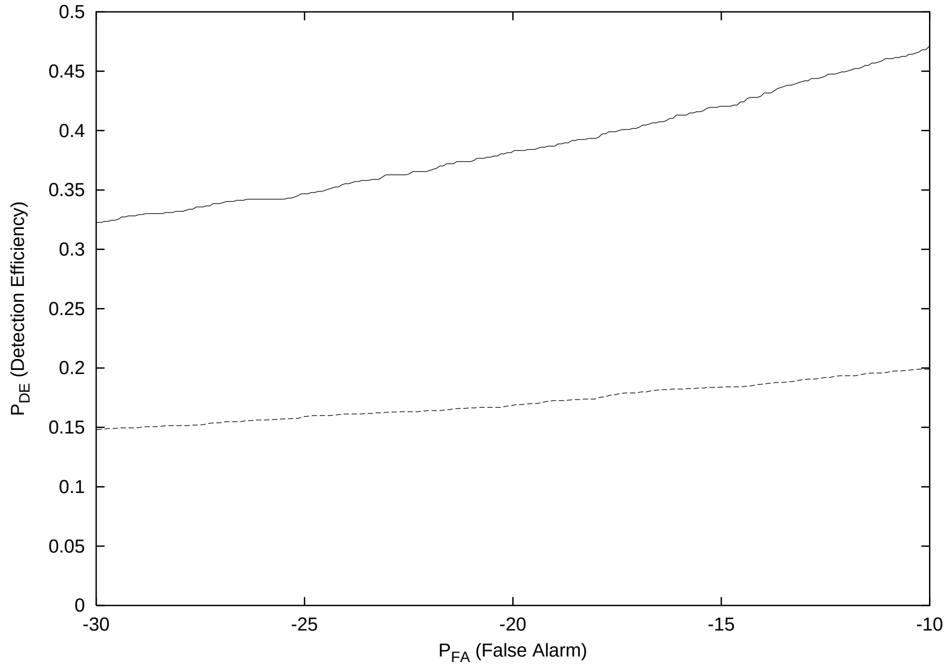

Figure 2: Receiver Operating Charachteristic curves for coherent and coincident detection of inspiraling binaries. The curves show that coherent search performs much better than the coincident one

inspirals to compare the two strategies.

The debate between the coherent and coincident strategies has existed in the community ever since the coherent strategy was formulated. While the coherent strategy involves more computational costs than the coincident strategy, the IUCAA and TAMA groups have shown for the simple case of two identical detectors in the same location and with same orientation, that the performance of the coherent strategy is superior to that of the coincidence strategy - the false dismissal is considerably less for the coherent as compared with the coincident at the same false alarm. This is in spite of the fact that for simplicity the detectors are taken to be co-aligned; it is expected that the coherent strategy will perform better in the case of non-aligned detectors than its competitor. In order to decide on the performance between the two strategies, the false dismissal versus false alarm curves are plotted - the *Receiver Operating Characteristic* (ROC) curves. The initial LIGO (LIGO I) noise curve assuming Gaussian stationary noise is used in the simulations.

The bottom line here is that the coherent strategy of detection is superior to the coincidence strategy. The ROC curves display this fact quantitatively for all the cases considered. The coherent detection strategy uses the likelihood function which inherently uses the information of phase coherence to decide on detection. This information is encoded in the pdf of the H_1 hypothesis, that a signal is present in the data. The pdf explicitly contains the signal from each detector in the network with consistent phase. Thus the coherent strategy inherently accommodates the phase information. Moreover, the likelihood analysis leads naturally to the matched filter which is the optimal filter for the network output. On the other hand, the coincidence strategy uses separate event lists formed by identifying candidate events in each detector considered in isolation - it ignores the crucial phase information that is inherent in a signal generated from a specific astrophysical source. This critical difference between the two analyses leads to the coherent analysis having superior detection performance.

Moreover, when the case of correlated noise between detectors is considered, the coherent strategy again leads to matched filters which are optimal. The correlations between the noise enter naturally into the likelihood analysis and the matched filter depends on these correlations. In coincidence analysis, on the other hand, the correlations between detectors simply do not play any role in the detection procedure and are thus *ipso facto* ignored.

The current work comprises two detectors with identical noise PSD, identically oriented and in the same location. The results are easily generalized to more than two detectors with identical noise PSD, with identical orientation and in the same location. These results can be further generalised to include arbitrarily oriented detectors in different geographical locations. This is work in progress. It is expected that the difference in performance between the two strategies to be more striking. One reason is that for differently oriented detectors, there is a finite possibility that a signal may not be detected separately by both detectors, thus ruling out coincidence detection, while coherently it could still be detected. In the figure below, the ROC curves are shown for the LIGO-VIRGO baseline where it has been assumed that the source distribution is uniform in space and in orientation. From the figure, it is evident that the coherent strategy outperforms the coincidence strategy by a large margin.

The work can be generalised in another direction in a straight forward manner to include other GW sources with known waveforms of finite duration. In particular, this work could be generalised to burst sources where the waveform could be constrained from physical and astrophysical considerations. This is a worthwhile future direction to adopt.

A general relativistic analysis of LISA dynamics and optics

The joint NASA-ESA mission LISA relies crucially on the stability of the three spacecraft constellation. Each of the spacecraft is in heliocentric orbits forming a stable triangle. In order for LISA to operate successfully, it is crucial that the three spacecraft which form the hubs of the laser interferometer in space maintain nearly constant distances between them. The distance between any two spacecraft is $\sim 5 \times 10^6$ km which must be maintained during the LISA's flight. However, in order to thoroughly study optical links and light propagation between these moving stations, one requires detailed analysis of the LISA configuration. The first goal was to analyse the motion of LISA spacecraft with a view to determine those spacecraft configurations which are stable from the point of view of laser frequency noise cancellation. This is now done in a series of papers by R. Nayak, *S. Koshti*, *S. Dhurandhar* and J-Y Vinet.

Cosmology and Structure Formation

Confronting higher dimensional cosmology with observations

One of the remarkable properties of our universe is that baryonic matter – the stuff of which we are made – accounts for only a small fraction of the total density of the universe. Galactic and extra-galactic observations carried out during the past several decades suggest that close to 96% of the density in the universe is either in the form of dark matter or dark energy. Although several candidates for both dark matter or dark energy have been suggested the precise nature of either of these substances remains unknown. One radical hypothesis is that the current acceleration of the universe is not caused by dark energy but comes about as a consequence of a modification of Einstein's equations. The late-time acceleration of the universe in this case is caused by a departure of space-time physics from general relativity on large scales and/or at late times. An important example of this class of models is braneworld cosmology according to which our three dimensional universe is a lower dimensional 'brane' embedded in a higher dimensional 'bulk' space-time. Braneworld models may provide a low energy manifestation of string/M-theory. As demonstrated by *Varun Sahni* and Yuri Shtanov, within the cosmological context braneworld models provide exciting new possibilities including: A family of braneworld models which unify the approaches of Randall-Sundrum and DGP allow the *effective* equation of state of dark energy to be 'quintessence-like' $w \geq -1$ as well as 'phantom-like' $w < -1$. In a subclass of these models the acceleration of the universe is a *transient* phenomenon, which gives way to matter dominated expansion in the future. The absence of horizons in a transiently accelerating space-time is an attractive feature of this scenario since it can reconcile current observations of acceleration with the demands of string/M-theory. The older age of some braneworld models also make them better equipped to explain the existence of high redshift QSO's. *Ujjaini Alam* and *Sahni* have tested a class of braneworld models against observations. They examine the braneworld models proposed by *Sahni* and Shtanov in the light of the Gold SNe data set and the 71 new SNe discovered by the Supernova Legacy Survey (SNLS). They use this data in conjunction with the recent discovery of the baryon acoustic peak (BAO) in the Sloan Digital Sky Survey to place constraints on the parameter space of accelerating braneworld models.

Braneworld models can be embedded in the five dimensional bulk in two distinct ways which leads to two complementary models Brane 1 and Brane 2. In Brane 1 the present value of the effective equation of state is *phantom-like* $w < -1$, whereas the opposite is true for Brane 2 which has $w > -1$. On the basis of the current data, *Alam* and *Sahni* conclude that, within 1σ, both classes of braneworld models are able to satisfy the current supernova data and therefore remain a possible candidate for dark energy together with the cosmological constant; see figure 3.

Quantum effects, soft singularities and the fate of the universe

Higher dimensional 'braneworld models' often show behavior which has no parallel in general relativity. As an example, it is well known that a homogeneous and isotropic universe can experience a big bang singularity in its past and/or a big crunch singularity in its future. At both singularities the density of matter diverges as does its expansion rate (described by the Hubble parameter). Within the braneworld context, *Varun Sahni* in collaboration with Shtanov, Tretyakov and Toporensky examined the possibility that the universe may encounter a fundamentally *new class of singularities*.

The rate of expansion of the universe and its ultimate fate depend on the system of equations governing evolution which are different for general relativity, scalar-tensor theory, braneworld theory etc. They also depend on the form of matter and, particularly, on its equation of state. In general relativity (GR), if one assumes that matter satisfies the strong energy condition (SEC) $\rho + 3p \geq 0$, then, within a Friedmann–Robertson–Walker (FRW) setting, the evolution of the universe is strongly dependent upon the spatial curvature: a spatially closed universe turns around and collapses whereas open and flat cosmologies continue to expand forever. The situation becomes more complicated (and interesting!) if one of the following assumptions is made: (i) the expansion of the universe is not governed by GR, (ii) matter can violate the SEC and even the weak energy condition (WEC) $\rho + p \geq 0$. In the latter case, if $w = p/\rho < -1$, then the expanding universe can encounter a "big rip" future singularity at which the density, pressure, and Hubble parameter diverge. In the former case, if the equations of motion have been derived from a braneworld action, then the expanding universe can encounter a new *quiescent* singularity, at which the density, pressure and Hubble parameter *remain finite*, but derivatives of the Hubble parameter, including $\dot{H}$, diverge. The occurrence of this singularity is related to the fact that the equations of motion are no longer quasi-linear (as they are, for instance, in general relativity) but include terms which are non-linear in the highest derivative.

Sahni and collaborators examine the issue of how quantum effects might influence a braneworld which encounters a quiescent singularity during expansion. It is well known that quantum effects come into play when the space-time curvature becomes large, as happens, for instance, in the vicinity of a black hole or near the Big-Bang and Big-Crunch singularities of general relativity. Although the density and pressure remain finite, the Kretschmann invariant diverges ($R_{iklm}R^{iklm} \rightarrow \infty$) as one approaches a quiescent singularity. One therefore expects quantum effects to become relevant in this case too.

This is indeed the case. Quantum corrections to the equations of motion at the semi-classical level result in several important changes to the evolution of the universe: the quiescent singularity changes its form and becomes a much weaker "soft" singularity, at which H and $\dot{H}$ remain finite but ${}^{(5)}ds^2 3h \rightarrow \infty$; (ii) vacuum polarization effects can cause *a spatially flat universe to turn around and collapse*.

Both (i) and (ii) demonstrate that the incorporation of quantum effects into the braneworld equations of motion can radically alter the future of our universe and lead to behaviour which differs significantly from general-relativistic cosmology. Since the quiescent singularity (and the associated quantum effects) arise as the density drops below a threshold value, it follows that those regions which are significantly underdense (voids) may be the first to encounter the quiescent singularity. *Sahni* and collaborators also discuss whether particle production effects could be significant as the universe approaches a quiescent future singularity. An interesting possibility that may arise in this case is that the universe expands in a regime in which the Hubble parameter *oscillates* about the de Sitter value.

Dark energy

There is a growing consensus in cosmology that the Universe is currently accelerating. Perhaps the simplest explanation of this property is the presence of a positive cosmological constant Λ. Although Λ appears to explain all current observations satisfactorily, to do so its value must necessarily be very small $\Lambda/8\pi G \simeq 10^{-47}\mathrm{GeV}^4$. So, it represents a new small constant of nature in addition to those known from elementary particle physics. However, since it is not known at present how to derive it from these other small constants and it is even unclear if it should be exactly constant, other phenomenological explanations for cosmic acceleration have been suggested. Collectively called *dark energy* (DE) models, they are based either on the introduction of new physical fields (quintessence and phantom models, the Chaplygin gas, etc.), or on *geometrical approaches* which attempt to generate acceleration by means of a change in the laws of gravity and, therefore, the geometry of space-time. Scalar-tensor gravity, $R + f(R)$ gravity and higher dimensional 'Braneworld' models are prominent members of this second category.

The growing number of dark energy models has inspired a complementary approach whose aim is to reconstruct properties of DE directly from observations in a quasi-model independent man-

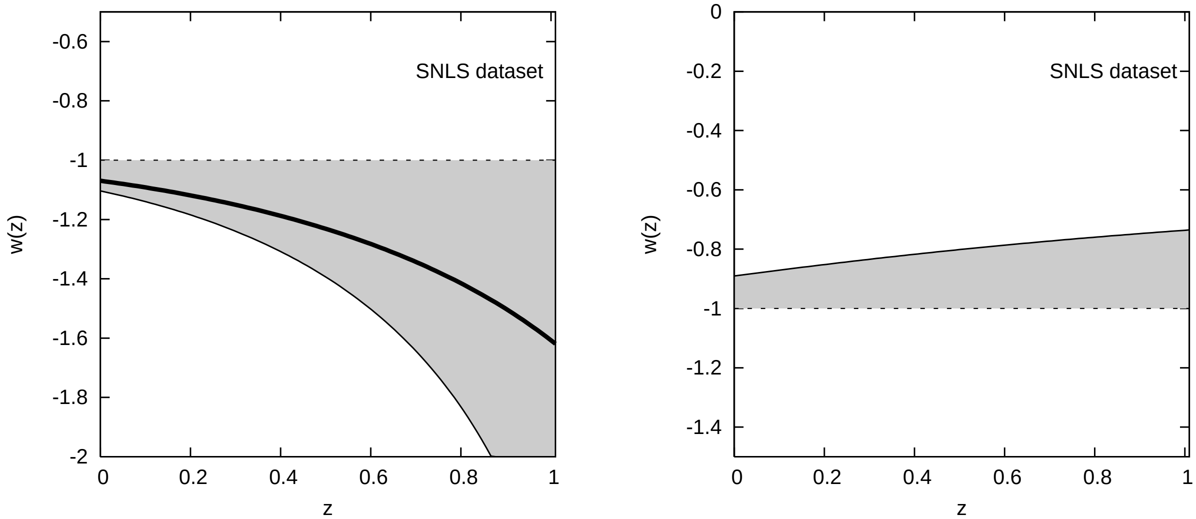

Figure 3: The redshift variation of the "effective" equation of state $w(z)$ for Brane 1 (left panel) and Brane 2 (right panel) models using the SNLS+BAO datasets. The light grey contours denote the 1σ errors around the best-fit, and the dashed line represents ΛCDM, which is the upper (lower) limit for $w(z)$ for the Brane 1 (Brane 2) model. We see that the behaviour of the "effective" equation of state of the braneworld models can be markedly different from ΛCDM ($w = -1$) within 1σ even for the small values of Ω_Λ allowed by the data.

ner. *Varun Sahni* and Alexei Starobinsky have made an exhaustive study of the model independent approach. In a collaboration with *Ujjaini Alam* they have investigated what new insights can be obtained about dark energy using the most recent data, and to see whether or not these data strengthen previously obtained results on the closeness of DE to Λ. *Alam, Sahni* and Starobinsky study two different supernova samples – the newly released Gold+HST sample and SNLS data – to see what constraints follow from them on possible evolution of dark energy. Although supernova data forms the major observational proof of dark energy, *Alam*, *Sahni* and Starobinsky also try to obtain independent information on the nature of dark energy from the other observational results by examining the following two datasets: (i) The R parameter characterizing acoustic peaks in the angular power spectrum of the cosmic microwave background (CMB) which helps in the investigation of the properties of dark energy. (ii) A remarkable confirmation of the standard big bang cosmology has been the recent detection of a peak in the correlation function of luminous red galaxies in the Sloan Digital Sky Survey. This peak, which is predicted to arise precisely at the measured scale of 100 h^{-1} Mpc due to acoustic oscillations in the primordial baryon-photon plasma prior to recombination, can provide a 'standard ruler' with which to test dark energy models.

Alam, Sahni and Starobinsky find that the Gold+HST dataset appears to favour an evolving model of dark energy with $w_0 < -1$ at present and with $w \sim 0$ at the redshift $z \sim 1$ over ΛCDM for its best-fit, however ΛCDM is still consistent at 2σ. For SNLS data, the reconstruction results are more consistent with ΛCDM.

It thus appears that results obtained using the SNLS data contradict the results obtained using the Gold dataset. However, the difference is not very large, at 2σ the results from both datasets are consistent with each other. The reason for this discrepancy could be due to the fact that the light-curve standardization of the two datasets is done using different methods, MLCS2k2 for Gold+HST and SALT for SNLS and it is well known different standardization techniques may lead to differences of upto 0.16 magnitude in the data. The discrepancy in cosmological results may therefore be attributed partly to the different standardization techniques. It may also be due to the fact that the low redshift and high redshift SNe are obtained by different surveys. Future surveys such as SNAP, JEDI and DUNE should have a better handle on the systematic errors and such discrepancies should disappear.

Alam, Sahni and Starobinsky conclude that their results are consistent with ΛCDM but do not rule out weakly time dependent dark energy. Cosmological reconstruction from the current datasets appear to be rather sensitive to the value chosen for the present matter density Ω_{0m}. As a result, it is difficult to reach firm conclusions on the nature of dark energy from these data until stronger model-independent constraints on Ω_{0m} are obtained, hopefully from future observations. Thus, even with the most recent data, the fundamental question of whether dark energy reduces to Λ or not, remains open.

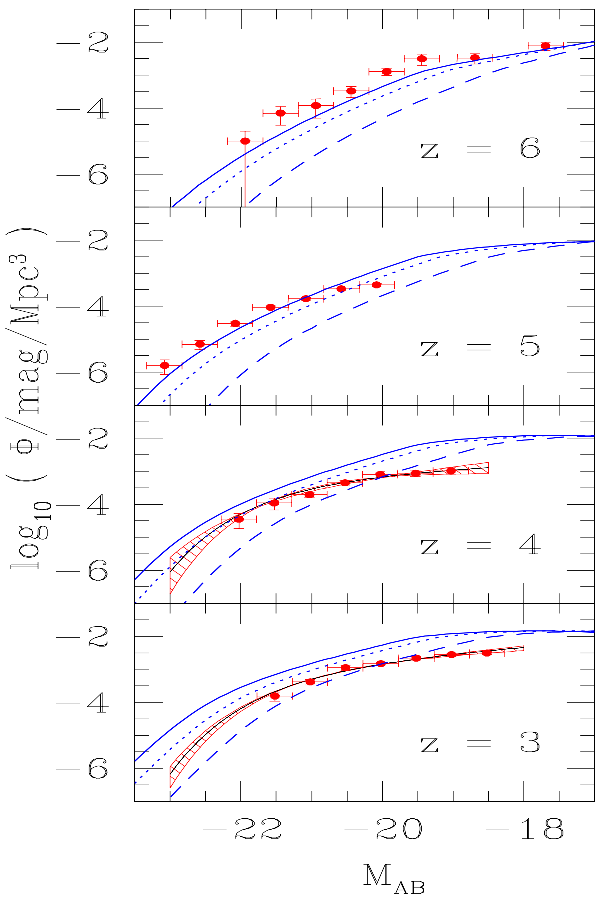

Figure 4: Luminosity function at different redshift bins. The solid, dotted and dashed curves are the predictions of models with lower mass cutoffs 1, 0.5 and 0.1 $M_{\odot}$ respectively. All the models assume Salpeter IMF with upper mass cutoff 100 $M_{\odot}$, metallicity $Z = 0.0004$, $\kappa = 1.0$ and $f_* = 0.5$.

Probing the star formation history using the redshift evolution of luminosity functions

Samui, Srianand and *Subramanian* have worked out a self-consistent, semi-analytical ΛCDM model of star formation and reionization. For the cosmological parameters favored by the WMAP third year data, their model consistently reproduces the electron scattering optical depth to reionization, redshift of reionization and the observed luminosity functions (LF) (see Fig. 4) and hence the star formation rate (SFR) density at $3 \leq z \leq 6$ for a reasonable range of model parameters. The suppression of small mass halos due to reionization feedback produces the correct shape of LF at $z = 6$. However, for $z = 3$ they need additional feedback that suppresses star formation activities in halos with $10^{10} < (M/M_\odot) < 10^{11}$. This could be due to the effect of galactic winds.

Models with prolonged continuous star formation activities are preferred over those with short bursts as they are consistent with the existence of an older population of stars (leading to a Balmer break) in considerable fraction of observed galaxies even at $z \sim 6$. The halo number density evolution from the standard ΛCDM structure formation model that fits LF up to $z = 6$ is consistent with the upper limits on $z \simeq 7$ LF and source counts at $8 \leq z \leq 12$ obtained from the Hubble Ultra Deep Field (HUDF) observations without requiring any dramatic change in the nature of star formation. However, to reproduce the observed LF at $6 \leq z \leq 10$, obtained from the near-IR observations around strong lensing clusters, we need a strong evolution in the initial mass function, reddening correction and the mode of star formation at $z > 8$.

They show that low mass molecular cooled halos, which may be important for reionizing the universe, are not detectable in the present deep field observations even if a considerable fraction of its baryonic mass goes through a star burst phase. However, their presence and contribution to reionization can be inferred indirectly from the redshift evolution of the luminosity function in the redshift range $6 \leq z \leq 12$. In their model calculations, the contribution of low mass halos to global SFR density prior to reionization reveals itself in the form of second peak at $z \geq 6$. However this peak will not be visible in the observed SFR density as a function of z as most of these galaxies have luminosity below the detection threshold of various ongoing deep field surveys. Accurately measuring the LF at high redshifts can be used to understand the nature of star formation in the dark ages and probe the history of reionization.

Alternative cosmology

Work by R.R. Vishwakarma and *Jayant Narlikar* on the quasi-steady state cosmology has continued on the observational front. A fitting of theoretical curve to the m-z relation for supernovae (Gold sample) shows that the QSSC is consistent with the data with comfortable confidnce levels. The optimum dust density that causes dimming of distant supernovae is consistent with that needed to thermalize relic starlight and produce microwave background.

Cosmic Microwave Background Anisotropy

In the short span of fifteen years since the first detection by the COBE satellite in 1992, remarkable improvements in sensitivity, resolution and sky coverage in the measurements of Cosmic Microwave Background (CMB) anisotropy have firmly established the area as centerpiece of Astronomy and Astrophysics, and played a key role in the rapid progress of cosmology and related areas. More recently, in the past five years, the detection and mapping of CMB polarization has added a new dimension to this success story.

As regularly reported in previous annual reports, *Tarun Souradeep* and his collaborators have sustained a successful research program covering a broad spectrum of issues related to the CMB anisotropy and polarization. Recent measurements from the Wilkinson Microwave Anisotropy Probe combine high angular resolution with full sky coverage allowed by a space mission. The second data release from WMAP in March 2006 was another milestone in CMB research that provided the first 'all sky' maps of (E-mode) of CMB polarization as well as updated CMB temperature anisotropy results based on three years of data. The WMAP results have made a deep impact on cosmology and related subjects. In the past year, *Souradeep* and collaborators have have applied different aspects program of research to the three years of WMAP data. The Planck Surveyor mission of ESA – arguably, the most ambitious of CMB experiments yet, is scheduled for launch in the next year. Hence, the current research has also focused on preparation for the upcoming richer data of unprecedented quality.

Estimating the angular power spectrum of CMB

The cosmological information that can be extracted from the exquisite CMB measurements is currently limited by the ability to analyze the large data sets,

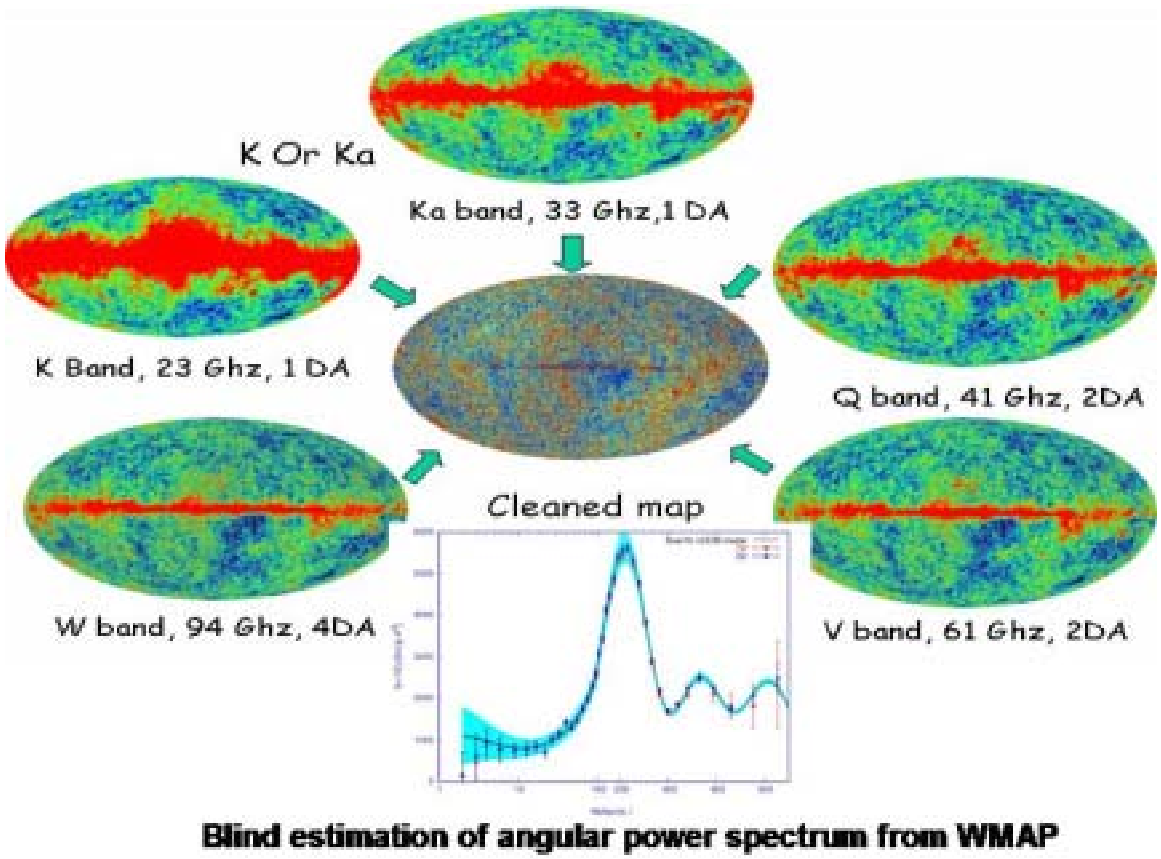

Figure 5: The angular power spectrum from WMAP-1year (red) and WMAP-3 year (blue) data obtained from the multi-frequency observations by WMAP using the blind estimation method developed by R. Saha, P, Jain and *T. Souradeep* that completely evades the modeling uncertainties of the foreground contamination in the CMB measurements

carefully accounting for very subtle systematic effects which become important at that level of sensitivity. These include the subtle biases arising from different approaches to the removal of foreground contamination and accurate modeling of the beam response of the experiments. *Souradeep*, Rajib Saha and Pankaj Jain of IIT Kanpur, have applied their novel method of self contained analysis of multi-frequency data (reported in the previous annual report) and provided an independent estimation of the angular power spectrum from 3-years of WMAP data soon after the second data release (see Figure 5). The group was one of five international research teams that jointly conducted a comprehensive reanalysis of the recently released three-years of WMAP data. In ongoing in depth study with Simon Prunet, IAP, they have identified and addressed the subtle bias issues of the method. The method is also being viewed with great promise for near future CMB polarization measurements since very little is known about the polarized foregrounds at CMB frequencies to allow for reliable modeling based approaches to foreground removal. This is under investigation by Rajib Saha who is visiting Simon Prunet and Francois Bouchet at IAP, Paris for a nine month period on an Indo-French Sandwich Ph.D. program sponsored by the French embassy.

The non-circularity of the experimental beam has progressively become an important systematic effect that challenges upcoming CMB experiments that strive to attain higher angular resolution and sensitivity. As reported in the previous annual report, former IUCAA students, *Sanjit Mitra* and A. Sengupta, carried out a comprehensive study of the effect of a non-circular beam on CMB power spectrum from WMAP. This effect has been noted and accounted for in the WMAP team's analysis accompanying the second release. In the past year, *Sanjit Mitra*, A. Sengupta, *Subharthi Ray*, R. Saha and *Souradeep* have significantly elaborated the scope of this approach to provide explicit analytic expressions for the effect of non-circular beam, now including the effect of non-uniform sky-coverage. These effort have initiated a CEFIPRA funded Indo-French collaboration with leading French scientists, Francois Bouchet and Simon Prunet in the the Planck Surveyor mission to address important systematic effects. Under the CEFIPRA program, *Soumen Basak* visited IAP, Paris and has embarked on an ambitious research program to decompose the non-circular part of beam prior to the map-making stage. This will allow CMB experiments, such as Planck, to produce final maps that are effectively smoothed by a circularly symmetric beam and will obviate the need to correct for beam non-circularity in the subsequent analyzes such as the estimation of the angular power spectrum.

Statistical Anisotropy of the CMB maps from WMAP

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. The detection of SI violation could have profound implications for cosmology. *Souradeep* has continued his collaboration with the former IUCAA student, Amir Hajian at Princeton University. They have published a detailed analysis of the second release of WMAP data (March 2006) on CMB anisotropy and polarization. In this recent work they have also introduced two new directional measures of statistical isotropy, namely, reduced Bipolar coefficients and the Bipolar map of correlation patterns.

Since CMB polarization is generated only at the surface of last scattering, violations of statistical isotropy are pristine cosmic signatures and cannot be explained in terms of the local universe. CMB polarization map over large areas of the sky has been delivered by WMAP second data release. The statistical isotropy of the CMB polarization maps will be an independent probe of the cosmological principle. Hajian, *Soumen Basak* and *Souradeep* have published the first study of the SI of CMB polarization maps using Bipolar harmonic analysis. The results have established the feasibility of bipolar analysis on CMB polarization and promise of the method when maps at much higher signal to noise will be available from Planck.

As reported in previous annual reports, the group at IUCAA has also studied the SI violation as a probe to constrain, or detect, signatures of specific theoretical possibilities, such as cosmic topology, cosmic magnetic fields and anisotropic cosmology. In particular, anisotropic,Bianchi VII_h cosmological models that predict a characteristic spiral pattern of temperature anisotropy embedded in the random CMB anisotropy from primordial perturbations have been recently proposed in the literature to explain potential anomalies in the CMB anisotropy as observed by WMAP (see Fig. 6). *Tuhin Ghosh*, *Amir Hajian* and *Souradeep* have investigated the violation of statistical isotropy due to the embedded Bianchi VII_h pattern in the CMB anisotropy maps. The bipolar analysis allows them to assess whether the existence of a hidden Bianchi in the WMAP data is consistent with the previous null detection of the bipolar power spectrum in the WMAP first year maps. By examining statistical isotropy of these maps, a limit of $(\frac{\sigma}{H})_0 \leq 2.77 \times 10^{-10} (99\% CL)$ can be placed on the shear parameter in Bianchi VII_h models.

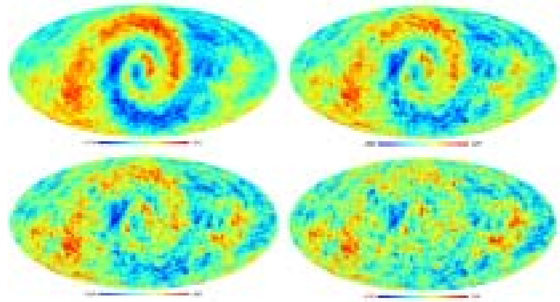

Figure 6: Four CMB maps in an anisotropic Bianchi VIIh universe with decreasing value of the shear, $(\frac{\sigma}{H})_0 = 1.83 \times 10^{-9}$ (*top left*), $(\frac{\sigma}{H})_0 = 1.09 \times 10^{-9}$ (*top right*), $(\frac{\sigma}{H})_0 = 7.3 \times 10^{-10}$ (*bottom left*), $(\frac{\sigma}{H})_0 = 3.66 \times 10^{-10}$ (*bottom right*). With decreasing value of shear, the characteristic CMB pattern sinks into the random CMB anisotropy from primordial perturbations. The violation of statistical isotropy can be clearly detected through its non-zero bipolar power spectrum even in the weakest case.

Early universe from CMB

The spectrum of primordial perturbations that seeded the large scale structure in the universe is assumed to follow the predictions from simplest models within the inflationary paradigm. 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 *Souradeep* to deconvolve the primordial power spectrum from the angular power spectrum of CMB anisotropy measured by WMAP. Their recent analysis of the three year data from WMAP confirms and strengthens the evidence for the prominent features of the recovered primordial power spectrum – a sharp, non-monotonic, infrared cut off on the horizon scale, seen in the first year results. The current analysis employs wavelet decomposition to identify features in the primordial primordial power spectrum as well as to smooth out artifacts from noise and deconvolution method. In another recent work published in Phys. Rev D. with collaborators P. Manimaran, R. Rangarajan and P. Panigrahi of PRL, Ahmadabad, wavelet analysis has been employed to asses the significance of the features in the primordial spectrum recovered from the first year data of WMAP.

Joint estimation of eight or more cosmological parameters is a computational challenge that has prompted use of fast, sub-optimal techniques like Markov Chain Monte Carlo method (MCMC). In another recent publication in Phys. Rev. D, *Rita Sinha* and *Souradeep* have carried out cosmological parameter estimation with classes of inflationary models that have an infra-red cutoff in the primordial power spectrum. Estimation of cosmological parameters for considerably extended parameter space is being currently pursued by *Subharthi Ray* and *Arman Shafieloo* with *Souradeep*.

Mapping the stochastic gravity wave background

Besides the CMB related effort, *Souradeep* is also involved in the direct measurement of the stochastic background using laser interferometers on ground such as LIGO and future space antennae (LISA). Map making of the stochastic gravity wave background bears close technical resemblance to that of CMB anisotropy. As members of the LIGO Science collaboration, *Sanjeev Dhurandhar*, *Sanjit Mitra* and *Souradeep* have developed and implemented a formalism for GW radiometry to map the stochastic GW background on the sky. They have imported techniques from CMB analysis and have developed and implemented the methodology for carrying out *gravity wave radiometry*. *Sanjit Mitra* visited LIGO, Caltech for three months in 2006 to work with stochastic sub-group of the LIGO Science Collaboration.

Observational Cosmology and Extragalactic Astronomy

VLA discovers cosmic shock waves around a cluster of galaxies

The distribution of galaxies in the universe is marked by vast cosmic voids embraced by a network of galaxy filaments and massive galaxy clusters containing up to thousands of galaxies. This inhomogeneous matter distribution emerged from an extremely smooth initial state with relative density fluctuations of only about 10^{-5}. Over billions of years, the initially tiny density variations grew through gravitational instability. Larger and larger structures still form today as a result of the violent merging of galaxies and clusters of galaxies. In addition, there is a continuous accretion flow of gas

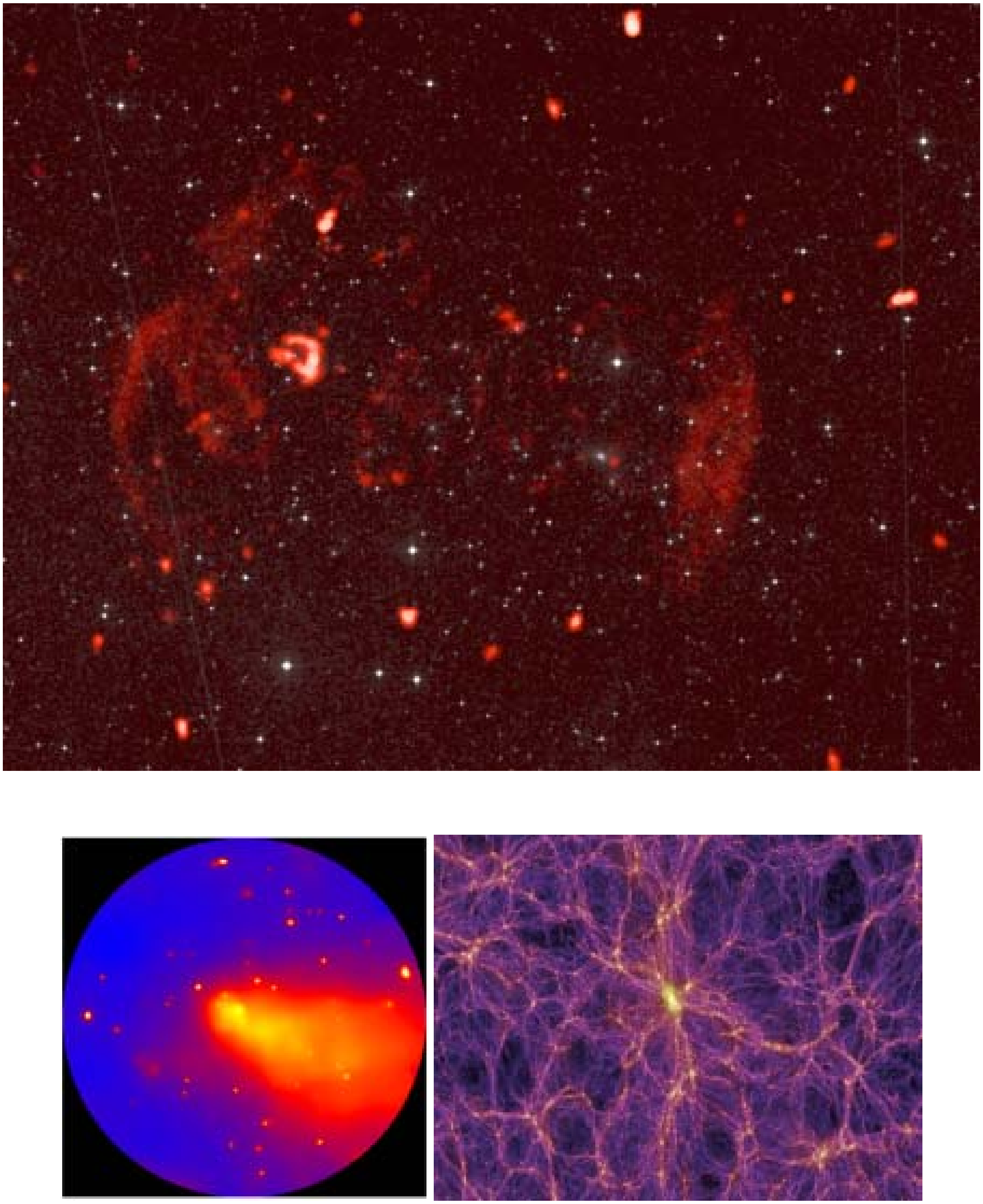

Figure 7: **Upper panel:** A large-scale radio/optical view of rich cluster of galaxies Abell 3376 in visible light (white) and 21-cm radio (red). The giant radio arcs surrounding the cluster were discovered using the Very Large Array. The visible-light image is from the Digitized Sky survey. **Lower left panel:** an X-ray image of Abell 3376 made using the European Space Agency's XMM-Newton telescope shows a spectacular, speeding-bullet shaped region of X-rays coming from gas heated to 60 million degrees Kelvin. The bullet shape results from the supersonic collision of a smaller galaxy subcluster with the main body of the larger cluster. **Lower right panel:** A numerical simulation showing projected dark matter distribution around a rich cluster of galaxies during its formation. The cluster is seen surrounded by numerous intersecting filaments and voids (courtsey: Volker Springel and 'Nature' magazine).

falling onto galaxy clusters out of the dilute intergalactic medium. Astronomers think that a significant fraction of the matter present in the universe could be in this thin, diffuse medium heated to temperatures of 10^5 K to 10^7 K by intergalactic shocks. The direct detection of this gas is an active field of research, and is a challenging task. One of the possible methods to detect such matter is the observation of peripheral regions in clusters of galaxies at radio wavelengths, where strongest shocks occur.

An international team led by *J. Bagchi*, using data from two of the world's largest and most sensitive telescopes; the Very Large Array (VLA) in radio, and the European Space Agency's XMM-Newton in x-ray wavelengths, have discovered giant, ringlike structures around a cluster of galaxies, known as Abell 3376. Abell 3376 is located some 600 million light years from earth; which is the distance estimated from it's redshift of 0.046. These huge, newly-discovered ring segments, some 6 million light years across (about 2 Mpc), were revealed in a deep VLA radio observation at the wavelength of 20 cm [see Figure 7]. These structures probably mark the sites of cosmological shock waves, caused by energetic collisions, mergers, and movement of gas and smaller galaxy groups in this massive cluster under construction. The discovery provides tantalizing new information about how such galaxy clusters are assembled, about magnetic fields in the vast spaces between galaxy clusters, and also about the origin of highest-energy cosmic rays. Cosmic rays are extremely energetic proton or nuclei with energies upto 10^{20} eV, but their origin is still unknown, and they have puzzled scientists for decades.

The x-ray observations of Abell 3376 obtained with the ROSAT and XMM-Newton satellites show that galaxy cluster has a spectacular "bullet" or "cometary" structure, elongated along the principal axis of the radio emission [Figure 7]. As in many galaxy clusters, this x-ray emission is attributed to a very hot and diffuse gas with a temperature of $\sim 6 \times 10^7$ K. The temperature map of this hot gas reveals the existence of alternatively hotter and cooler zones. This suggests that a small cluster is crossing a larger one, creating shock waves which are heating the gas in some regions. The movement of the small cluster is probably along the direction of the "wake" visible on the x-ray image, and this direction is perpendicular to that of the large scale shocks, which led to the formation of gigantic arcs of radio emission at the location of shock fronts.

But what produces the radio waves emitted from the giant ring structures? Gas falling into the gravitational wells of galaxy clusters can reach velocities of up to a few thousand kilometers per second. When it collides with the hot and ionized gas at a temperature of 10^7 to 10^8 K within clusters, large-scale "accretion" shock waves form that heat the infalling gas to similar temperatures. Magnetic fields in the gas may permit a small fraction of the thermal gas particles to scatter back into the upstream region of the shock wave and to undergo the energizing shock compression again and again. This so-called diffusive shock acceleration process produces nonthermal particles with an energy spectrum easily extending into ultrarelativistic energies (close to speed of light), where particle energies exceed their rest mass energies by large factors. Although the number of these relativistic particles is small compared with the thermal ones, they can account for a substantial fraction of the dissipated shock energy. The highly energetic electrons can be "kicked" by the shock waves to very high energies. These electrons would then gyrate across the magnetic field lines and emit the feeble radio waves picked up by the highly sensitive VLA radio antennas. This so-called synchrotron radiation is also observed in particle accelerators on earth, as well as in the expanding shock fronts of supernovae, radio-jets and gamma-ray bursters.

In a paper published in Science, *J. Bagchi et al.* show that the pair of giant radio structures in galaxy Abell 3376 may be emission from the accretion shocks of the cluster. This dual radio morphology is possibly caused by the stronger matter flow onto the cluster along an embedding galaxy filament, as seen in a computer simulation image shown in Figure 7 . If this interpretation is correct, it would be a remarkable finding, because it would imply the presence of magnetic fields in the infalling gas, whereas magnetic fields have so far only been detected within galaxy clusters. Furthermore, it would be the first observational identification of an accretion shock wave. Accretion shock waves are very interesting because they may also be linked to the origin of the mysterious ultra-high-energy cosmic rays which may contain extremely energetic protons with energies up to 10^{20} eV. Although most of the energy of the cosmic structure formation is dissipated in the centers of galaxy clusters, the shock waves in the outskirts and especially the accretion shocks have much higher Mach numbers and therefore should be more efficient particle accelerators. The highest energy electrons from such shocks can scatter photons of the cosmic microwave background into gamma ray bands and thereby contribute to the observed and still unresolved gamma-ray background. As a result, the giant radio rings in Abell 3376 mark locations to be monitored in the future for all kinds of high-energy radiation.

Interestingly, there is another plausible explanation for the double radio arcs. One can interpret that the shock waves that energized these electrons came from the collision of a smaller group of galaxies with the main body of the larger cluster, as revealed in the highly elongated XMM-Newton x-ray image. When two such massive objects crash into each other at supersonic speed, gigantic ripple-like shock waves are created in the surrounding gas, which race out to the outer regions of the forming cluster at a speed of thousands of kilometers per second. These shock waves steepen as they run into the more dilute gas of the cluster outskirts, similar to tsunami waves propagating into shallower water. A resulting pair of radio relics was indeed observed in a morphologically similar merging cluster, Abell 3667, and well reproduced by numerical simulations. Possibly, the radio structures in Abell 3376 are also of this type. In any case, it is exciting that the giant radio arcs in Abell 3376 provide us with direct insight into the fluid dynamics of cosmic structure formation. This important and surprising observation gives a foretaste of the radio glow of the cosmic large-scale structure, which one hopes to discern with the next generation radio telescopes such as the Low Frequency Array (LOFAR), the Long Wavelength Array (LWA), and the Square Kilometre Array (SKA).

Morphological diversities among Lyman-break galaxies

In the last couple of years, the approach towards understanding the formation and evolution of galaxies has undergone a revolution through the large number of multi-wavelength surveys that cover large areas on the sky. The combination of deep imaging and follow-up spectroscopy using best telescope facilities, allows to select galaxies by their redshifts, or by known color-selection methods and trace the evolution of galaxies through cosmic time. The deep, multi–wavelength images obtained by the Great Observatories Origins Deep Survey (GOODS) provide unprecedented large sample ($\sim$ 4700) of Lyman-break galaxies (LBGs) at $z > 2.5$, and starburst galaxies (~ 292) at $z \sim 1.2$. With the high resolution (< 700 parsecs at $z > 2.5$) offered by the *HST*/ACS images, it has become possible for the first time to quantify the structural parameters of statistically significant number of LBGs. *S. Ravindranath* and collaborators have performed morphological analysis based on light profile shape and ellipticity for $\sim$ 1333 of the most luminous (> 0.5 L*) LBGs. About 40% of LBGs at $z \sim 3$ have exponential profiles, $\sim$ 30% of the galaxies have steep ($r^{1/4}$-like) profiles, and ($\sim$ 30%) of LBGs have multiple cores or disturbed morphologies suggestive of close pairs or mergers. The fraction of spheroid-like LBGs decreases by about 15% from $z \sim 5$ to 3. A comparison of LBGs with the starburst galaxies at $z \sim 1.2$, shows that disk-like and merger morphologies are dominant, but the fraction of spheroid-like profiles is about 20% higher among LBGs. The ellipticity distribution for LBGs exhibits a pronounced skew towards high ellipticities ($\epsilon > 0.5$), which cannot be explained by morphologies similar to the local disks and spheroids viewed at random orientations. The peak of the distribution evolves toward lower ϵ, from 0.7 at $z = 4$ to ~ 0.5 at $z = 3$. The ellipticity distribution for the $z \sim 1.2$ galaxies is relatively flat similar to that seen for present–day galaxies. The dominance of elongated morphologies suggests that in a significant fraction of LBGs we may be witnessing star-formation in clumps along gas-rich filaments, or the earliest gas-rich bars that encompass essentially the entire visible galaxy.

Evolution of star-forming galaxies

S. Ravindranath and collaborators have used the multiwavelength photometric and spectroscopic data covering the Chandra Deep Field South (CDF-S) obtained within the GOODS program, to investigate the rest-frame UV properties of galaxies out to $z \sim 2.2$, including the evolution of the luminosity function, the luminosity density, star formation rate (SFR), and galaxy morphology. They found a significant brightening (~ 1 mag) in the rest-frame 2800Å characteristic magnitude (M*) over the redshift range $0.3 \leq z \leq 1.7$ and no evolution at higher redshifts. The rest-frame 2800Å luminosity density shows an increase by a factor of ~ 4 over the redshift range investigated. They estimated the SFR density to $z \sim 2.2$ from the 1500 and 2800Å luminosities and found that the SFR (without extinction correction) derived from the 2800Å luminosity density is almost a factor of 2 higher than that derived from the 1500Å luminosities. Attributing this difference to differential dust extinction, they found that E(B - V) = 0.20 results in the same extinction-corrected SFR from both 1500 and 2800Å luminosities. The extinction-corrected SFR is a factor of $\sim$6.5 ($\sim$3.7) higher than the uncorrected SFR derived from 1500Å (2800Å) luminosity. They also studied the morphological composition of our sample by fitting Sérsic profiles to the HST ACS galaxy images at a fixed rest-frame wavelength of 2800Å at $0.5 \leq z \leq 2.2$ and found that the fraction of apparently bulge-dominated galaxies (Sérsic index $n > 2.5$) increases from $\sim$ 10% at $z \sim 0.5$ to $\sim$30% at $z \sim 2.2$. At the same time, the galaxies get bluer at increasing redshift. This suggests a scenario where an increased fraction of the star formation takes place in bulge-dominated systems at high redshift. This could be evidence that the present-day elliptical galaxies are a result of assembly (i.e., mergers) of galaxies at $z \geq 1$. Finally, the galaxy size for a luminosity-selected sample evolves as $r_h \propto (1+z)^{-1.1}$ between redshifts z = 2.2 and 1.1, consistent with the evolution reported previously over the redshift $0 \leq z \leq 6$.

Star formation at high redshift from the Hubble Ultra Deep Field

In another investigation *S. Ravindranath* and collaborators studied the photometric redshift distributions, spectral types, Sérsic indices, and sizes of all resolved galaxies in the Hubble Space Telescope Ultra Deep Field (UDF) in order to understand the environment and nature of star formation in the early Universe. Clumpy disk galaxies that are bright at short wavelengths (restframe < 5000Å) dominate the UDF out to $z \sim 5.5$. Their uniformity in V/V_{max} and co-moving volume density suggest they go even further, spanning a total time more than an order of magnitude larger than their instantaneous star formation times. They precede as well as accompany the formation epoch of distant red galaxies and extreme red objects. Those preceding could be the pre-merger objects that combined to make red spheroidal types at $z \sim 2-3$. Clumpy disks that do not undergo mergers are likely to evolve into spirals. The morphology of clumpy disks, the size and separation of the clumps, and the prevalence of this type of structure in the early Universe suggests that most star formation occurs by self-gravitational collapse of disk gas.

Morphological mix of Luminous Compact Galaxies at intermediate redshifts from the HST/ACS GOODS survey

The LCGs also known as *Compact Narrow Emission Line Galaxies* CNELGs, are galaxies which were originally identified as star-like objects with colors unlike typical stars. Abhishek Rawat in collaboration with Ajit Kembhavi and Sudhanshu Barway and Francois Hammer and Hector Flores (l'Observatoire de Paris France) used multiband imaging data from Chandra Deep Field South CDFS half of the HST/ACS GOODS survey to determine the quantitative morphological parameters of a complete sample of LCGs in the intermediate redshift range. They derive the following morphological mix for their sample of intermediate redshift LCGs: Mergers: ∼36%, Disk dominated: ∼25%, S0: ∼17%, Bulge dominated: ∼7%, Irr/tadpole: ∼15%.

They establish that LCGs are intermediate mass objects with stellar mass ranging from $9.44 \leq Log_{10}(M/M_\odot) \leq 10.96$, with a median mass of $Log_{10}(M/M_\odot) = 10.32$. They also derive SFR values ranging from a few to $\sim 65\ M_\odot$/year as expected for this class of objects. They find that LCGs account for ∼26% of the $M_B \leq -20$ galaxy population in the redshift range $0.5 \leq z \leq 1.2$. They estimate a factor ∼11 fall in the comoving number density of blue LCGs from redshifts $0.5 \leq z \leq 1.2$ to the current epoch. The strong redshift evolution exhibited by LCGs, and the fact that a significant fraction of LCGs are in merging systems, seem to indicate that LCGs might be an important phase in the hierarchical evolution of galaxies. It is envisaged that some of the LCGs that are classified as merging systems, might go on to rebuild their disks and evolve into disk galaxies in the local universe.

Evolution in merger rate of galaxies with redshift from HST/ACS GOODS dataset

Abhishek Rawat and Ajit Kembhavi in collaboration with Francois Hammer and Hector Flores (l'Observatoire de Paris) worked on the problem of determining the evolution in merger rate of galaxies with redshift out to $z \sim 1.2$. This involved counting pair of galaxies within a projected distance $\leq 20\,\mathrm{kpc}$. They then estimate the *fraction* of galaxies that exist in pair in a given redshift bin. This pair fraction the can be translated into a merger fraction using some reasonable assumptions about the probability of a close pairs of galaxies to merge together. They use a combination of deep, high angular resolution imaging data from the HST/ACS GOODS survey and ground based near-IR K_s images to derive the evolution of the galaxy major merger rate in the redshift range $0.2 \leq z \leq 1.2$. They select galaxies on the sole basis of their J-band rest-frame, absolute magnitude, which is a good tracer of the stellar mass. They find steep evolution with redshift, with the merger rate $\propto (1+z)^{2.44\pm0.39}$ for optically selected pairs, and $\propto (1+z)^{2.07\pm0.74}$ for pairs selected in the near-IR. Their result is unlikely affected by luminosity evolution which is relatively modest when using a rest-frame J band selection. The apparently more rapid evolution that they find in the visible is caused by biases affecting the near IR photometry, underestimating pair counts at higher redshifts. The major merger rate evolves by a factor ∼5 from the current epoch to $1.6 \times 10^{-3}\,\mathrm{Mpc}^{-3}\,\mathrm{Gyr}^{-1}$ at $z \sim 1.2$, suggesting that $58\% \times (0.5\,\mathrm{Gyr}/\tau)$ of all galaxies with $M_J \leq -19.5$ have undergone a major merger in the last $\sim 8\,\mathrm{Gyr}$ (where τ is the merger timescale). They also find some evidence for increased star formation due to possible interactions between members of a pair.

Photometric Identification of Quasars from the Sloan Survey

With the onset of several very large area data sets covering much of the sky to considerable depths, the photometric database has grown many folds. The Sloan Digital Sky Survey (SDSS) is one such all sky survey spanning 8000 $\deg^2$ of the sky in the optical regime imaging more than 200 million galaxies, stars and quasars with its recently completed first phase (http://www.sdss.org). However, the spectroscopic data exists for only a tiny fraction of the imaging data leaving a vast scope for an automated technique of identifying possible candidates belonging to different spectral types. It is well known that neural networks are powerful tools for modelling, control, discrimination and automatic classification. *Rita Sinha* and *Ajit Kembhavi* in collaboration with N. S. Philip (of St. Thomas College, Kerala) and A. Mahabal (of Caltech, USA) have used point sources from the Sloan data release 5 (DR5) that have been spectroscopically identified as quasars and different type of stars, to train a Difference Boosting Neural Network (DBNN) that looks for differences in the colours of the objects to classify them. The four independent colours, u-g, g-r, r-i, i-z, the point spread function 'asinh' magnitude i and the spectral type of the objects have been used as the inputs for the network which returns a predicted spectral type for each object assigning some confidence value to each prediction. The quality of the 'training' is examined by employing it to predict the nature of objects with known spectroscopic identities with the estimation of completeness and contamination. Fig. 9 shows the fraction of quasars passed in the u-$g$$-$$g$-$r$ color-color space on 'testing' DBNN on a sample consisting of quasars and different type of stars of known spectral type. The best trained network is used to produce a quasar catalogue from the Sloan photometric database. Fig. 10 shows the quasar candidates that have been predicted by DBNN including the new quasar candidates which are not part of the SDSS DR5 quasar catalogue. Extensive use of the Virtual Observatory tools have been made to validate the approach and results wherever required.

AGN, Quasars and IGM

Detecting Cold Gas at Intermediate Redshifts

Physical conditions in the high redshift protogalaxies can be studied by detection the 21-cm absorption from these systems. However, intervening H I 21-cm absorption systems at $z \geq 1.0$ are very rare and only 4 confirmed detections have been reported in the literature. Despite their scarcity, they provide interesting and unique insights into the physical conditions in the interstellar medium of high-z galaxies. Moreover, they can provide independent constraints on the variation of fundamental constants. Recently *Srianand* and his collaborators (Neeraj Gupta, Patrick Petitjean, Pushpa Khare, D.J. Saikia, D. York) have reported 3 new detections based on their ongoing Giant Metrewave Radio Telescope (GMRT) survey for 21-cm absorbers at $1.10 \leq z_{\rm abs} \leq 1.45$ from candidate damped Lyman-α systems. The 21-cm lines are narrow for the $z_{\rm abs}$= 1.3710 system towards SDSS J0108$-$0037 and $z_{\rm abs}$= 1.1726 system toward SDSS J2358$-$1020. Based on line full-width at half maximum, the kinetic temperatures are $\leq$ 5200 K and $\leq$ 800 K, respectively. The 21-cm absorption profile of the third system, $z_{\rm abs}$=1.1908 system towards SDSS J0804+3012, is shallow, broad and complex, extending up to 100 km s^{-1}. The centroids of the 21-cm lines are found to be shifted with respect to the corresponding centroids of the metal lines derived from SDSS spectra. Such shifts have already been observed in other systems. It is also known that H_2 carrying components in DLAs, that are believed to trace the CNM gas, often show similar shifts (although less pronounced) with respect to the strong metal line components. H_2 components often distinguish themselves with respect to the rest of the velocity components by the presence of excited fine-structure lines of C I and C II and in some cases by large depletion factors. It would be very important to obtain high resolution optical spectra of these sources to see if this is also true in the case of the 21-cm absorption systems.

It is important to obtain independent constraints on the time variation of fundamental constants in order to resolve the controversy regarding the variation of the fine structure constant α. As the energy of the 21-cm transition depends on the electron-to-proton mass ratio (μ), the fine-structure constant (α) and the proton g-factor (g_p), high resolution optical spectra in conjunction with high resolution 21-cm spectra can be used to probe the variation of these constants. However, it is important first to understand the origin of the relative shifts that we observe between the redshifts of the atomic heavy element lines and the 21-cm absorption. This needs detailed modeling of the absorption systems taking into account all transitions simultaneously. This is what the group plans to do in the near future.

Multiwavelength investigation of a near-solar metallicity sub-DLA

Multiwevelength studies of QSO absorption system are important to understand the nature of different indicators of physical conditions in the protogalax-

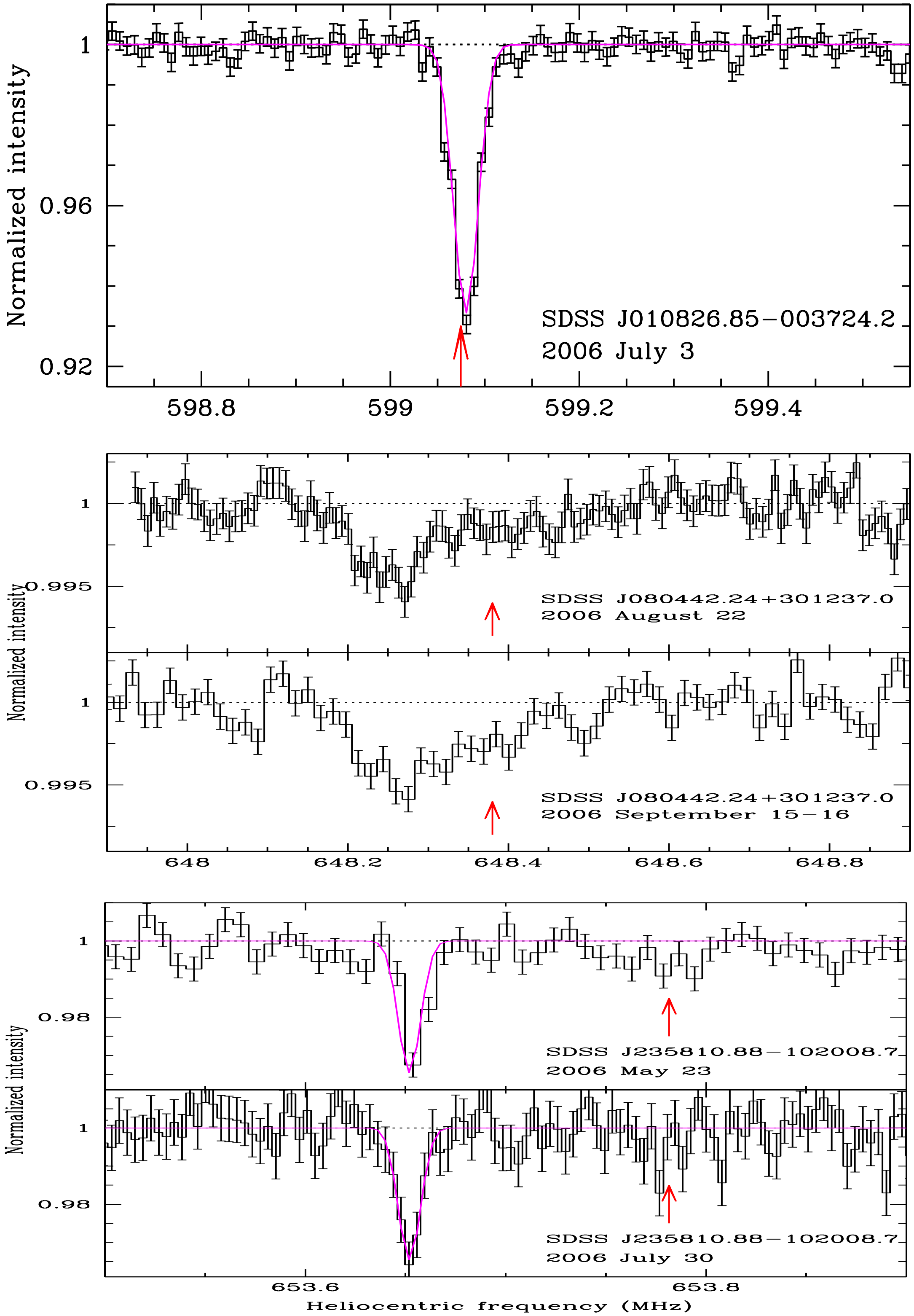

Figure 8: GMRT H I spectra of the sources with 21-cm absorption. Single Gaussian fits are over-plotted in the case of J0108−0037 and J2358−1020. Arrows mark the expected positions of 21-cm absorption based on the metal absorption lines.

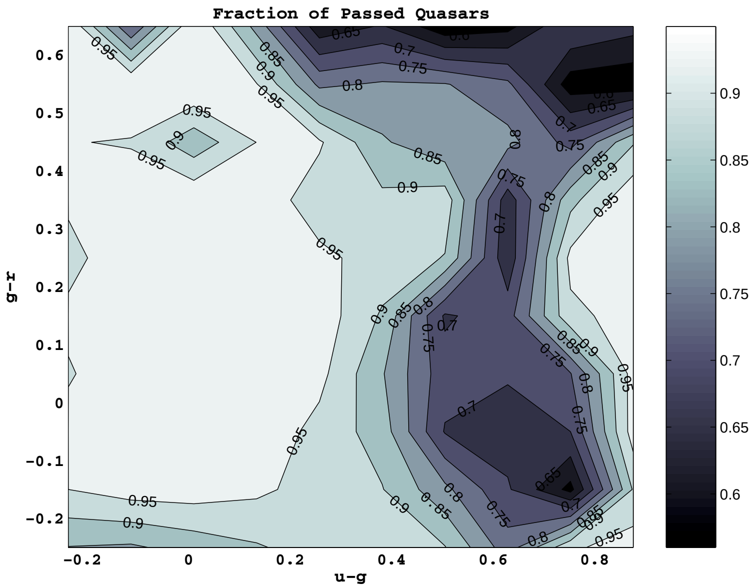

Figure 9: The fraction of quasars passed successfully in the u-g−g-r color-color space on 'testing' DBNN on a sample consisting of quasars and different type of stars of known spectral type.

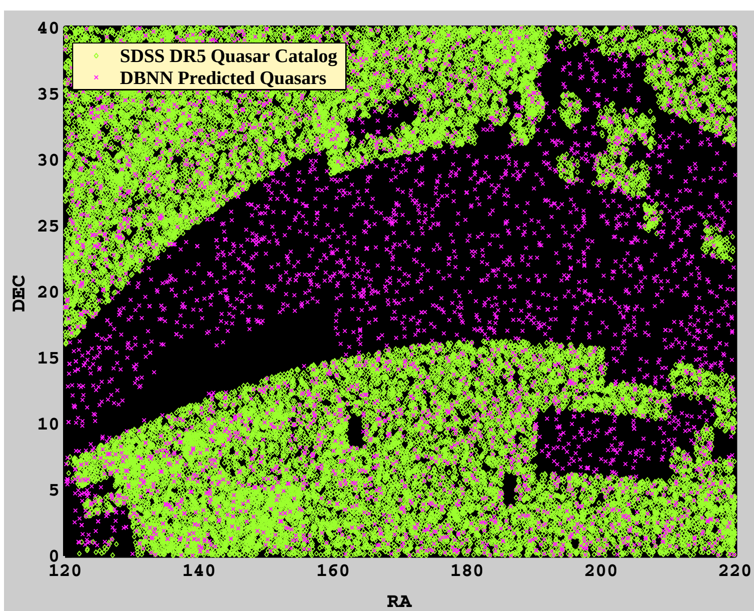

Figure 10: Quasar candidates that have been predicted by DBNN including the new quasar candidates which are not part of the SDSS DR5 quasar catalogue

ies. *Srianand* and his collaborators (Neeraj Gupta & Patrick Petitjean) searched for 21-cm absorption associated with the $z_{abs} = 1.3647$ absorption system toward PKS 0237-233 using the GMRT. A high quality UVES spectrum shows that C I and C I* are detected at this redshift together with C II*, Mg I, Mg II, Si II, Al II, Fe II and Mn II. The complex profiles, spread over 300 km/s, are fitted with 21 Voigt profile components. None of these components are detected in 21-cm absorption down to a detection limit of $\tau(3\sigma) \leq 3 \times 10^{-3}$ (or N(HI)/T_S < 10^{17} cm $^{-2}$ K^{-1}). They derive log N(HI)<19.30±0.30 using the Lyman alpha absorption line detected in the IUE spectrum of the quasar. Mg II, Si II and Al II column densities are consistent with near solar metallicity and they measure [O/H]> -0.33.

Using photoionization models constrained by the fine-structure excitations of C I and C II, and the 21-cm optical depth, they show that the C I absorption arises predominantly either in WIM or WNM in ionization and thermal equilibrium with the meta-galactic UV background dominated by QSOs and star forming galaxies. Photoionization models for the individual components are consistent with ionization by meta-galactic UV background. However, inconsistent with very large local radiation field as one sees in H_2 components in high-z DLAs. This suggests that the system is, at the time of observation, in a low star-formation state. The estimated thermal pressure of the gas is of the same order of magnitude over different velocity ranges through the absorption profile (2.6≤ log [P/k cm^{-3} K]≤ 4.0). The gas-phase metallicity corrected for ionization is Z>0.5 $Z_\odot$ with a signature of Fe co-production elements being under abundant compared to α-process elements by 0.5 dex. At z>1.9, C I absorption is usually associated with H_2 absorption arising from cold gas in DLAs.It is therefore somewhat surprising to have found a wide-spread C I absorption associated with the sub-DLA system. This suggests high metallicity. This system and the z=2.139 toward Tol 1037-270 are the only two systems known which show that C I absorption can also be detected in warm gas provided the metallicity is high enough. Interestingly, both the systems are part of unusual concentrations of absorption lines.

GMRT observations give a good constraint on N(H I)/T_s if one assumes complete coverage. However the background source show structures at milli-arcsec scale with a separation between the two brightest components of 85 pc at the absorption redshift. It is unclear which of these two components coincides with the optical point source. If the brightest component that has most of the flux in the redshifted 21 cm range coincides with the optical source then we would have detected 21 cm absorption if the C I gas originates from the CNM. The non-detection would be a definite argument for the gas being warm. However, if the weaker radio component coincides with the optical source, then even if the C I absorption originates from CNM gas our GMRT observations would not be able to detect the corresponding 21 cm absorption as the expected size of the cloud is smaller than the radio source separation. It is known that strong Mg II systems (with W_r >0.3Å) show coherent absorption over more than $\sim$ 2 kpc (Petitjean et al. 2000, Ellison et al. 2004). The fact that we find 20 distinct components along the line of sight to the optical point source means that it is likely that the overall system covers both sources. In that case GMRT observations are consistent with no CNM with log N(H I)≥ 19 along the radio source as well. Thus, it seems most likely that the region probed by the Mg II absorption system at z_{abs}= 1.365 is composed mostly of a warm neutral medium and/or warm ionized medium.

Out of the 50 Mg II systems studied in the ESO large programme 'The Cosmic Evolution of the IGM', only two systems show C I absorption (i.e z_{abs}= 1.365 and 1.6724 towards PKS 0237−233). The inferred N(H I), metallicity, and depletion pattern at z_{abs}= 1.365 toward PKS 0237−233 are similar to what is observed at z_{abs}= 2.139 toward Tol 1037−2703. The latter system also shows detectable C I* and C II* absorption lines spread over $\sim$ 70 km s^{-1}and distributed in two distinct velocity components without detectable H_2 absorption. Interestingly the only other system that shows C I absorption in the large programme data is also found towards PKS 0237−2703. This line of sight is famous for the presence of a super-cluster of C IV absorption lines. Thus, this study provides yet another motivation to go for further deep imaging and follow-up spectroscopic observations of the field. The article is published in MNRAS (Ref: *Srianand*, Gupta, Petitjean, 2007, MNRAS, 375, 584)

Hot halos around high redshift protogalaxies

In another work *Srianand* and his collaborators (Andrew Fox, Patrick Petitjean, Cedric Ledoux) have presented a study of the highly ionized gas (plasma) associated with damped Lyman-α (DLA) systems at z = 2.1-3.1. they searched for O VI absorption and corresponding Si IV, C IV, and N V in a Very Large Telescope/Ultraviolet-Visible Echelle Spectrograph (VLT/UVES) sample of 35 DLA systems with data covering O VI at S/N >10. They then used the optical depth profile comparisons and ionization modelling to investigate the properties, phase structure, and origin of the plasma.We reported twelve DLAs (nine intervening and three at

<5000 km s^{-1} from the QSO redshift) with detections of O VI absorption. There are no clear O VI non-detections, so the incidence of O VI in DLAs is between 34% (12/35) and 100%. Among these 12 DLAs, C IV and Si IV are seen whenever data is available, and N V is detected in 3 cases. Analysis of the line widths together with photoionization modelling suggests that two phases of DLA plasma exist: a hot, collisionally ionized phase (seen in broad O VI components), and a warm, photoionized phase (seen just in narrow C IV and Si IV components). The presence of inflows and/or outflows is indicated by individual O VI and C IV components displaced from the neutral gas (either blueshifted or redshifted) by up to 400 km s^{-1}. They have found a tentative evidence (98% confidence) for correlations between the DLA metallicity (measured in the neutral gas) and high-ion column density, and between the DLA metallicity and high-ion line width, as would be expected if supernova-driven galactic outflows rather than accretion produced the high ions. Using conservative ionization corrections, we found lower limits to the total hydrogen column densities in the hot (O VI-bearing) and warm (C IV-bearing) phases in the range log N_{HII}^{Hot} >19.5 to >21.1, and log N_{HII}^{Warm} > 19.4 to >20.9. On average, the hot and warm phases thus contain ≥ 40% and ≥ 20% of the baryonic mass of the neutral phase in DLAs, respectively.

Metallicity as a criterion to select H_2-bearing damped Lyman-α systems

In this work *Srianand* and his collaborators (Petitjean, Noterdaeme & Ledoux) have characterized the importance of metallicity on the presence of molecular hydrogen in damped Lyman-alpha (DLA) systems. They construct a representative sample of 18 DLA/sub-DLA systems with log N(HI)>19.5 at high redshift (z>1.8) with metallicities relative to solar [X/H]> -1.3 (with[X/H]= log (N(X)/N(H))-log(X/H) solar and X either Zn, S or Si). They gathered the data covering the expected wavelength range of redshifted H_2 absorption lines on all systems in the sample from either the literature (10 DLAs), the UVES-archive or new VLT-UVES observations for four of them. The sample is large enough to discuss for the first time the importance of metallicity as a criterion for the presence of molecular hydrogen in the neutral phase at high-z. From the new observations, they report two new detections of molecular hydrogen in the systems at z=2.431 toward Q2343+125 and z=2.426 toward Q2348-011. They compare the H_2 detection fraction in the high-metallicity sample with the detection fraction in the overall sample from Ledoux et al. (2003). They have shown that the fraction of DLA systems with log f=log 2N(H2)/(2N(H2)+N(HI))> -4 is as large as 50% for [X/H]> -0.7 when it is only about 5% for [X/H]< -1.3 and about 15% in the overall sample (with -2.5 <[X/H]< -0.3) (see Fig. 11). This demonstrates that the presence of molecular hydrogen at high redshift is strongly correlated with metallicity.

Velocity-metallicity correlation for high-z DLA galaxies: Evidence of a mass-metallicity relation?

If the DLAs trace starforming regions one expect to see the signatures of mass metallicity relation seen in galaxies. *Srianand* & his collaborators have used their large database of VLT-UVES quasar spectra to build up a sample of 70 Damped Lyman-α (DLA) or strong sub-DLA systems with total neutral hydrogen column densities of log N(H I)≥20 and redshifts in the range 1.7< z_{abs} <4.3. For each of the systems, they measured the metallicities relative to solar in an homogeneous manner, [X/H] (with X=Zn, or S or Si), and the velocity widths of low-ionization line profiles, ΔV. For the first time, they have provided evidence for a correlation between DLA metallicity and line profile velocity width, which is detected at the 6.1σ significance level. This confirms the trend previously observed in a much smaller sample by Wolfe & Prochaska (1998). The best-fit linear relation is [X/H]=1.55(± 0.12)logΔV -4.33 (± 0.23), with ΔV expressed in km s^{-1}. The slope of the DLA velocity-metallicity relation is the same within uncertainties between the higher (z_{abs} >2.43) and the lower (z_{abs} ≤ 2.43) redshift halves of their sample. However, the two populations of systems are statistically different. There is a strong redshift evolution in the sense that the median metallicity and median velocity width increase with decreasing redshift. We argue that the existence of a DLA velocity-metallicity correlation, over more than a factor of 100 spread in metallicity, is probably the consequence of an underlying mass-metallicity relation for the galaxies responsible for DLA absorption lines. Assuming a simple linear scaling of the galaxy luminosity with the mass of the dark-matter halo, they find that the slope of the DLA velocity-metallicity relation is consistent with that of the luminosity-metallicity relation derived for local galaxies. If the galaxy dynamical mass is indeed the dominant factor setting up the observed DLA velocity-metallicity correlation, then the DLA systems exhibiting the lowest metallicities among the DLA population should, on average, be associated with galaxies of lower masses (e.g., gas-rich dwarf galaxies). In turn, these galaxies should have the lowest luminosities among the DLA galaxy popula-

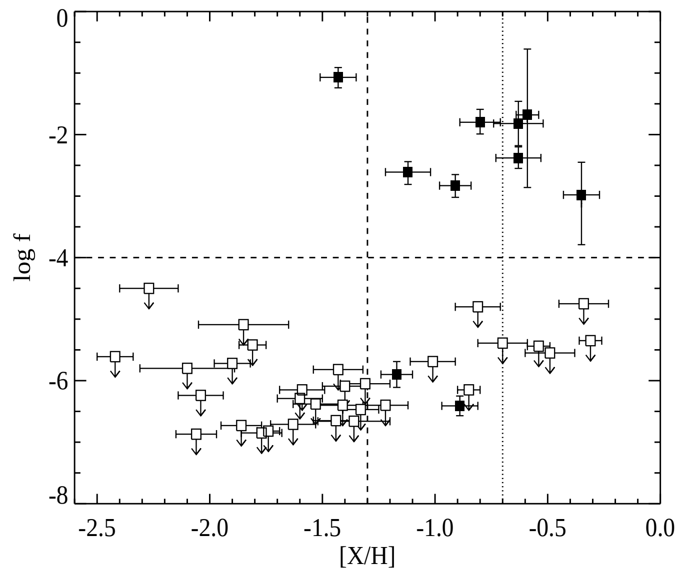

Figure 11: Logarithm of the molecular fraction, $f = 2N(\mathrm{H_2})/(2N(\mathrm{H_2}) + N(\mathrm{H\,I}))$, versus metallicities, $[\mathrm{X/H}] = \log N(\mathrm{X})/N(\mathrm{H}) - \log(\mathrm{X/H})_\odot$ and X either Zn, S or Si, in DLAs from the sample described in this paper ($[\mathrm{X/H}] > -1.3$, see Table 1) and the sample of Ledoux et al. (2003, $[\mathrm{X/H}] < -1.3$). Filled squares indicate systems in which H_2 is detected. Dashed lines indicate the limits used in the text ($\log f = -4$; $[\mathrm{X/H}] = -1.3$). The dotted line indicate the median of the high-metallicity sample ($[\mathrm{X/H}] = -0.7$).

tion. This could explain the difficulties of detecting high-redshift DLA galaxies in emission. The results are published in A&A.

Warm Absorbers in AGN

Warm Absorbers are highly photoionized gas found along our line of sight to the continuum source of active galactic nuclei (AGN). Their signatures are a wealth of absorption lines and edges from highly ionized species, notably OVII, OVIII, CV, FeXVII, NeX, in the soft X-ray (0.3-1.5 keV) spectra. The typical column density observed for the gas is $N_\mathrm{H} \sim 10^{22\pm1}\,\mathrm{cm}^{-2}$ and the temperature T is typically estimated to be a few times 10^5 K. Susmita Chakravorty and Ajit Kembhavi with collaborators Martin Elvis (CFA, Harvard University, USA) and Gary Ferland (Kentucky University, USA) are working on two parallel issues regarding warm absorbers.

Effect of Dielectronic Recombination Coefficient on the calculations for warm absorbers and other similar plasma

Any stable photoionized gas will lie on the thermal equilibrium curve or 'stability' curve, in the the temperature - pressure phase space, where heating balances cooling. The equilibrium depends on the shape of ionizing continuum and the chemical abundance of the gas which can be used as parameters in generating the curves using photoionization codes like CLOUDY. Fig. 12 shows such stability curves generated by an older (1993-96) version C84 and a more modern (2006) version C06 of CLOUDY for the same set of physical parameters, viz. an optically thin, gas of Solar metallicity and with constant density $10^9\,\mathrm{cm}^{-3}$, being ionized by a power-law continuum with photon index $\Gamma = 1.8$, extending from 13.6 eV to 40 keV. $\xi = L/nR^2$ is the ionization parameter, where L is the luminosity of the central engine of the AGN, n the density of the absorbing gas and R its distance from the central source. ξ/T is proportional to the ratio of the radiation pressure to the gas pressure; so an isobaric perturbation of a system in equilibrium is represented by a vertical displacement from the curve, and only changes the temperature. If the system being perturbed is located on a part of the curve with positive slope, which covers most of the curve, then a perturbation corresponding to an increase in temperature leads to cooling, while a decrease in temperature leads to heating of the gas. Such a gas is therefore thermally stable. But if the system is located on one of the few parts of the curve with negative slope, then it is thermally unstable because isobaric perturbations will lead to runaway heating or cooling.

From the stability curves it was found that the results are significantly different in the tempera-

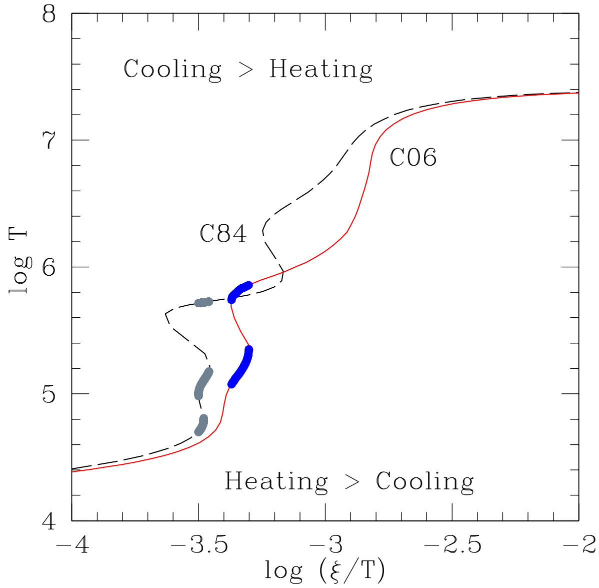

Figure 12: Stability curves derived using different version C84 and C06 of CLOUDY

ture range $10^{4.5} \lesssim T \lesssim 10^{7.2}$ K, which is the region of interest for the warm absorbers. C84 predicts three discrete phases coexisting at the same pressure, whereas C06 shows only two phases. Most interestingly, C84 predicts the warm absorber to be in pressure equilibrium with a 10^4 K gas and may imply some connection between X-ray and UV absorption systems as have been observed in some objects. However, no such possibility is exhibited in version C06.

In order to isolate the atomic physics underlying the change in the stability curve, the fractional variation of temperature $\Delta T/T_{C06} = (T_{C84} - T_{C06})/T_{C06}$, from one version to another is plotted against $\log \xi$ in top left panel of Figure 13. The ions which are the major cooling agents for the absorbing gas are indicated in the middle left panel. Similarly, the principle heating agents are shown in the lower left panel. To identify the ions which are responsible for $\Delta T/T_{C06} \gtrsim 80\%$, the column densities of all these ions are compared for both the versions in the right panel of Figure 13 where C84 is dotted lines and C06 is solid. Maximum variation in column densities, up to even a factor of 10, are shown by the major cooling agents like He+1, high ionization species of silicon (+10, +11 and +12) and iron (+21, +22 and +23). These are among the ions for which dielectronic recombination rate coefficients have been updated over the last decade. Hence, it was shown that the enhanced cooling in C06 due to the change in drrc is the cause of the shift in the stability curves and hence the differences in the physical predictions for warm absorbers. This puts constraints on the reliability of earlier results, and also cautions about the likelihood of further changes in the future due to such changes in the underlying atomic physics database which play a major role in calculating the values for the crucial physical parameters.

Study of nature of warm absorber as a function of the irradiating ionizing continuum and the abundance of the absorbing gas

Various authors have considered the possibility of the warm absorber being a two or three phase medium. The nature of the WA and its thermal stability are most significantly affected by the shape of the ionizing continuum emitted by the central source of the active galactic nucleus and the chemical composition of the absorber.

The soft X-ray part of the observed spectra for AGN are usually modeled as a simple powerlaw. Another observational constraint from observations comes from $1.0 < \alpha_{OX} < 2.0$ where α_{OX} is a measure of the relative flux at 2500$\mathring{A}$ and 2 keV. Taking all these observational constraints into account, the SED of the ionizing continuum for the WA is assumed to be a combination of two powerlaws. α_1 is the flatter spectral index responsible for the flux index in the soft X-ray and the steeper component with index $\alpha_2 = 2.0$ is added to get the value of α_{OX} in the observed range by adjusting some normalisation factor η. For most quasars, the soft X-ray spectral index lies in the range $1.7 < \alpha_1 < 1.9$. From the stability curves generated, it is found that AGN having flat soft X-ray spectra with $\alpha_1 < 0.4$ are not likely to have WAs. Multiphase nature of the gas can only be seen for AGN spectra with in-

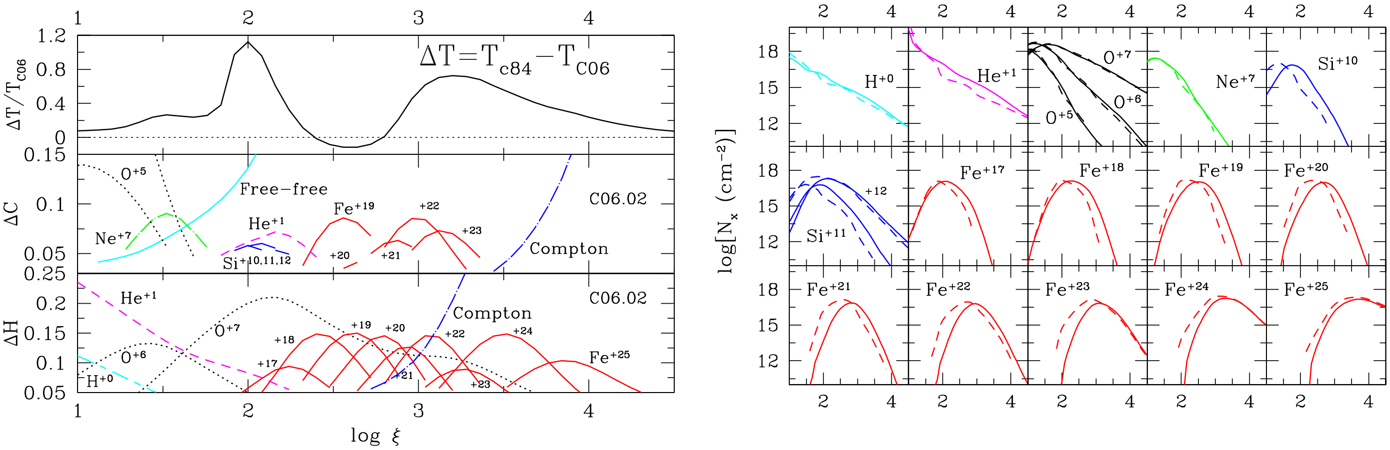

Figure 13: Left panel : The ions which are the principal cooling and heating agents are indicated along as a function in the same $\log \xi$ range where $\Delta T \neq 0$. Right panel : The column densities for the principal cooling and heating agents are compared from version C84 to C06

termediate slopes $0.4 \lesssim \alpha_1 \lesssim 0.9$, if the gas has Solar metallicity. If the chemical composition is altered, then the multiphase behaviour of the gas changes very significantly. Similar trends are shown by the EUV to soft X-ray slope α_{OX}.

Similar analysis done for the chemical composition of the absorbing gas shows that as the metallicity of the absorber is decreased from super-Solar to Solar to sub-Solar, the stability curve flattens gradually. The possibility of finding multiphase warm absorber decreases with decrease in metallicity. It also decreases if the absorbing medium is deficient in some elements. It is interesting to note that if a WA lacks iron, but has all the other elements with Solar abundance, it will mimic the stability properties as an absorber with half-Solar abundance! The X-ray group of elements (oxygen, carbon, neon and iron) are the most influential in making multiple phases possible. A stable solution for the WA is present for all non-zero metallicities we have considered; only the nature of the WA varies with the change in its chemical composition. However, a primordial gas of hydrogen and helium gas has no stable thermal states corresponding to warm absorber temperatures.

To complete this work, a quantitative comparison on the multiphase nature of the WAs as a function of the various parameters discussed above, is being attempted.

Magnetic Fields in Astrophysics

Galactic dynamos supported by magnetic helicity fluxes

The major controversy in mean-field dynamo theory is related to its nonlinear form relevant when the initial exponential growth of the large-scale magnetic field saturates and the field reaches statistical equilibrium. The core of the problem is the effect of the small-scale (turbulent) magnetic field on the evolution of the large-scale (mean) magnetic field. In particular, the α-effect (a key ingredient of the mean-field dynamo) could be catastrophically quenched well before the large-scale magnetic field can be amplified to the strength observed in astrophysical objects. The suppression of the α-effect has been now shown to be a a consequence of the conservation of magnetic helicity in a medium of high electric conductivity. The losses of the small-scale magnetic helicity through the boundaries of the dynamo region can alleviate such quenching and so be essential for mean-field dynamo action.

A simple semi-analytical model of nonlinear, mean-field galactic dynamos was developed and used by *S. Sur*, *K. Subramanian* and A.Shukorov to study the effects of various magnetic helicity fluxes. The dynamo equations are reduced using the '*no-z*' approximation to a nonlinear system of ordinary differential equations in time. The model reproduces accurately earlier results, including those where nonlinear behavior is driven by a magnetic helicity flux. The implications and interplay of two types of magnetic helicity flux, one produced by advection (e.g., due to the galactic fountain or wind) and the other, arising from anisotropy of turbulence as suggested by Vishniac and Cho, were analyzed.

The latter is shown to be significant if the galactic differential rotation is strong enough. The intensity of gas outflow from the galactic disc optimal for the dynamo action is close to that expected for normal spiral galaxies. The steady-state strength of the large-scale magnetic field supported by the helicity advection is still weaker than that corresponding to equipartition with the turbulent energy. However, the Vishniac-Cho helicity flux can boost magnetic field further to achieve energy equipartition with turbulence. For stronger outflows that may occur in starburst galaxies, the Vishniac-Cho flux can be essential for the dynamo action. However, this mechanism requires a large-scale magnetic field of at least $\simeq 1\mu$ G to be launched, so that it has to be preceded by a conventional dynamo assisted by the advection of magnetic helicity by the fountain or wind.

Kinetic and magnetic alpha effects in nonlinear dynamo theory

In the kinematic regime, the α-effect, a crucial driver of the mean field dynamo (MFD), depends only on the helical properties of the turbulence. It is crucial to understand how the α-effect gets modified due to the back reaction of the generated mean and fluctuating fields. Using closure schemes or the quasi-linear approximation it has been argued that, due to Lorentz forces, the α-effect gets "renormalized" by the addition of a term proportional to the current helicity of the generated small scale magnetic fields. However, it has been argued by others that, even the nonlinear α-effect can be expressed exclusively in terms of the velocity field, albeit one which is a solution of the full momentum equation including the Lorentz force. In the latter case, it is not obvious that the helicity of the small scale magnetic field plays any explicit role in the back reaction to α. It is important to clarify this issue, as it will decide how one should understand the saturation of turbulent dynamos, as well as the possibility of catastrophic quenching of the α-effect and ways to alleviate such quenching.

In order to clarify these conflicting views, *S. Sur*, *K. Subramanian* and A. Brandenberg examined an exactly solvable model of the nonlinear back reaction to the α-effect, where they assume small magnetic and fluid Reynolds numbers. In this limit one can use the first order smoothing approximation (FOSA) to solve both the induction and momentum equations and hence exactly solve for the α-effect. Obviously, this approach does not allow them to address the question of catastrophic quenching of astrophysical dynamos, at large Reynolds numbers directly, but it allows them to make novel and unambiguous statements that help clarifying the nature of magnetic saturation.

Both steady and time dependent forcings were considered. The nonlinear α-effect is then shown to be expressible in several equivalent forms in agreement with formalisms that are used in various closure schemes. On the one hand, one can express α completely in terms of the helical properties of the velocity field as in traditional FOSA, or, alternatively, as the sum of two terms, a so-called kinetic α-effect and an oppositely signed term proportional to the helical part of the small scale magnetic field. These results hold for both steady and time dependent forcing at arbitrary strength of the mean field.

In addition, the α-effect is computed in a manner akin to a recently introduced closure, called the τ-approximation. One gets in this method interesting differences between the steady and time dependent forcing. For steady forcing, the correlation between the forcing function and the small-scale magnetic field turns out to contribute in a crucial manner to determine the net α-effect. However for delta-correlated time-dependent forcing, this force–field correlation vanishes, enabling one to write α exactly as the sum of kinetic and magnetic α-effects, similar to what one obtains also in the large Reynolds number regime in the τ-approximation closure hypothesis.

In the limit of strong imposed fields, B_0, they find $\alpha \propto B_0^{-2}$ for delta-correlated forcing, in contrast to the well-known $\alpha \propto B_0^{-3}$ behavior for the case of a steady forcing. The analysis is also shown to be in agreement with numerical simulations of steady as well as random helical flows. On the whole, this work demonstrates, using an exactly solvable model, that the effect of Lorentz forces can indeed be thought of as renormalizing the α-effect by the addition of a term proportional to the current helicity of the generated small scale magnetic field.

Simulations of the anisotropic kinetic and magnetic alpha effects

Using simulations of isotropically forced helical turbulence *K. Subramanian* and A. Brandenberg have computed the contributions to kinetic and magnetic alpha effects were computed. It was shown that for the parameter regimes considered in an earlier work the expressions for isotropic and anisotropic alpha effects give quantitatively similar results. Both kinetic and magnetic alpha effects are proportional to a relaxation time whose value, in units of the turnover time, is shown to be approximately unity and independent of the magnetic Reynolds number.

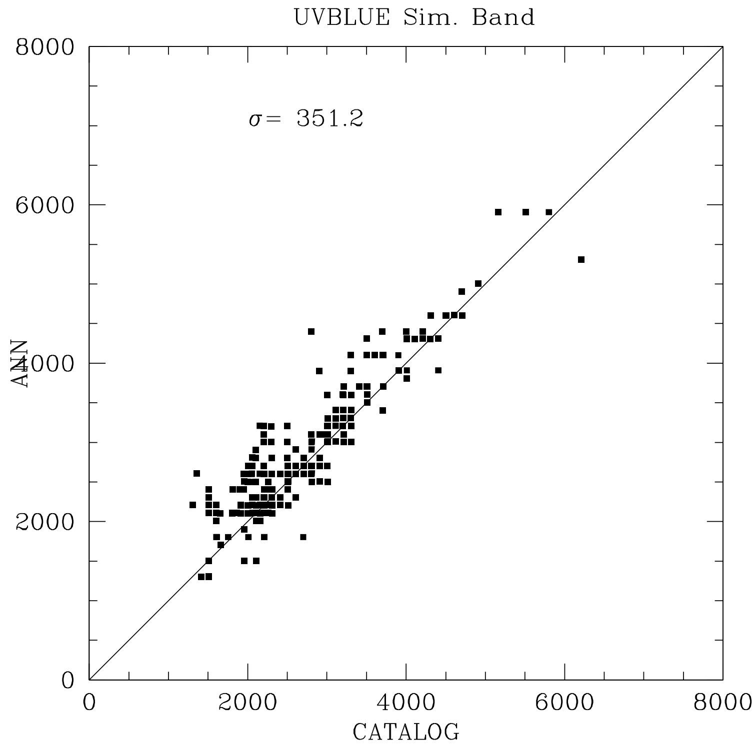

Figure 14: Scatter plot of classification accuracy of the 229 IUE spectra using 286 simulated TAUVEX spectra of the training set. Both IUE and simulated spectra have four values of integrated fluxes in the four TAUVEX filter bands.

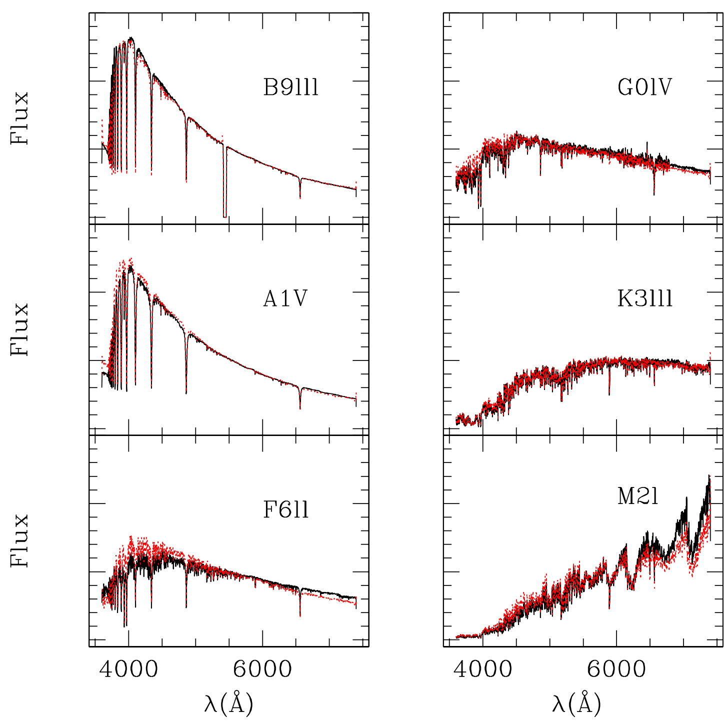

Figure 15: Recalibration of some of the CFLIB spectra with MILES interpolator. The black spectra are the original CFLIB spectra and the ones in red color are after the recalibration process.

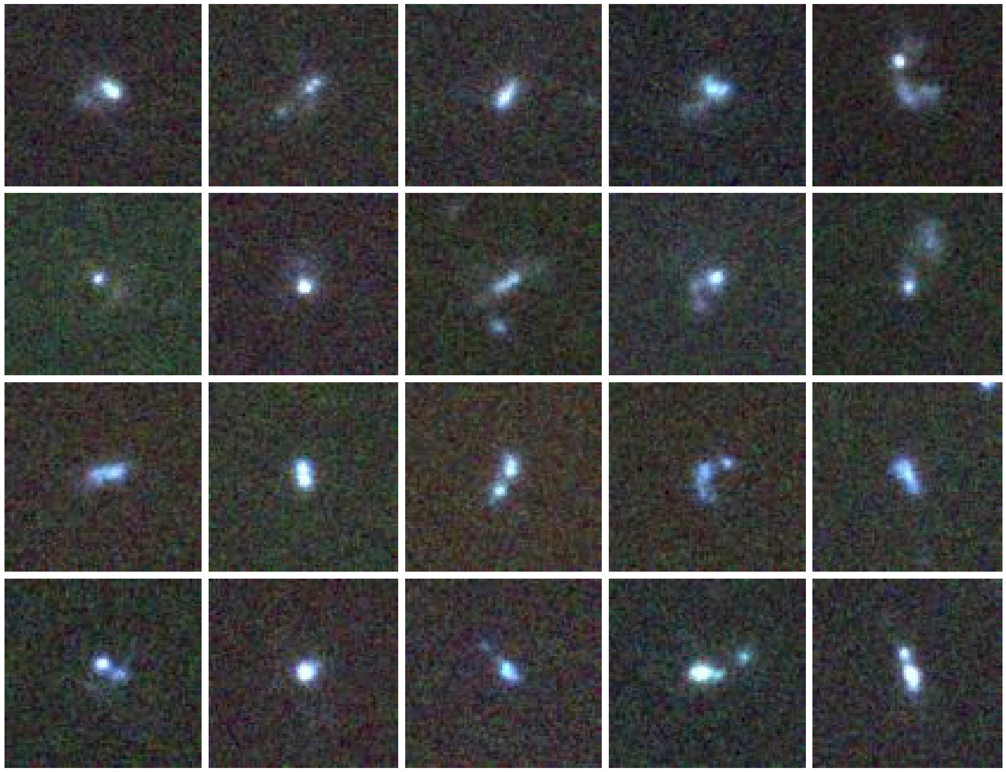

Figure 16: Viz color composites of the Lyman-Break Galaxies (LBGs) at $2.5 < z < 3.1$ from the *Hubble Space Telescope*/ACS images obtained by the GOODS treasury project. The LBGs were selected as U-dropouts using combination of the *HST*/ACS images and deep, ground-based U-band imaging.

High Energy Astrophysics

Ultra-luminous X-ray (ULX) sources

Ultra-luminous X-ray (ULX) sources are X-ray points sources in nearby galaxies, which are extremely bright ($> 10^{39}$ ergs/sec) and hence are expected to harbor intermediary size black holes ($10^2 - 10^4 M_\odot$). A. Senorita, *R. Misra*, *V. K. Agrawal* and Y. P. Singh have undertaken a systematic spectral study of these sources. Apart from studying the effect different spectral models on the analysis, their goal was to identify truly extremely luminous sources ($> 10^{40}$ ergs/sec) which must necessarily harbor these anomalous black holes. Out of the 365 sources from thirty galaxies they analyzed, they found four excellent candidates for such sources. Follow up and more detailed analysis can now be undertaken on these sources. F. Yuan, R. E. Taam, *R. Misra*, X. B. Wu and Y. Xue, studied the the spectrum of a bright ULX in the galaxy M82, and compared it with the expected emission from a Advection dominated accretion flow (ADAF) around a intermediate size black hole. They found that the model is consistent with the data and hence provided evidence for the existence of such black holes.

Black hole binaries

The spectra of black hole binaries is a result of complicated processes involving pair production/annihilation and Inverse Comptonization. S. Bhattacharyya and *R. Misra* are continuing their study of these processes and in particular are addressing the issue of computing the effect of Inverse Comptonization between high energy photons and low energy (thermal) electrons. In this regime, the range of change in energy of the photon is very large and hence difficult to numerically implement. They are testing a hybrid scheme where a diffusion equation and an Intergo-differential one is used to describe the phenomenon.

Gamma Ray Bursts

Although it has now been well established that Gamma-Ray Bursts (GRB) are of cosmological origin, their nature and source still remains a mystery. The detection of supernova light curve in the afterglows of long duration nearby GRB has indicated that a fraction of the GRB occur during the the collapse of a massive star. Other mechanism that could produce GRB are the merger of compact objects like a pair of neutron stars or a neutron star with a black hole. Thus GRB may be an heterogeneous group and a proper classification of the phenomena is crucial to isolate and identify the possible different sources. Such a classification will also enable the identification of spectral or temporal correlations which may exist only for a particular class of GRB. T. Chattopadhyay, *R. Misra*, A. K. Chattopadhyay and M. Naskar have applied two different multivariate clustering techniques, the K-means partitioning method and the Dirichlet process of mixture modeling, to the BATSE Gamma-ray burst (GRB) catalog, to obtain the optimum number of coherent groups. In the standard paradigm, GRB are classified in only two groups, the long and short bursts. However, for both the clustering techniques, the optimal number of classes was found to be three, a result which is consistent with previous statistical analysis. It is speculated that the three kinds of GRB reflect three different origins which may be mergers of neutron star systems, white dwarf with neutron stars and collapse of massive stars.

Black hole motion as a catalyst of orbital resonances

Black hole dynamics in galactic nuclei has attracted attention for many years. The advent of high-resolution spectroscopic cameras in the 1990's, such as the STIS on-board the HST, has led to the identification of a pletora of supermassive black hole (BH) candidates in nearby galaxies. The influence of a black hole on its surrounding stars is felt first through the large velocity dispersion and rapid orbital motion of the inner-most cluster stars ($\sigma \sim v_{1d} \sim 10^3$ km/s). This sets a scale GM_{bh}/σ^2 ($\simeq 0.015 - 0.019$ pc for the Milky Way, henceforth MW) within which high-angle scattering or stellar stripping and disruption may take place. For the MW, low-impact parameter star-BH encounters are likely, given the high density of $\rho \sim 10^7 M_\odot/\mathrm{pc}^3$ within a radius of about 10 pc. Star-BH scattering, occurring over a relaxation time, leads to the formation of a Bahcall-Wolf stellar cusp of density $\rho_\star \sim r^{-\gamma}$ where γ falls in the range 3/2 to 7/4. Genzel et al. (2003) modeled the kinematics of the inner few parsecs of Sgr A$\star$ with a mass profile $\rho_\star \sim r^{-1.4}$, suggestive of a strong interplay between the black hole and the central stellar cusp. More recently, Schödel et al. (2007) presented a double power-law fit to the data, where the power index changes from 1/2 to 7/4 around a breaking radius of $r_{br} \simeq 0.2$ pc. This is indicative of ongoing evolution inside r_{br} not accounted for in the Bahcall-Wolf solution.

Most, if not all, studies of galactic nuclei dynamics assume a fixed black hole (or black hole binary) at the centre of coordinates. *Padmanabhan* (in collaboration with C.Boily and A. Paiement) has recently studied the effects of relaxing this assumption. They find that, under certain circumstances, a moving black hole can act as a catalyst transferring the energy between the stars. In doing this, they aim to fill an apparent gap in the modeling of black hole dynamics in dense nuclei, by relaxing further the constraint that the hole be held fixed at the centre of coordinates.

The motion of a black hole about the centre of gravity of its host galaxy induces a strong response from the surrounding stellar population. They treat the case of a harmonic potential analytically and show that half of the stars on circular orbits in that potential shift to an orbit of lower energy, while the other half receive a positive boost and recede to a larger radius. The black hole itself remains on an orbit of fixed amplitude and merely acts as a catalyst for the evolution of the stellar energy distribution function $f(E)$. *Padmanabhan* and collaborators further show that this effect is operative out to a radius of $\approx$ 3 to 4 times the hole's influence radius, R_{bh}. Using numerical integration to explore more fully the response of a stellar distribution to black hole motion, they consider orbits in a logarithmic potential and compare the response of stars on circular orbits, to the situation of a 'warm' and 'hot' (isotropic) stellar velocity field. While features seen in density maps are now wiped out, the kinematic signature of black hole motion still imprints the stellar line-of-sight mean velocity to a magnitude $\simeq 18\%$ the local root mean-square velocity dispersion σ. These effects have potentially observable consequences.

Stars and Interstellar Medium

Galaxy and interstellar medium

Under an ISRO-RESPOND project for Spectral Classification of stars from the database of TAUVEX satellite, *Archana Bora*, *Ranjan Gupta* and H.P. Singh have successfully developed an Artificial Neural Network based code for spectral classification of the TAUVEX UV band data. Fig. 14 shows the scatter plot of this classification where an accuracy of approximately 3 sub-spectral class has been obtained by training simulated TAUVEX band flux data testing on equivalent IUE data.

Stellar physics

Under an INDO-FRENCH collaborative programme, Phillipe Prugniel, *Ranjan Gupta*, H.P. Singh and S. Jotin Singh have performed the flux recalibration of the INDO-US CFLIB spectral library by using ELODIE spectral interpolator. A typical flux recalibration is shown in Fig. 15

Instrumentation

FIFUI - Fibre-based integral field unit for IFOSC

M. Srivastava and *A. N. Ramaprakash* have been working on designing a Fibre-based Integral Field Unit for IUCAA Faint Object Spectrograph Camera (IFOSC), the main instrument which is mounted on the direct Cassegrain port of IUCAA telescope. It is based on the idea of connecting an area at the focal plane of the telescope with the slit of the spectrograph using a fibre bundle with some coupling optics. In this way spectra of the entire surface of an extended object can be taken in one go. Each individual spectrum appears well separated on the detector; therefore, spatial information and spectral information are collected simultaneously. The proposed IFU would be optimized for visible spectrum and would consist of 100 fibres. The field of view of this IFU would be 14 arc sec X 7 arc sec with three modes of sky sampling i.e 1 arc sec per fibre, 0.8 arc sec per fibre and 1.2 arc sec per fibre. The optical design of the IFU is presented here.

The IFU is made up of three sections: (1) Fore Optics, (2) Lenslets + Fiber Unit and (3) the Output Optics. The primary job of the fore-Optics is to provide the necessary magnification to feed an array of lenslet coupled fibres with the correct spatial sampling. It has to produce a telecentric output so that maximum light coupling would be achieved between the lenslets and the fibres. The designed fore Optics consists of an achromatic doublet lens (made up of PFK85 and KF5 glasses from Sumita Optical Glasses, Japan) and a single field lens (made up of PFK85 glass from Sumita Optical Glasses, Japan). Depending on the mode of sampling, three different achromatic doublet lenses having different focal lengths would be used to provide magnification of 20.6 (for 1 arc sec per fibre), 25.75 (for 0.8 arc sec per fibre), and 17.17 (for 1.2 arc sec per fibre), while the singlet lens has the same focal length in all the three cases. The Optical layout of the fore-Optics and the corresponding spot diagram are shown in Fig.17 and Fig.18 respectively, corresponding to the magnification of 20.6.

The lenslet+fibre unit is used to sample the magnified image and to transport the light from the magnified image plane to the spectrograph. The lenslets (hexagonal in shape) form a continuous 2-Dimensional surface and an Optical Fibre would be attached behind each lenslet. The Plano-convex lenslets are designed with PFK85 glass (from Sumita Optical Glasses, Japan) having diameter of 2.1mm . These lenslets would feed light into the Optical fibres (having core diameter 70 micron) with the f/4 beam. This focal ratio and core diameter are chosen to minimize the Focal ratio degradation (FRD) effects in the optical fibres and to maximize the light coupling efficiency between lenslet and fibre.

Finally, at the output, the fibres would be aligned along an one dimensional slit and an Output Optics is used to couple this fibre slit to the Spectrograph. Considering that the fibre slit would provide f/4 beam at its output and the spectrograph (IFOSC) is designed to accept f/10 beam, this output optics is designed to provide magnification of 2.5 in the telecentric way. The Output optics consist of two singlet lenses (made up of BK7 glass from Sumita Optical Glasses, Japan) and an achromatic doublet lens (made up of PFK85 and KF5 glasses from Sumita Optical Glasses, Japan). The Optical layout of the Output Optics and the corresponding spot diagram are shown in Fig.19 and Fig.20 respectively.

Mirror coating plant for IUCAA Telescope:

A mirror coating plant based on the magnetron sputtering technique has been fabricated at HHV, Bangalore and is in the process of commissioning at the IUCAA Giravali telescope site by *Ranjan Gupta*, *A.N. Ramaprakash*, *H.K. Das*, *M.P. Burse* and *A. Kohok*.

Detectors with high spatial resolution for Ultra Violet Imaging Telescope (UVIT)

Ultra Violet 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 year 2008. UVIT makes images in a field of 0.5 degree with a resolution of < 1.8”, simultaneously in three channels: 1200 - 1800 A, 1800 - 3000 A, and 3500 - 5500 A.

Spatial resolution of < 1.8” is one of the most important features of UVIT – this can be compared with a spatial resolution of 5” for Galex. To achieve this a programme of development of intensified-imaging-detectors was undertaken, and a contract was awarded to Photek Ltd., UK. The detectors made at Photek have now been tested for their resolution in near ultraviolet. The results are shown in Fig. 21. It is seen that a gap of 0.12 mm, between photo-cathode and MCPs, can give an image size of 20 microns at 180 nm; 20 microns corresponds to 0.8” for UVIT. This result has been obtained with a detector for visible range, and it is expected that a detector for near ultraviolet would give a better resolution, as these detectors have a cut-off at 300 nm and hence the photo-electrons

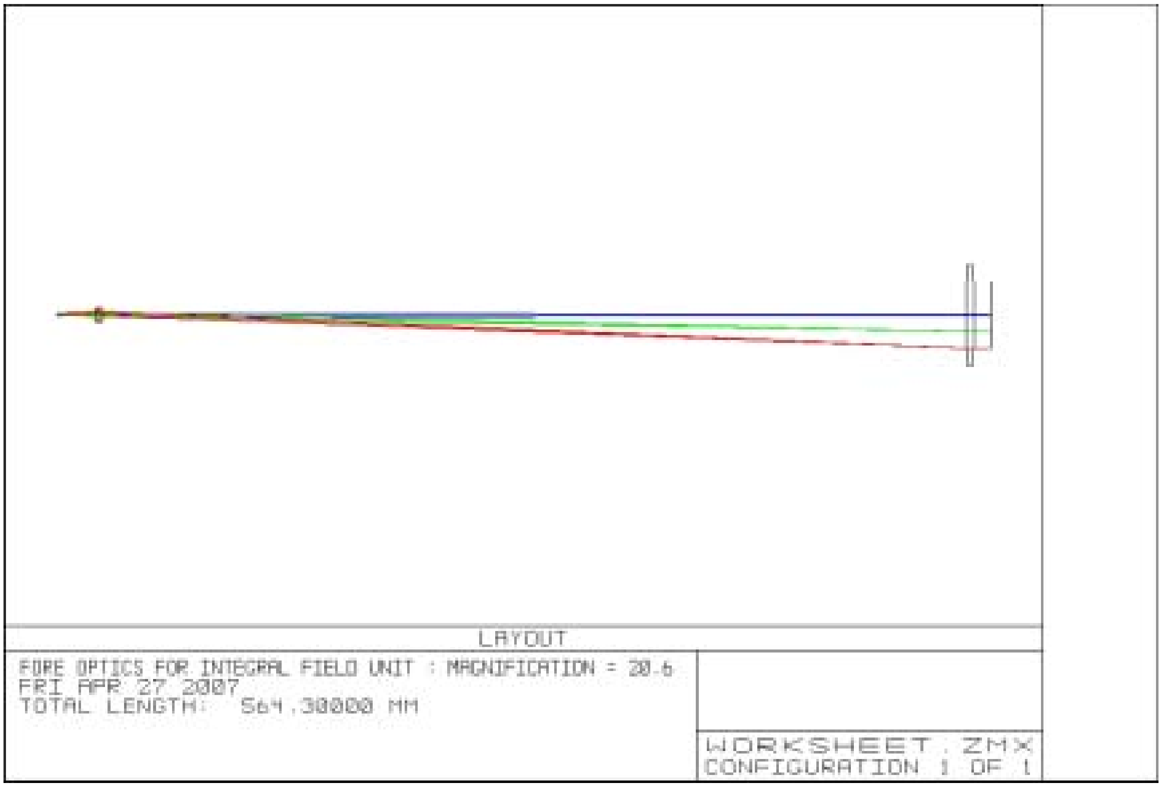

Figure 17: Optical layout of the Fore-Optics for the magnification of 20.6

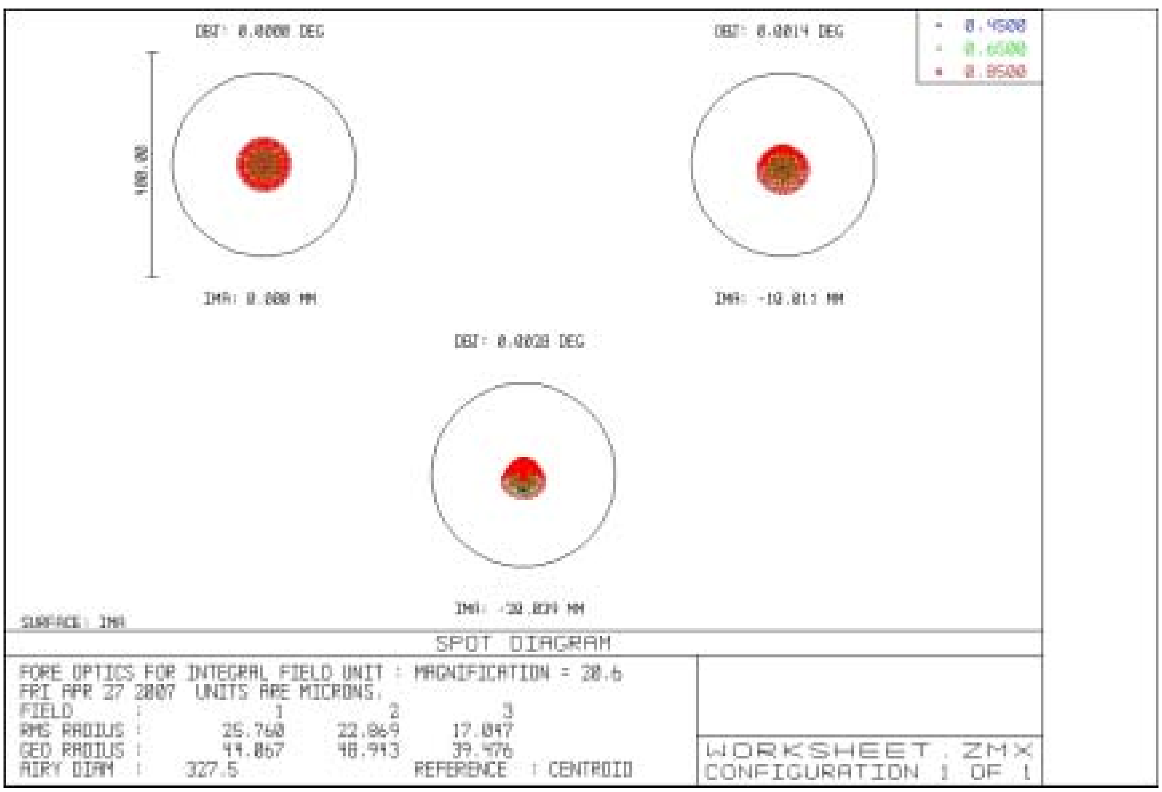

Figure 18: Performance of the Fore Optics: Spot Diagram; For the magnification of 20.6

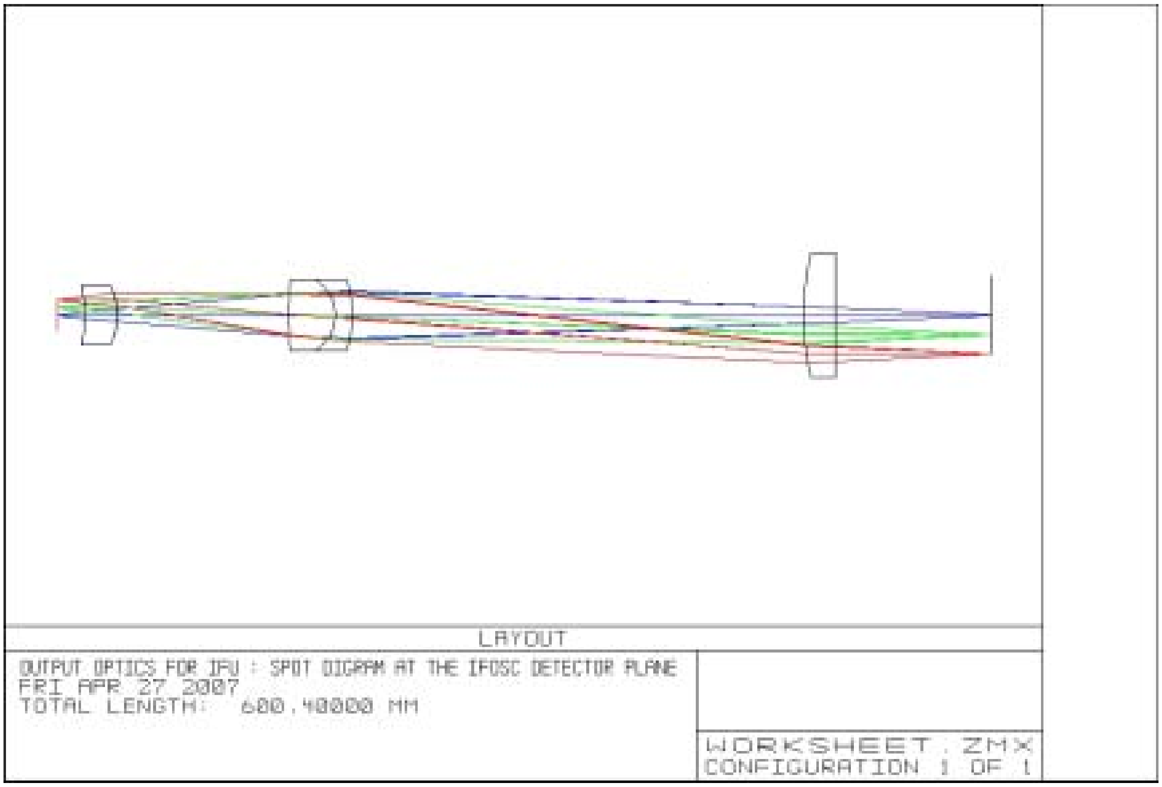

Figure 19: Optical layout of the Output Optics

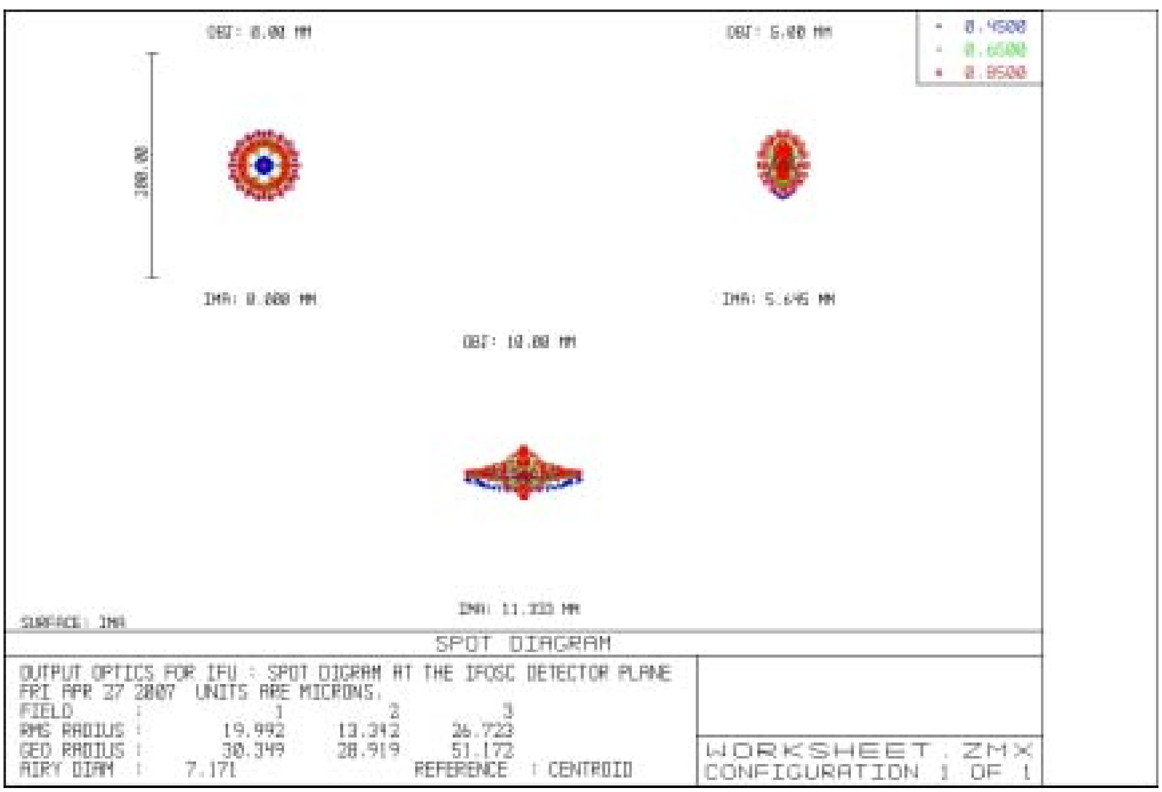

Figure 20: Performance of the Output-optics: Spot diagram at the IFOSC detector plane

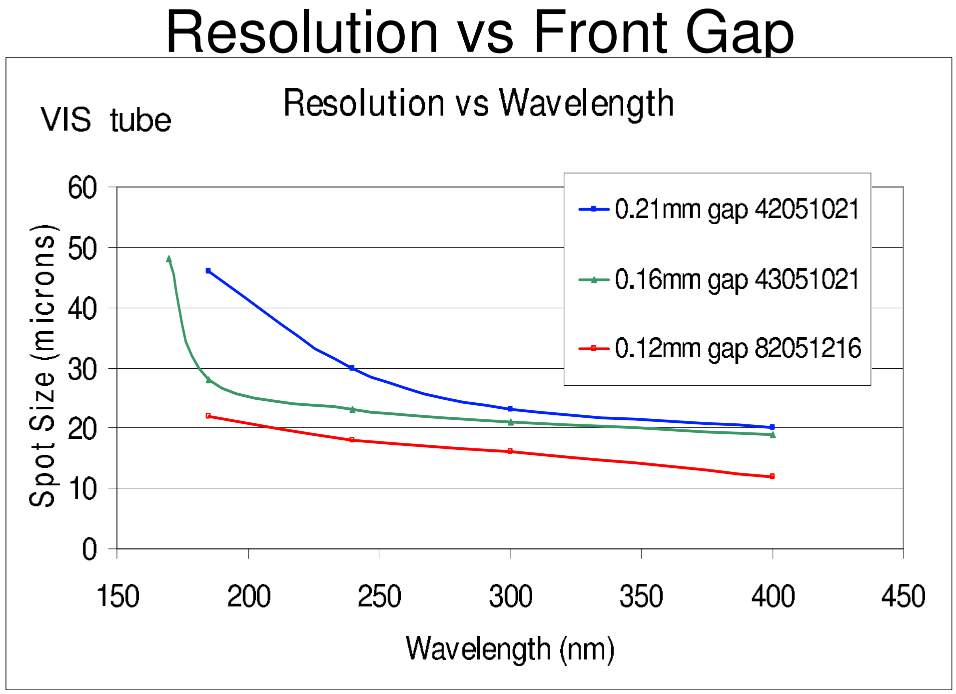

Figure 21: The dependence of spatial resolution of a detector is shown, for three values of the gap between photo-cathode and MCPs, as a function of wavelength, (from a report by Photek Ltd. UK)

would have a lower energy. The cut-off for far ultra-violet detectors is 180 nm, and the photo-electrons for 130 nm in this detector would have the same energy as those for 180 nm in the visible detector. The tests on bending of MCPs showed that a gap of 0.1 mm between photo-cathode and MCPs is large enough to ensure safety against vibration/shock of the launch, and thus the gap can be kept as small as 0.1 mm to get a good spatial resolution. Thus, it is expected that contribution of the ultraviolet detectors to the resolution would be < 1", in the overall resolution of 1.8".

Search for micro-organisms in outer space

In collaboration with the National Centre for Cell Sciences (Yogesh Shouche), Centre for Cellular and Molecular Biology (Shivaji),Tata Institute of Fundamental Research (R. Manchanda) and ISRO (C.B.S. Dutt), *J.V. Narlikar* has been involved as Principal Investigator of a project to sample air at varying heights up to 41 km, using a cryosampler attached to a balloon. The air samples are being analysed at NCCS and CCMB and the results are expected later in 2007. U.R. Rao (ISRO) and P.M. Bhargava (Anveshna) are advisors to this investigation.

(II) RESEARCH BY VISITING ASSOCIATES

Archaeoastronomy

Iqbal, Naseer

A collaborative group comprising of M. N. Vahia of TIFR (Mumbai) along with Naseer Iqbal and others from Department of Physics, University of Kashmir, Srinagar have analyzed a rock carving found in Sopore(Kashmir) first reported by Banday(2003) and described by Yatoo(2005). The question is when did humans begin astronomical observations and the answer can be given by studying the Architecture of ancient monuments, simulations of ancient astronomical observatories and situations, study of stone carvings, cave paintings, temple and city architecture, computer simulation of evolution of cultures and carbon dating. This part of the observational astronomy is called archaeoastronomy. The group has recently identified one Paleolithic rock carving and comparison with the geographical features of the region show how several components of it agree with the local geophysical morphology. An interpretation of the carving based on comet showers and astronomy seems a very likely one. Some tests are to be conducted to check this interpretation.

Accretion Disks

Chaudhuri, Sarbeswar

Studies on accretion disks have gained much importance in relativistic astrophysics. The problem becomes more interesting when the disk properties are analyzed with a mass (such as a black hole) at its centre. The black hole due to its intense gravitational field attracts matter from its surroundings. The attracted matters owing to its angular momentum drift towards the black hole in a spiral path. The material particles are highly compressed and form an accretion disk around the black hole.

S Chaudhuri is now engaged in studying the behavior of various types of accretion disks around black holes. Disks are classified in to two categories: thin disk and thick disk. For thin disk, the mass of the disk is assumed to be negligible in comparison with the mass of the black hole while for thick disk, the disk mass has to be taken into consideration. Although the solution of a rotating disk around a stationary black hole represents the real physical situation, the complexity of the problem does not always allow to construct physically acceptable solutions by analytical methods. In order to make the calculations simple, both the disk and the black hole are assumed to be static. A static disk is interpreted in the literature as the rotation and counter rotation of equal number of particles so that the total angular momentum of the system is zero.

A number of solutions with different disk potentials have been derived. The energy density, pressure and the stability of the disk with or without a black hole at the centre are investigated. It is observed from the analysis that for a Kuzmin disk around a Schwarzschild black hole, as $r \longrightarrow \infty$, both the energy density and pressure of the disk - black hole combination becomes zero. At $r = 0$, the energy density becomes zero whereas the pressure does not vanish there. This signifies that the presence of the black hole tends to stabilize the disk. When r is large but finite, the energy density of the disk varies with the inverse cube power of r and the pressure varies inversely with r. The disk particles acquire superluminal velocities inside the photonic orbit (i.e. $r < 3m$).

Compact Objects, X-ray Binaries and Globular Clusters

Chattopadhyay, Tanuka and Asis

Characterizing the shape and evolution of pulsar radio emission beams is important for understanding the observed emission. The various attempts by earlier workers investigating beam shapes have resulted in widely different conclusions. Let α be the angle between rotation axis and magnetic axis of the pulsar and β be that between magnetic axis and line of sight then a rotating vector model (RVM) is more or less appropriate for explaining the relationship between the observed position angle (Ψ) and longitude (Φ) of any pulsar provided it is assumed all the pulsars have the same emission mechanism. So RVM model can be used as a tool to determine α, β by fitting curves to observed Ψ and Φ data. Different authors have fitted two curves to two branches of (Ψ, Φ) data and have taken the mean profile to define a unique curve for each pulsar. This method has various discrepancies as the data suffer from missing values as well as using average profiles for the actual curve. So it will be better if a nonlinear regression model for curve fitting can be applied successfully to a multiple branch data for estimating the values of α, β through RVM. Such a model is in the stage of preparation and then a classification scheme will be applied for the classification of pulsar beam with these new values of α, β to explain the radiation mechanism.

The HB of a GC in color magnitude diagram (CMD) is composed of stars with helium burning cores and hydrogen burning shell which have evolved off the red giant branch (RGB). Since the stars in HB are bright and their luminosity is not very dependent on color they could give direct information about their distance. Thus HB stars play an important part in defining the absolute distance scale in the Universe as well as their spatial distribution in the Galaxy. There are various HB morphology parameters used by various authors and different independent parameters like (i) metallicity (ii)cluster age (iii) He mixing and radiative levitation (iv) cluster density and concentration (v) He abundance and rotation (vi) influence of planets etc. to explain the morphology but studying the effect of each parameter taking one at a time. We have used a multivariate study 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. We have tested the robustness by taking several bootstrap samples and extended the study for M31 and LMC globular clusters also.

Tikekar, Ramesh and Jotania, Kanti

The super dense stars with mass-to-size ratio exceeding 0.3 are expected to be made of strange matter. Assuming that the 3-space of the interior space time of a strange star is that of a three-paraboloid immersed in a four-dimensional Euclidean space, a two-parameter family of physically viable relativistic models of compact stars has been obtained. This *ansatz* determines density distribution of the interior self-gravitating matter up to one unknown parameter. The Einstein's field equations determine the fluid pressure and the remaining geometrical variables. The information about mass-to-size ratio together with the conventional boundary conditions lead to the determination of total mass, radius and other parameters of the stellar configuration.

The ground state of hadronic matter is the state in which quarks are confined in individual hadrons. It is believed that in the natural ground state, matter may be in a de-confined state of quark, which is called strange matter. A universal process in which the confined state could slowly evolve into strange matter is through the formation of neutron stars with dense cores in which phase transition to quark matter is likely to occur. If the strange matter is true ground state, the entire star may get converted into a strange matter star. The strange matter is the most likely candidate for the interior of any fast rotating pulsar compared to a hardonic matter of a neutron star. The strange stars can be divided into two types: Type I: SS with $(m = a) > 0.3$ and Type II: SS with $0 : 2 < (m = a) < 0 : 3$. In the case of Type-II: SS, reliable information about the density profile, mass and radius will be essential to distinguish them from their neutron star counterparts and the lower limit may be still lower. The theoretical models which stipulate variable density profiles for interior matter of compact stars in hydrostatic equilibrium are definitely more incisive in quantifying astrophysical parameters in this respect.

Recent observation of LXMB 2S 0921-30 contains massive compact object of mass. This object could be either low-mass black hole or strange star. Because a neutron star having a radius of about 10-12 km and interior matter with nuclear density cannot accommodate the mass mentioned above, the object 2S 0921-30 is expected to be a compact star with compactification parameter $0 : 33 < m/a < 0 : 40$. The object, if it is not a black hole, can exist as a strange star only. The upper limit is an extremely high value admissible in the case of theoretical models based on the paraboloidal *ansatz*. Accordingly, formulation of reliable criteria to distinguish a strange star from other super-dense stars such as a neutron star is highly desirable.

Since strange matter is likely to be inside the core of a compact star it is important to explore core envelope models in which core consists of anisotropic fluid and envelope region isotropic fluid. Also core region should have radius about 6-7 Kms and envelope region size about 1.5 -2.5 Kms which would have nuclear density. The class of models include models with these desirable features. Detailed studies of issues related to these are under consideration.

Usmani, Anisul Ain

Strangeness degree of freedom, when trapped in a bound nuclear system, affects every physical observable, starting from deuteron to neutron stars. It induces subtle distortions in the system even with the presence of a single hyperon. The hypernuclear systems with one or two quanta of strangeness in a finite nucleus and also with the bulk of it as in an infinite-body hyperon star offer an unique opportunity to enrich our knowledge about the role of strangeness in a nuclear medium of different densities. Study of such systems may provide useful informations about baryon-baryon and three baryon forces.

There is a need to investigate the role of all the strength of the strange sector potentials on finite nuclei as well as on infinite-body systems such as neutron stars. It is therefore, necessary to know precise information on the $\Lambda\Lambda$ potential strength. A.A. Usmani and Z. Hasan have determined it, recently, and have also determined the ΛN space-exchange strength through the study of ${}^{5}_{\Lambda}He$ and ${}^{6}_{\Lambda\Lambda}He$ hypernuclei. These informations would be useful for future studies of neutron stars.

Classical and Quantum Cosmology

Banerjee, Narayan

Narayan Banerjee, along with his collaborators, has investigated the possible role of curvature in driving the recent cosmic acceleration. They have considered two examples where nonlinear contributions of the ricci scalar in the Einstein-Hilbert action can give rise to an accelerated expansion at the present epoch after having a decelerated expansion in the recent past. They have also studied the role of minimally and also non minimally coupled scalar fields in driving an accelerated expansion. They showed that in Brans-Dicke theory it is possible to construct a quintessence field which has an interaction with the Brans-Dicke scalar field such that the quintessence field has an oscillatory field in the past and grows only during the later phase of the evolution so as to drive a late surge of acceleration.

Chaudhuri, Sarbeswar

In brane cosmology it is assumed that our four dimensional universe is a hyper surface, the brane, embedded in a higher dimensional space-time, called the bulk. Randall and Sundrum (RS) presented a theory of gravity with an infinite fifth dimension and showed that the standard 4D gravity is reproduced on the brane even if the fifth dimension is uncompactified [Physical Review Letters, 83, 3370 (1999); Physical Review Letters,83, 4690 (1999)]. Chen, Harko and Mak presented exact solutions of gravitational field equations in the generalized RS model for an anisotropic brane with Bianchi type-I and IV geometry with perfect fluids and scalar fields as matter sources [Physical Review D64, 044013 (2001)].

S. Chaudhuri in collaboration with S. Chakraborty, is now engaged in research work to derive the solutions of anisotropic brane with Bianchi-I universe with perfect fluid model having nonvanishing Weyl tensor of the bulk. It is shown that the high energy density brane universe evolves from a singular state from time $t = 0$. In the early stage of evolution (near $t \approx 0$), the expansion factor is infinitely large. When $t \longrightarrow \infty$, the volume scale factor becomes infinite and the expansion scalar tends to zero. For a universe with cosmological constant $\Lambda = 0$, the evolution of the high density brane universe starts from $t = 0$ from a singular state V = 0 when the initial cosmological time is suitably redefined by adjusting the parameters of the solutions. At $t = 0$, the deceleration parameter has a constant value $q = 3$. When $t \longrightarrow \infty$, the volume of the universe expands to infinity and the deceleration parameter becomes unity.

It is now believed that scalar fields play an important role in the evolution of the early universe. SChaudhuri and SChakraborty derived the field equations for the scalar field evolution on the anisotropic Bianchi type-I universe taking nonzero value of the Weyl tensor of the bulk into account and analyzed the properties of the relevant physical quantities of interest such as the expansion scale factor, anisotropy, shear and deceleration parameter etc. associated with the evolution of the universe in presence and in absence of the cosmological constant.

Chandra, Deepak

Deepak Chandra has continued his study of the dark energy problem in cosmology. He is exploring the different dark energy models (scalar fields, phantom fields, Chaplagyn gases etc) and their equations of state. It is believed that the scalar field models may play an important role in describing the current observations which indicate that our Universe is accelerating due to the presence of a matter component with negative pressure like the cosmological constant. The scalar field (tracker) models can remove the fine-tuning problem that bogs the cosmological constant.

Deepak Chandra is also studying the modified gravity models which modify the geometry and do not need dark energy to explain the acceleration of the Universe. Theories with extra large dimensions provide interesting possibilities.

Debnath, Ujjal

U. Debnath has studied the junction conditions between static and non-static space-times for analyzing gravitational collapse in the presence of a cosmological constant. The collapse of a quasi-spherical star is considered where the exterior geometry corresponds to Schwarzschild-de-Sitter space-time. The analysis shows that the presence of Λ-term slows down the collapsing process and hence influences the time difference between the formation of the apparent horizon and the singularity. As the presence of a cosmological constant (dark energy) induces a potential barrier to the equation of motion so particles with a small velocity are unable to reach the central object. This ideas can be used astrophysically for a particle orbiting a black hole, which contains dark energy and an estimation of minimum velocity can be done for which the particle enters inside the black hole. Consequently, the amount of dark energy in the black hole can be calculated. Lastly, due to the presence of the cosmological constant, there are two physical horizons- the black hole horizon and the cosmological horizon. Further, for more massive collapsing system, the time of formation of the two horizons become very close to each other. Moreover, asymptotic flatness of the space-time is violated due to the presence of the cosmological constant.

Gravitational collapse of FRW brane world embedded in a conformaly flat bulk is considered for matter cloud consists of dark matter and dark energy with equation of state $p = \varepsilon\rho, (\varepsilon < -1/3)$. The effect of dark matter and dark energy is being considered first separately and then a combination of them both with and without interaction. In some cases the collapse leads to black hole in some other cases naked singularity appears.

Debnath has considered a model of modified Chaplygin gas in VSL theory with variable gravitational constant G. If c = constant and G = constant then the evolution of the universe starts from radiation to Λ CDM model. The variable c and G can drive the evolution of the universe from radiation to phantom stages instead of Λ CDM stage. If G = constant or c = constant then any one of variable G and c can drive the evolution of the universe into the phantom model. Thus variable G or c has significant role for the evolution of the universe in late stages.

Guha, Sarbari

Sarbari Guha has worked on the representation of the evolution history of universe models in three-dimensional phase space. The evolution trajectories of the corresponding universes are generated completely in terms of the constants of motion. From the theory, the magnitude of the transition redshift is also calculated. The theoretical value is found to agree well with the current observational values. The analysis is found to hold even when the cosmological term is interpreted as a dark energy component. It is also shown that terms associated with square of the redshift parameter and higher in the luminosity-distance relation can be written in terms of the current values of the density parameter.

Iqbal, Naseer

Naseer Iqbal has studied the phenomena of clustering of galaxies in an expanding universe from a theoretical point of view on the basis of thermodynamics and correlation function together with Farooq Ahmad and M S Khan. They have developed two partial differential equations in combination with the equation of state taking gravitational interaction between particles(galaxies) in to consideration and both of these equations clarify the dependence of two particle correlation function on the number density n, temperature T and the inter-particle distance r. The evaluation of the two particle correlation function is in close agreement with the Peebles power law and hence confirms the applicability of the approach for understanding the phenomena. The evaluation of the measuring parameter b on the basis of correlation function seems to be much better clarified and provides a lot of physical understanding by making use of various boundary conditions.

Jain, Deepak

It is now well established that the expansion of the universe is accelerating. One possible explanation is that the energy density of the universe is dominated by dark energy with negative pressure and almost not clustering. The simplest candidate for dark energy is cosmological constant but it suffers from fine tuning and cosmic coincidence problem. Consequently several models have been proposed to describe the observed universe, such as quintessence, phantom, tachyonic and so on. It is also possible to explain the acceleration of the universe by using the 'Chaplygin gas' model. The attractive feature of this model is that it can explain both dark energy and dark matter with a single component.

Recently, a 'Variable Chaplygin gas' model has been proposed which has the ability to explain the accelerated expansion of the universe in the recent times. They constrain the parameters of this model by using the location of peaks of the CMBR spectrum and the SNe Ia gold data set. The results are compatible with the results obtained from other observational tests like X- ray gas mass fractions in galaxy clusters. etc.

John, Moncy

The cosmological data of unprecedented accuracy made available during the past decade have emboldened investigators to aspire for some sort of precision cosmology. At the same time, it has also become more and more apparent that precision data require sophisticated tools for their analysis. In recent years, cosmologists have used Bayesian model comparison as one such tool. Within the Friedmann-Lamaitre-Robertson-

Walker (FLRW) model, Bayes theory was used by A. Jaffe (1996) to estimate the cosmological density parameters. Bayesian model comparison technique was used for the first time by Moncy V. John and J.V. Narlikar (2002), for comparing physically distinct cosmological models (including the standard FLRW model). Thereafter, a host of different standard and nonstandard cosmological models were put under scrutiny by using this method and the programme has aroused much interest in the literature.

The recent releases of SNe Ia data is far more accurate and reliable than the earlier ones. Moncy V. John has been attempting to extract useful information from these recent data, by resorting to the Bayesian method. In addition, if one uses the model-independent approach developed by this author in the previous years, many interesting conclusions regarding the expansion history of the universe can be made. It was also found that if the posterior distribution for parameters obtained in the previous analyses is used as the prior in the new one, the dependence of the results on priors can altogether be minimised.

Paul, B.C.

Gravitational instantons are employed to study quantum creation of an inflationary universe with a pair of black holes in a modified theory of gravity. The action B.C. Paul and D. Paul consider contains $\alpha R^2, \delta R^{-1}$ terms and a cosmological constant (Λ) in the Einstein-Hilbert action. They consider two different topologies one accommodating a pair of black holes and the other without black holes to compute probability of a particular kind of universe. Using a technique prescribed by Bousso and Hawking to determine the quantum creation of a universe in a semi-classical approximation with Hartle-Hawking boundary condition we evaluated the probabilities. They obtain new gravitational instant on solutions in the theory which are physically relevant and useful to study quantum creation of universe. They note that the probability for the creation of a universe with a pair of black holes is strongly suppressed with a positive cosmological constant when $\delta = 4\Lambda^2/3$ for $\alpha > 0$ but it is more probable for $\alpha < -1/(6\Lambda)$. It is found that a new class of gravitational instant on solutions exist in the theory proposed by Carroll *etal*. [Phys. Rev. D 70, 043528 (2004)] which accommodate an accelerating universe in the presence of a curvature square term. These are physically interesting for quantum creation which puts a bound on the values of Λ.

B.C. Paul and collaborators explored a cosmological model of an ever-existing universe, which eventually enters at some stage in to the standard Big Bang epoch and has features precisely known to us. We have shown that emergent universe scenarios are not isolated solutions and they may occur for different combinations of radiation and matter. Considering a known feature of the scale factor in the Einstein equation we look for the equation of state (EOS) which leads to such scenario. They note that an EOS: $P(\rho) = A\rho - B\rho^{1/2}$ where A and B are constants led to an emergent universe. The energy density ρ may have different components, each satisfying its own equation of state. The choice of the above equation of state may be looked upon as a mathematical tool for generating solutions for emergent universe. Although emergent universe scenario explored earlier by different authors our model is special since it accommodates a spatially flat universe.

Pradhan, Anirudh

Topological structures produces phase transitions in the universe as it cools. Phase transitions gives birth also to soliton like structures such as monopoles, strings and domain walls. Within the ambit of general relativity, A. Pradhan, together with S. Otarod and Raj Bali studied plane symmetric inhomogeneous domain walls and string cosmological models with time dependent bulk viscosity. It is observed that a network of domain walls accelerates the expansion of the Universe, it also exerts a repulsive force expected to help the formation of large-scale structure. An interesting result that emerged in this work is that the pressure perpendicular to the wall is non-zero.

A. Pradhan and G. P. Singh are continuing the investigation on dynamic models of cosmological term Λ in higher dimensions. A. Pradhan and others has studied the higher dimensional cosmological implications of a decay law for Λ- term. The cosmological tests pertaining to proper distance, luminosity distance, angular distance, and look back time in the framework of multidimensional space-time have been discussed. The results for the cosmological tests are found to be compatible with the present observations.

A. Pradhan in collaboration with Kanti Jotania and others has obtained new exact solutions of EFES for cylindrically symmetric non-static inhomogeneous and Bianchi type V space-time with a bulk viscous fluid as source of matter and cosmological term varying with time. The values of cosmological "constant" for these models are found to be consistent with the results from recent supernovae Ia observations. Our strong point of these models is that it incorporates matter density naturally and so makes feasible a model which can incorporate the physical constrains. Some physical and geometric aspects of the models are also investigated.

In earlier literature cosmological models with a constant deceleration parameter have been studied by several authors. But redshift magnitude test has had a chequered history. During the 1960s and the 1970s, it was used to draw very categorical conclusions. The deceleration parameter q_o was then claimed to lie between 0 and 1 and thus it was claimed that the universe is decelerating. In today's situation, we feel, it is hardly different. Observations (Knop et al., 2003; Riess et al., 2004) of Type Ia Supernovae (S Ne) allowing to probe the expansion history of the universe. The main conclusion of these observations is that expansion of the universe is accelerating. A. Pradhan together with S. Otarod are premier in studying the cosmological models of the universe with time dependent deceleration parameters and Λ -term in general Relativity from which three models of the universe are derived: exponential, polynomial, and sinusoidal forms respectively. The values of the cosmological "term" for these models are found to be consistent with the results from recent supernovae Ia observations.

Seshadri, T. R.

T. R. Seshadri has been studying the statistical properties of Cosmic Microwave Background Radiation. In particulat Non-gaussianity in the CMBR due to cosmic magnetic fields is being analyzed. This work is in collaboration with K. Subramanian.

The reliability and the quantification of errors in studying the clustering properties of matter in the Universe over large scales is being studied in collaboration with Jasjeet Bagla and Jaswant Yadav.

Singh, G.P.

On the basis of observational evidences now it is well established that the universe is dominated by an energy component with an effective negative pressure. One possibility for such component is the cosmological constant and the other possibility is quintessence, a slowly varying scalar field with an appropriate potential. The role of dissipative effects in the evolution of the universe, particularly during its early stages, is also a subject of importance. The simplest generalization of Einstein's theory of gravity are scalar - tensor theories. G.P. Singh and his coworkers are studying effect of quintessence in the presence of dissipative cosmic fluid under the framework of scalar-tensor theories. G. P. Singh and A.Pradhan are continuing the investigation on dynamical models of cosmological term Λ in higher dimensions. The analytical expressions of cosmological variables indicate a clear dependence of dynamical properties on dimensionality of the spacetime. The derived models solve the entropy problem. This may present a significant problem to structure formation or brane world cosmology.

Dynamics

Jain, Sanjay

Sanjay Jain and collaborators have studied the motion of the infinitesimal mass in the following cases:

1. Periodic orbits around the collinear libration points in the restricted three body problem when the smaller primary is a triaxial rigid body. 2. Periodic orbits around the collinear libration points in the restricted three body problem when both the primaries are triaxial rigid bodies. 3. Periodic orbits around the collinear libration points in the restricted three body problem when the more massive body is a source of radiation and the smaller primary is a triaxial rigid body.

In first problem, they have generalized the problem studied by Ragos and Zagouras (1991), who have studied the periodic orbits in the restricted three-body problem when the primaries are spheres or point masses (classical case). Jain and collaborators have taken the smaller primary a triaxial rigid body and the more massive body a sphere or a point mass (Sun-Earth case).

In the second problem, Jain and collaborators have considered with the periodic orbits in the restricted three body problem (Earth-Moon case) when both the primaries are triaxial rigid bodies with its equatorial plane coincident with the plane of motion. They draw the periodic orbits and discuss their stability by taking different five values of semi axes of the primaries.

In the last problem, they have studied the periodic orbits belonging to stromgren families A, B, C around the collinear libration points in the restricted three body problem (Sun-Earth case) when the smaller primary is a triaxial rigid body and more massive body is a source of radiation pressure. These families are determined in three different cases. (i) Classical case (ii) When bigger primary is a source of radiation pressure (iii) When smaller primary is a triaxial rigid body and bigger primary is a source of radiation pressure.

Galaxies and Quasars

Jacob, Joe

Joe Jacob is collaborating with J. Bagchi (IUCAA) in the study of galaxy clusters. During his first year of visit to IUCAA as 'Visiting Associate' he participated in the GMRT observations (during the nights of December 2-3), aimed at investigating the nature of a ∼200kpc-scale mini radio-halo MRC 0116+111, recently discovered at the center of a distant cluster of galaxies at redshift z = 0.13. Multifrequency GMRT data were obtained at the wavelengths of 20, 50 and 90 centimeters. Since his main aim is to acquire proficiency in radio astronomy data analysis and in the use of GMRT and other radio/optical telescopes for research in the frontier areas, he plans to utilize the computational and other resources at IUCAA, in particular using the AIPS software for data reduction of the GMRT data.

Besides these activities at IUCAA he is actively engaged in Astronomy popularization in his region through lectures and interactive sessions with students. With the guidance of Dr. Bagchi he is planning to setup a 'Radio Astronomy' lab at his institution, to give training to students in radio astronomy.

Jog, Chanda

Nearly all spiral galaxies show warped outer disks, and a large fraction of the warps are now known to be asymmetric. Chanda Jog has worked out the mechanism for the origin of the asymmetric warps as arising due to a dynamic superposition of $m = 1$ modes (s-shaped warps) and $m = 0$ modes (bowl-shaped distribution). The results naturally explain the wide variety of asymmetry in warps that is observed, including the extreme cases of U-shaped and L-shaped warps. For details, see Saha & Jog 2006, A & A, 446, 897.

A self-consistent calculation of the galactic disk repsonse to the vertical perturbations shows a surprising but generic physical result that the self-gravity of the disk resists any distortion in the inner regions. The net warps are shown to occur only beyond 4-5 disk scalelengths, this result physically explains the well-known Briggs law that the warps is galaxies are observed to set in beyond this radius. For details, see Saha & Jog 2006, MNRAS, 367, 1297.

A harmonic analysis was carried out on the HI data obtained at GMRT for a sample of 18 galaxies in the Eridanus group. This is the first such study of HI asymmetry in spiral galaxies. The use of HI as a tracer has allowed the measurement of lopsidedness to much larger radii than done earlier using the near-IR data on stars. The lopsided amplitude measured is found to be larger by a factor of 2 compared to the field galaxies, and also the early-type galaxies show higher lopsidedness contrary to the case in the field galaxies. These two results obtained indicate a different physical mechanism, namely tidal interactions, for the origin of lopsidedness that is observed in the group galaxies. For details, see Angiras et al. 2006, MNRAS, 369, 1849.

The analysis of 2MASS archival data for a sample of advanced remnants of mergers of galaxies was done, which shows that their centres exhibit non-axisymmetry with high amplitudes. The centres of isophotes are not constant but instead show upto 30% sloshing or wandering within the central 1 kpc, and also the Fourier analysis shows large lopsided amplitude of upto ~ 0.2. These remnants are ~ 1 Gyr old as shown by our previous N-body analysis (Bournaud, Combes & Jog 2004, A & A Letters, 418, L27). Thus, the central asymmetry is long-lived, lasting for ~ 100 local dynamical timescales and could therefore be important in the fuelling of the central AGN. For details, see Jog & Maybhate 2006, MNRAS, 370, 891.

Khare, Pushpa

Pushpa Khare with her collaborators compiled evidence to prove that the dust obscuration effects are not important and that the observed anticorrelation between metallicity and H I column density in QSO absorbers is real. Using the observed mass-metallicity relation for galaxies they argued that the sub-DLAs may indeed be associated with massive galaxies while the DLAs are produced by dwarfs or low mass galaxies.

Pushpa Khare with her collaborators showed that the metallicity evolution in sub-DLAs is faster than that in DLAs. At $z_2 : 5$ sub-DLAs contribute about 25% of the DLA contribution to the metal buget of the Universe. They suggested that at low redshifts, the sub-DLAs contribution may be several times that of the DLAs.

Pushpa Khare along with her collaborators observed several $zabs < 1 : 5$ Damped Lyman Alpha systems (DLAs) and sub-DLAs in the spectra of QSOs, with the Magellan telescope with the aim of determining the metal abundances in these systems. The sub-DLAs, in general, were found to have higher metallicity compared to the DLAs. The sub-DLAs were shown to have a correlation between metallicity and velocity widths, possibly indicating that sub-DLAs are associated with more massive absorbers.

Pandey, S.K.

Collaborative programme on multiwavelength surface photometric studies of early-type galaxies was continued during the year. During the period images in broad band BVRI filters were taken for few more early-type galaxies from the selected sample of galaxies were using the 2m telescope at the IGO. Preliminary reduction of the data obtained from HCT during the year 2005-06 is nearing completion, and detailed analysis of properties of dust in the sample galaxies is in progress. Ms Samridhi Kulkarni, a research student at Raipur, is also involved in this programme.

Significant progress was also made in the analysis of galaxies from LFC survey fileds during the year. At present redshifts are available only for a few bright galaxies from the field. A survey is planed to get redshifts and spectral information for large sample of galaxies using 3.9m Anglo Australian Telescope (AAT). The sample contains $\sim$ 270 galaxies per field which are brighter than 20.5 magnitude in i band. Use of multifiber spectroscope, AAomega, on AAT was proposed, which can be used to get spectra of $\sim$ 400 targets at a time within field of view of 2 degrees. One of the LFC fields, SDSS1208 was observed for one hour in service mode, on June 22, 2006 using AAT.

Compactness of the field and constraints of fiber allocation limited the target allocation to 135 galaxies. Reliable redshifts were obtained for 55/135 (40%) of the galaxies targeted to get the low resolution spectra in wavelength range 370 nm to 880 nm. A 100% success was achieved for the brightest targets, i.e. galaxies with g(fiber) magnitude < 21.2. A mean S/N per pixel of around 4 in the blue and 10 in the red arm of spectroscope were attained for targets with g(fib) $\sim$ 21. However, the success rate fell rapidly for fainter galaxies. The preliminary investigation of spectra shows the presence of passively evolving elliptical galaxies, galaxies with substantial on-going star formation, 'E+A' or 'a+k' type galaxies, in the sample. The absorption lines such as Mg, Na and Fe, as well as the Balmer lines and the CH G-band were also seen. Information on the metallicity was obtained, for different star formation histories, from such spectra. Preliminary results were presented at the XXIV Th meeting of ASI held at Osmania Univ., Hyderabad during Feb. 7-9, 2007.The same field was again observed on March 27, 2007 in the service mode for 1.5 hours. The spare fibers, after allocation of target form the field were used to allocate the galaxies selected from the SDSS survey. This observation yielded spectra of 235 galaxies, for which data analysis is in progress. This is a collaborative research programme involving A. K. Kembhavi, Russell D. Cannon, Ashish Mahabal and Laxmikant Chaware, a research student working for his doctoral work at Raipur.

Patil, M.K.

M.K. Patil in collaboration with Professor S.K. Pandey and Professor Ajit Kembhavi, is involved in studying the dust extinction properties in extragalactic universe based on the multi-band imaging observations of early-type galaxies. They studied the wavelength dependent nature of the dust extinction for a sample of 30 galaxies and have derived the extinction curves for these galaxies. Extinction curves derived for majority of these galaxies run parallel to the canonical curve of the Milky Way, implying that the properties of dust in extragalactic environment are identical to those of the canonical grains in the Milky Way. The R_V value, which characterizes the extinction curve in the optical region, are found to vary between 2.03 to 3.46 compared to the canonical value of 3.1 for our galaxy. Dust within galaxies in "loose" environment is typically characterized by smaller R_V (i.e. smaller grains) and is distributed in prominent dust lanes with a smooth, relaxed morphology. On the other hand, dust present in galaxies that are in or near the center of dense groups or clusters is typically irregularly distributed, and is characterized by R_V values close to the Galactic one. The dust content derived from optical extinction method provides a lower limit compared to that derived from the IRAS flux densities as well as from ISO data. This discrepancy in the two estimates implies that a large fraction of dust which is distributed within galaxy remained undetected in the optical method. To address the issue of origin of dust, they have explored various possibilities have found that internal mass-loss from evolved stars alone cannot account for the observed dust in these galaxies and therefore is believed that a significant fraction of dust might have originated through a direct merger or accretion or tidal capture of gas from the neighboring galaxies.

Patil and his collaborators 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. The nature of X-ray emission from these systems reveals the mass, distribution and relative abundances of the metal constrains the enrichment; and therefore is related to the star formation history of these galaxies. The complicated nature of optical abundance studies emphasizes the value of the complementary method of X-ray spectroscopy of hot gas that originates as stellar mass loss.

Ravikumar, C.D.

Ravikumar is involved in studies on formation and evolution of galaxies. In collaboration with the scientists from Paris Observatory and IUCAA he has produced spectroscopic redshifts for about 700 galaxies in the Chandra Deep Field - South. The data has been made public to the astronomical community through CDS, and more advanced analysis is being carried out with observations using sensitive GIRAFFE and FORS spectrographs. He has studied the K-band properties of early type galaxies. Studying the bulges of galaxies of different Hubble types he has shown that there exists a clear dichotomy in different correlations between the bulge structural parameters. His studies on the properties of lenticular galaxies with Prof. Ajit Kembhavi and Dr. Sudhanshu Barway of IUCAA, Dr. Yogesh Wadadekar of Princeton University and Dr. Divakar Mayya of Instituto Nacional de Astrofisica, Mexico, and supports a clear division in the formation scenario for lenticulars, with secular evolution for fainter S0s, and a more merging dominant formation for brighter lenticulars.

Gravitational Theory

Chakraborty, Subenoy

Dynamical symmetry in gravitational collapse has been studied by Subenoy Chakraborty and coworkers. S. Chakraborty in collaboration with Sanjukta Chakraborty have investigated the role of initial data, anisotropy and inhomogeneity in determining the end state of collapse. By linear scaling the initial data set and the area radius, they have found that the dynamics of quasi-spherical collapse remains invariant. The linear transformation identifies an equivalence class of data sets for which physical parameters like density, pressures, shear remains invariant and the final state of collapse is identical. Subsequently, they have extended this work by choosing the initial area radius to be an arbitrary function of 'r' and have studied the gravitational collapse with dust or anisotropic pressure as the matter source.

S. Chakraborty in collaboration with Soma Nath and Ujjal Debnath has investigated gravitational collapse in quasi-spherical Szekeres' model with cosmological constant as the matter and have shown the role of cosmological constant during collapsing process and final fate of singularity. They have evaluated the apparent horizon and have found that due to presence of the cosmological constant there are two physical horizons - the blackhole horizon and the cosmological horizon. They have shown that asymptotic flatness of the space-time is violated due to the presence of the cosmological constant and it slows down the collapsing process.

In another work, S. Chakraborty in collaboration with Soma Nath and Ujjal Debnath has considered gravitational collapse of FRW brane world embedded in a conformally flat bulk for matter cloud in the combination of dark matter and dark energy. The dark energy is in the form of perfect fluid with equation of state $p = \varepsilon\rho(\varepsilon < -1/3)$. They have shown that in some cases the collapse leads to black hole, in some other cases naked singularity appears.

Chaudhuri, Sarbeswar

Solutions of Einstein-Maxwell Field equations in General Relativity are of much importance in the analysis of the behavior of astrophysical objects. Several such solutions exist in the literature but not all of them reduce to the Schwarzschild form in the static limit. Bonnor [Z.Phys. 161, 439 (1961); Z.Phys. 190, 444 (1966)] constructed some exact solutions of Einstein-Maxwell field equations, but they do not reduce to the Schwarzschild static limit. Manko and his coworkers, presented some static and stationary solutions of Einstein-Maxwell field equations which reduce to the Schwarzschild solution in absence of magnetic field [Gen.Rel.Gravit., 20, 327 (1988); Physics Letters, A132, 85 (1988); Gen.Rel.Gravit., 22, 799 (1990)]

S Chaudhuri is now carrying out his research work in constructing some magnetostatic solutions of Einstein-Maxwell equations for static and rotating masses possessing magnetic dipole moments using the technique of Das-Chaudhuri [Pramana-J.Physics, 40, 277 (1993)]. The generated solutions are found to be asymptotically flat and contain monopole, dipole and other higher mass multipoles. In pure vacuum limit, the solutions reduce to the Schwarzschild metric. With some restrictions on the constants, the solution of a massless source having a magnetic dipole moment is obtained. It is also shown that using the technique of Das-Chaudhuri, the magnetostatic solution obtained from the stationary field corresponding to the Kerr metric, under some restrictions on the constants, gives a monopole solution M = 2m, together with other higher mass multipoles. This result exactly coincides with that obtained by Bonnor.

Ghosh, Sushant G.

S.G. Ghosh, in collaboration with A.K. Dawood, have proved a theorem that characterizes a large family of non-static solutions to Einstein equations, representing, in general, spherically symmetric Type II fluid. It is shown that the best known dynamical black hole solutions to Einstein equations are particular cases from this family. The solutions depend on one parameter k, and two arbitrary functions $M(v)$ and $C(v)$ (modulo energy conditions). It is possible to generate various solutions by proper choice of these functions and parameter k. Many known solutions are identified as particular case of this family and hence there exists realistic matter that follows the restrictions of the theorem. It would be of interest to see if there exists a physically valid new solution. They have extended to higher dimensional space-time, above theorems, which, with certain restrictions on the EMT, characterizes a large family of radiating black hole solutions in N-dimensions.

Ghosh, in collaboration with Viktoriya Morozova of Institute of Nuclear Physics, Uzbekistan, modified the above theorem, so that a large family of exact non-spherically symmetric radiating anti-de Sitter black hole solutions is possible. The family solutions generated represent generalization of non-spherical Vaidya-like solutions in an anti-de Sitter background.

S.G. Ghosh, in collaboration with D.W. Deshkar, has obtained the analogue of collapsing Vaidya-like solution to include both a null fluid and a string fluid, with a linear equation of state ($p_\perp = k\rho$), in non-spherical (plane symmetric and cylindrically symmetric) anti-de Sitter spacetimess. It turns out that the non-spherical collapse of two fluid in anti-de Sitter space-times, in accordance with cosmic censorship, proceed to form black holes, i.e., on naked singularity ever forms, in accordance with cosmic censorship, violating hoop conjecture. They have also obtain another Vaidya-like solutions to include both a null fluid and a string fluid in non-spherical (plane symmetric and cylindrical symmetric) anti-de Sitter space-times. Here, assuming that string fluid diffuse, we find exact solutions of Einstein's field equations. Thus we extend a recent work of Glass and Krisch to non-spherical anti-de Sitter space-times.

They have studied the junction conditions for non-spherical collapsing radiating star consisting of a shearing fluid undergoing radial heat flow with outgoing radiation. Radiation of the system is described by plane symmetric version of Vaidya solution. Junction conditions, match the collapse solutions to an exterior Vaidya metric, show that at the boundary, the pressure is proportional to the magnitude of the heat flow vector. Physical quantities, analogous to spherical symmetry related to the local conservation of momentum and surface red-shift, are also obtained. Finally, exact gravitational collapse solutions, for both shear and shear-free case, have been obtained by integrating a field equation.

Kuriakose, V.C.

Black holes continues to be black and so far they have not yet revealed themselves to us. The 'no-Hair' theorem says that a black hole may reveal to exterior world only through its mass, charge and angular momentum. The situation could change when the black hole is placed in a scalar filed. Kuriakose and Kuriakose have studied the effect of placing a Banados - Teitelboium - Zernelli (BTZ) black hole in a scalar field with double-well potential. They have obtained nontrivial black hole solution showing no divergence at the horizon and asymptotically falling to the vacuum value which shows that BTZ black hole can have scalar-hair. The presence of black holes can be inferred only through indirect methods. It is well a established procedure to learn about a physical system by letting waves of known characteristics be scattered of it. Hence much attention has been paid to study scattering problems involving black holes. Classically the event horizon of black holes absorbs everything falls on it and unable to emit anything into the outside world. But, event horizons need not be fully absorptive type but can reflect waves falling on it which can be understood as a quantum property of the event horizon. Sini and Kuriakose have studied the scattering of scalar waves by Schwarzschild - de Sitter black hole considering the reflection property of the event horizon and found that their result could be reduced to the known results.

Nandi, Kamal Kanti

Professor Kamal Kanti Nandi, with collaborators, has been engaged in studying various aspects of classical and quantum gravity including Brans-Dicke Theory. During the period of the report they were engaged in studying the semiclassical ANEC constraint in wormhole spacetime. The result shows that traversable wormholes can only be of microscopic nature. In another work, they attempted to show the signatures of wormholes to be seen via strong field gravitational lensing. Another work discusses the similarities and differences between the two frames, Einstein and Jordan, in any scalar field theory.

Patil, K.D.

KD.Patil has studied the gravitational collapse of higher dimensional inhomogeneous dust model. He proposed the concept of "trapped range" of initial data in different higher dimensional space-times and shown that "trapped range" of initial data increases with the increase in dimensions of the space-times.

K.D.Patil, in collaboration with S.S.Zade, has generalized the earlier studies on the spherically symmetric gravitational collapse in four - dimensional space-times to higher dimensions. They have shown that the central singularities may be naked in higher dimensions but depend sensitively on the choice of the parameters. These naked singularities are found to be gravitationally strong that violate the cosmic censorship hypothesis.

K.D.Patil together with U.S.Thool has investigated the influence of monopole field on the occurrence of the space-time singularities in the gravitational collapse of anti-de Sitter-Vaidya space-time. It has been shown that the spherically symmetric monopole-anti-de Sitter-Vaidya space-time contradicts the CCH, whereas the non-spherical collapse respects it.

Ray, Saibal

Saibal Ray, in collaboration with Basanti Das, Farook Rahaman and Subharthi Ray, has considered Einstein-Maxwell space-time in connection to some of the astrophysical solutions as previously obtained by Tolman (1939) and Bayin (1979). The effect of charge inclusion in these solutions has been investigated thoroughly and also the natures of fluid pressure and mass density throughout the sphere have been discussed. Mass-radius and mass-charge relations have been found out for various cases of the charged matter distribution. Two cases are obtained where perfect fluid with positive pressures give rise to *electromagnetic mass* models such that gravitational mass is of purely electromagnetic origin.

Exact solutions of the Einstein field equations with cosmic string and space varying cosmological constant, viz., $\Lambda = \Lambda(r)$, in the energy-momentum tensors are presented by Saibal Ray, Farook Rahaman and Utpal Mukhopadhyay. Three cases have been studied: where variable cosmological constant (1) has power law dependence, (2) is proportional to the string fluid density, and (3) is purely a constant. Some cases of interesting physical consequences have been found out such that (i) variable cosmological constant can be represented by a power law of the type $\Lambda = 3r^{-2}$, (ii) variable cosmological constant and cosmic string density are interdependent to each other according to the relation $\Lambda = -8\pi\rho_s$, and (iii) cosmic string density can be scaled by a power law of the type $\rho_s = r^{-2}$. It is also shown that several known solutions can be recovered from the general form of the solutions obtained here.

Srivastava, D.C.

D. C. Srivastava and his research student Shweta Srivastava are involved in a collaboration with N. Kantharia, NCRA and P. K. Srivastava, another IUCAA associate for a project of radio studies of the continuum at 1.4 GHz and at lower frequencies and of the radio emission lines of He II from near by Wolf Rayet (WR) Galaxies using the GMRT. The detection and analysis of WR star population in young starburst is a powerful tool to reveal the properties of the star forming events. A better knowledge of the duration, initial mass function etc., in nearby galaxies is a key issue to follow the evolution of the large population of star forming galaxies.

The current interest in the study of WR galaxies is because these have been characterized as a subtype of starburst Galaxies where a large portion of stars of the star burst is WR stars. The star burst is commonly defined as phenomenon where continued star formation with current star formation rate (SFR) is such that it would exhaust the available gas reservoir in much less than the age of the Universe and also much less than the dynamical timescale of the Galaxy (perhaps one rotation period in a disk type Galaxy). The intense burst of star formation results due to a collision or close encounter between two galaxies.

The Far Infra Red (FIR) and 1.4 GHz radio continuum, which are among the best studied indicators of SFR, are found to be highly correlated over many orders of magnitude. A multi-wavelength study of few selected nearby star burst galaxies will allow us to study the star formation history of the Universe by observing high red shift star burst galaxies. A large number of the very distant galaxies seen, for example, in the Hubble deep field are known to be star bursts but they are far away to be studied in any detail. Observing near by examples and exploring their characteristics can give us an idea of what was happening in the early Universe as the light we see from these distant galaxies left them when the Universe was much younger.

Machine Learning and Virtual Observatory

Chattopadhyay, Asis Kumar

Under VO-India, VOSTAT is a proposed module which can used to make statistical analysis of data obtained either through VO Tables or from any other possible sources.

During this period attempts have been made to develop some sub modules of VOSTAT related to statistical methods like Exploratory data Analysis, Regression Analysis, Statistical Tests, Nonparametric methods, Multivariate Classification etc, which users of VO India and also scientists from other disciplines may use for their research using large data sets. The target of this project is to develop a complete statistical package under VO which can be used in a user friendly way without taking help of any costly Statistical package.

The programs have been written in R so that anybody can freely use it as R is a free access software in the Internet. As the R codes can also be accessed through VOSTAT anybody with a little knowledge of R programming may also write their own programs in R. We are also interested to build up a stand alone version of this statistical package.

Ninan Sajeeth Philip

Until recently, astronomy was limited to the study of a finite number of celestial candidates, usually bright objects. The information thus derived was extrapolated to the remaining vast number of objects to build a cosmological model of the universe. The major bottleneck in this issue was the limitation in the computational and observational machinery required to handle faint and deep sky objects. Thanks to modern computers, intelligent adaptive optics and new technology telescopes, a drastic changes to this scenerio is on the way.

Many large sky surveys such as the SDSS, for example, is trying to map the entire observable universe (up to a certain limiting magnitude) from the location of the observatory. The resulting huge databases makes it possible for astronomers to search for objects of any specific kind over the entire region of the sky without having to wait for unrealistic observational telescope times. Needless to say, a major role in such a facility is catered by modern machine learning tools that automatically extract parameters to build catalogue that may be readily used by astronomers.

The quality of any automated, machine learning algorithm is measured by its ability to correctly classify all the objects in a dataset. This would be possible only if the parameters that are used to specify each object is nonoverlapping in the feature space. In astronomy, this is a less frequent reality. There are too many unknowns such as redshift, spectral variations among similar objects, surface temperatures and brightness variations, atmospheric turbulence, absorption by interstellar media, reddening etc associated with each of the measurements. This reduces the relative confidence by which a classification can be made.

To quantitatively measure the accuracy in a prediction, one requires a data for which the actual classes of the objects and its measurable parameters are known in advance. N. Sajeeth Philip, in collaboration with Rita Sinha, Ajit Kembhavi and Ashish Mahabal used a subsample of spectroscopically determined quasars to measure the accuracy of the quasar detection problem. Two measures that completely define the accuracy of a network are the completeness and contamination in its prediction. Completeness is the fraction of objects in a class that were correctly classified by the network. Contamination is the fraction of objects belonging to a different class that got classified into a target class. A good algorithm is one which has a maximum value for completeness and a minimum value for contamination.

A study done with all the photometric parameters available from SDSS DR5 data release showed that the four colours (u-g,g-r,r-i,i-z) and one magnitude (i band) were the best parameters for detecting quasars. This was in agreement with the observations published by other researchers as well. As mentioned before, redshift is one source of contamination in the extracted features. This is because the colours of the same objects change as it gets redshifted. This causes them to be mistaken for an object belonging to another class. In the quasar detection problem, due to redshift, the colour of quasars and stars merge over one another at a redshift of 2.5 and above. This means that the contamination at such redshifts will be much higher than that at lower redshifts. We used the difference boosting neural network (DBNN) algorithm for quasar classification. Using photometric information, the network was able to detect quasars at low redshifts accurately. The contamination from stars was about 2% and completeness as compared to spectroscopically detected SDSS quasars in the region was about 98%.

The classification difficulty at higher redshifts can be minimized on subdividing the colour space into smaller regions and using a different network for each region. Since colour information is available from photometry, this does not cause any additional constrain on the training algorithm. However, taking into consideration the large data sizes, this becomes a computationally demanding problem. A cluster computing system to handle such data sizes is under development.

Non-linear dynamics

Ambika, G.

G. Ambika, along with Ambika K, has studied numerically the phenomenon of synchronization in two models of two dimensional discrete systems by coupling them to three different types of coupling. It is found that linear coupling effectively introduces control of chaos along with synchronisation, while synchronised chaotic states are possible with an additive and parametric coupling, both being equally relevant for specific applications. The basin leading to synchronisation in the initial value plane and the choice of parameter values for synchronization in the parameter plane are isolated in each case. A detailed analysis of the error function dynamics was carried out.

They also studied the possibility of simultaneous and sequential synchronization of vertical and horizontal arrays of unidirectionally coupled systems. The synchronized state was characterized using variation of synchronization time with coupling and size of the array. This was worked out in two systems viz. Gumowski-Mira maps and Predator-Prey systems In the case of horizontal array for the former case, the total time of synchronization can be controlled by increasing the coupling constant step wise in small bunch of units. In the latter case, synchronized clusters were observed before total synchronization.

In collaboration with A K Kembhavi and R Misra of IUCAA and K P Harikrishnan, Cochin College, Kochi, she has developed an adaptation of the standard Grassberger- Proccacia algorithm for estimating the correlation dimension of a time series in a non subjective manner. This is being extended to multifractal analysis and applied to analyze X-ray data from GRS 1915+105 and physiological data.

Kuriakose, V.C.

Studies on propagation of electromagnetic waves through optic fibres and bulk materials find very wide applications such as optical communication, optical switching, optical computing etc.. In many situations ideal systems which are far from reality are considered. Jisha, Subha and Kuriakose have tried to consider some real systems and studied the propagation of electromagnetic waves through them.

They have studied the propagation of an optical high power cylindrically symmetric beam in a material characterized by cubic-quintic nonlinearity both analytically and numerically. The analytical results are found to be in very good agreement with the numerical results.

Another problem studied by them is on the propagation of spatio-temporal (Light Bullets) through a cubic-quintic medium. When a pulsed optical beam propagates through a bulk nonlinear medium, it is affected by diffraction and dispersion simultaneously and at the same time the two effects become coupled through the nonlinearity of medium. Such a space-time coupling leads to various nonlinear effects like the possibility of spatio-temporal collapse or pulse splitting and the formation of light bullets. They could show the existence of stable light bullets in this medium using both analytical and numerical studies. They extended the studies to bulk photorefractive polymer and showed the existence of incoherently coupled two dimensional soliton pairs under steady state condition and soliton pairs can exist under the condition that the two beams are mutually incoherent and have the same wavelength and polarization.

They have also studied the effect of coupling of light in a directional coupler formed in a photopolymer. The two waveguides are formed very close to each other such that there is no interaction between the two waveguides, except the evanescent wave coupling between the two waveguides. The coupled equation describing the beam propagation has been studied both analytically and numerically.

The study of the dynamics of Josephson junctions is of great interest from theoretical as well as experimental points of view. The interaction of Josephson junctions with external fields have played important roles in the development of chaotic dynamics of Josephson junctions. Chitra and Kuriakose have investigated the effect of phase difference of the applied field on the dynamics of mutually coupled Josephson junctions. We found that by keeping the value of phase difference as π, the system exhibits periodic motion for a wide range of values of system parameters. This may find applications in devices like voltage standards, detectors, SQUIDS etc.

Vishwakarma, J. P.

The problem of shock wave propagation in a dusty gas is of importance in the study of a collision flow pattern of a coma with a planet. J. P. Vishwakarma, in collaboration with G. Nath obtained similarity solutions for unsteady isothermal or adiabatic flow behind a strong exponential shock driven out by a piston moving with time according to an exponential law. It is found that the assumption of zero temperature gradient brings a profound change in the density distribution as compared to that of the adiabatic case. Effects of a change in the mass concentration of the solid particles in the mixture and the ratio of the density of solid particles to that of initial density of the gas are also obtained. In another paper, J. P. Vishwakarma and G. Nath studied the problem of converging detonation waves in a dusty gas. An expression for the similarity exponent is determined for the detonation wave travelling in the Chapman-Jouguet regime. It is determined that the presence of dust particles in the medium has significant effects on the similarity exponent and the flow variables.

When the flow takes place in extreme conditions, the assumption that the gas is ideal is no more valid. J. P. Vishwakarma in collaboration with S. N. Pandey studied the propagation of converging cylindrical shock waves in a non-ideal gas in presence of an axial magnetic field. Chester-Chisnell-Whitham's method is employed to determine the shock velocity and the other flow variables in the cases when (i) the gas is weakly ionised, (ii) the gas is strongly ionised, and (iii) non-ionised gas undergoes intense ionisation as a result of the passage of the shock. It is investigated that the magnetic field and the gas-ionising nature of the shock have damping effect on the convergence of the shock It is also concluded that in the case of non-ideal gas there is generation of higher pressure near the axis in comparison with that in the case of a perfect gas.

Rotation of stars significantly affects the process taking place in their outer layers. Therefore questions connected with the explosions in rotating gas atmospheres are of definite astrophysical interest. J. P. Vishwakarma in collaboration with S. Vishwakarma obtained similarity solutions for a magnetogasdynamic cylindrical shock wave propagating in a rotating medium in presence of a variable or constant azimuthal magnetic field. Initial density of the medium is assumed to be obeying a power law and the initial angular velocity to be decreasing. Effects of an increase of the Alfven-Mach number and the variation of the initial density, initial magnetic field and the initial angular velocity, on the flow-field behind the shock, are obtained.

Plasma Physics

Kumar, Nagendra

Nagendra Kumar. in collaboration with Pradeep Kumar, Shiv Singh and Anil Kumar studied the propagation and dissipation of slow magnetoacoustic waves in an inhomogeneous viscous coronal loop plasma permeated by uniform magnetic field. They considered coronal loop as a static, straight, gravitationless, low-β plasma slab with half length L along the z-axis of the cartesian coordinate system taking into account viscosity and thermal conductivity as dissipative processes. The damping lengths of slow-mode waves exhibit varying behaviour depending upon the physical parameters of the loop in an active region AR8270 observed by TRACE. Damping length of slow-mode waves with periods 200 s to 400 s increases sharply for loop heights $10 \times 10^9 cm$ to $3{\cdot}5 \times 10^9$ cm from coronal base and then decreases for the heights $3 \cdot 5 \times 10^9$ cm onwards. The wave energy flux associated with slow magnetoacoustic waves turns out to be of the order of 10^6 erg cm$^{-2}s^{-1}$ which is high enough to replace the energy lost through optically thin coronal emission and the thermal conduction below to the transition region. It is also found that only those slow-mode waves which have periods more than 240 s provide the required heating rate to balance the energy losses in the solar corona and calculated wave periods for these waves nearly match with the oscillation periods of loop observed by TRACE.

Observations have indicated that magnetic reconnection may occur frequently in the photosphere-chromosphere region as well as in the solar corona. The magnetic reconnection in chromosphere region via tearing instability has been studied by Nagendra Kumar along with his student Pradeep Kumar. In three dimensions this instability leads to the formation of islands, which suggest that the isolated loops of magnetic flux can leave the reconnection region in any direction. The rate of magnetic reconnection in terms Alfvenic Mach number has been estimated. They also calculated the growth rate of tearing mode, island length scales, and energy dissipation rate necessary to heat the chromospheric plasma and found that the magnetic Reynolds number for the current sheets in the photosphere-chromosphere region varies from 1.14×10^3 to 1714×10^7. The field lines in the photosphere and chromosphere reconnect with speed that is 0.00034 to 0.0297 times the Alfven speed. Frequency of MHD waves generated in the chromosphere reconnection region is of the order of 100 Hz and these high frequency waves may be the source of coronal heating and solar wind acceleration. The hot flowing plasma of these waves in the solar wind disrupts the Earth's magnetosphere and may lead to magnetic storm.

Stars and Interstellar Medium

Chandra, Suresh

Professor 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 H2CO, H2CCO, H2CCC and H2CCCC molecules and found that some of their lines may show anomalous absorption. In the investigation, they 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. The importance of the work is that this phenomenon of anomalous absorption may be used as a technique for identification of molecules in cool cosmic objects. Identification of as many molecules as possible in a cool cosmic object will undoubtedly help in understanding the physical conditions prevailing in the objects and will through light on the chemical reactions going on there.

Goraya, P.S.

P.S. Goraya has obtained spectroscopic and spectropolarimetric observations of large number (about 200) of Be/shell stars with the IUCAA's 2-m telescope in collaboration Dr. Vijay Mohan and Dr. Ranjan Gupta. The observations have been gathered in the optical part of the spectrum. These observations are being reduced and analyzed with the help of Mr. Nardeep Kumar to explore the state of various emission features which are useful to investigate the state of the extended circumstellar envelope and to explore variability. P.S. Goraya has also analyzed the spectrophotometric observations of above Be/shell stars obtained from ARIES's Nainital 1-m and 0.5-m telescopes and has studied the behaviour of the continuum energy distributions of these objects. Many peculiarities regarding excess radiation have been found.

Kumbharkhane, A.C.

In molecular clouds, newly formed massive stars are emitters of ultraviolet radiations. Massive early type stars emit extreme ultraviolet photons that will be absorbed by hydrogen atoms creating a bounded zone of ionized hydrogen that is called an HII region. Those photons which are not energetic enough to ionize hydrogen and create HII regions penetrate into the surrounding molecular gas where they can dissociate most molecules and ionized atoms with ionization potential below 13.6ev, such as carbon (11.3ev), Silicon (8.2ev) and sulfur (E10.4ev). For decade's astronomer have been interested in the partially ionized gas associated with Galactic HII regions. The discovery of radio emission lines has played an important role in the development of our knowledge of high mass star forming in the Galaxy. The radio recombination lines (RRL) have proved useful to the understanding of the kinematics and physical conditions of ionized gas. A.C. Kumbharkhane and collaborators have chosen to study S64, known as W40 is an HII region lying above the Galactic plane and approximately 700pc from the earth. Observation of radio recombination line gives the carbon line flux and is directly proportional to the electron density, the carbon ion density and is inversely proportional to the Doppler width and electron temperature. Kumbharkhane and his research team developed radio astronomical image processing facility in the school of physical sciences at Swami Ramanand Teerth Marathwada University, Nanded with financial support from the Indian Space Research Organization (ISRO) under the RESPOND programme.

Pandey, S.K.

With a view to explore the long-term spot activity variations in chromospherically active stars published photometric data on a sample of 18 chromospherically active stars were collected from the archive. A variety of activity tracers like integrated magnitude, amplitude, total spot area etc. were used with a view of examining as to which one of these could be a better tracer of the stellar activity. The analysis reveals the presence of spot activity cycles in most of stars in the sample, with periods ranging from about 4 years to more than 50 years. Integrated amplitude correlates tightly with the other photometric activity tracers suggesting that loss of star light is due to spots on the stellar surface. Correlation between different tracers of stellar activity suggest that integrated amplitude is the best tracer among the ones used in the analysis. A paper based on this study was presented at the IAU XXVIth GA, JD-08- Solar and Stellar Activity Cycles, Prague, Czech Republic, August 14-25, 2006. This work formed a part of doctoral thesis of Sudhanshu Barway. An invited talk on "Teaching and Research in Astronomy using Small Aperture Optical Telescope" was presented at IAU XXVIth GA, SPS5- Astronomy for the Developing Countries, Prague, Czech Republic, August 14-25, 2006.

Pandey, U.S.

U.S. Pandey present the B light curves of the pulsating chemically peculiar Am stars HD 13038 and HD 13079. The pulsations in both the stars have been discovered by Martinez el al (1999a, 1999b) at Nainital using single channel fast photometer equipped at 104-cm telescope. These stars were observed because neither CCD photometric nor differential photoelectric light curves of these two chemically peculiar Am stars had been published. All the photometric observations of both the stars were made 104 -cm telescope of ARIES equipped with CCD as N-star photometer. A new pulsation having a period of about 3.6 hr and peak to peak B amplitude 0.02 mag in HD13038 was reported along with its other pulsations discovered by us earlier (Martinez etal., 1999a).

In ARIES erstwhile U.P. State Observatory Nainital, photoelectric photometry of bright eclipsing variables were commenced in the year 1957-58 on the 10-inch reflector using B, V and interference filters. Some of the stars selected for the observations were eclipsing binaries HD214419, HD193576, Bita Lyr Delta Ori and AR Cas. Since 1964, the systematic studies of eclipsing binary systems has been undertaken with a view to obtain their complete light curves in U, B and V of Hohnson and Morgon system and to analyze the light curves for determining their geometrical elements. As most of the eclipsing binaries selected for this purpose were those for which spectroscopic elements were available in a literature, the aim was, also to obtain the absolute elements such as masses and radii of the systematic components. Pulsation is a common phenomenon among the A-F stars. About half of the stars in this part of the H-R diagram are pulsating stars which pulsate with amplitudes ranging from a few mmag to a mag and with periods between about half and hour to 8 hours (Breger, 2000). As most of the earlier studies at ARIES erstwhile U.P. State observatory Nainital on these enormous data of eclipsing binaries obtained at Nainital between 1957 to 1992, were confined in studying the light variations which occur due to the mutual eclipse of the systematic components. Therefore, Pandey reanalyzed those observations with a aim to search the pulsations present into the systemic components of those studies eclipsing binary star.

Rastogi, Shantanu

The ubiquitous mid IR features at 3.28, 6.2, 7.7, 8.6 and 11.2 μm result from emissions from a family of Polycyclic Aromatic Hydrocarbon (PAH) molecules consisting of neutrals, cations, anions and hydrogenated/de-hydrogenated species. Spectral variations with shape, size and ionization state of PAHs have been studied by Amit Pathak and Shantanu Rastogi to relate the source to source variations in the features with type of PAHs surviving in different regions. Several PAHs and their cations with 10 to 96 Carbon atoms have been studied using ab-initio Density functional method. Large computations are done using the HPC facility at IUCAA. A composite emission model taking different PAH size groups is used to compare observations. The models show good profile match with observations. Correlation with features and intensity ratios between modes obtained from the models are useful in putting constraints on the PAH size and ionization states in ISM.

The presence of nanodiamonds is suggested by observation of 3.43 and 3.53 μm lines in Ae/Be Herbig stars and by detection in certain carbonaceous meteorites. Using the discrete dipole approximation technique scattering and extinction of nanodiamonds are studied by Rakesh K. Rai and Shantanu Rastogi. Pure nanodiaomond grains of various sizes and ellipsoidal shapes and a core-mantle model taking nanodiamond core and non-spherical mantle of different carbon metamorphs (graphite or amorphous carbon) are studied. The 220 nm peak and the overall extinction curve gets modified. The far UV extinction rise points towards possible contribution of nanodiamonds towards extinction in starbursts. Incorporating PAHs and nanodiamonds in dust models is under study.

Singh, Harinder P.

H.P. Singh and collaborators have examined the behaviour of penetrative turbulent compressible convection under the influence of rotation by means of three dimensional numerical simulations of solar-type convection zones. They estimate the extent of penetration below a rotating convection zone in an f-plane configuration. Several models have been computed with a stable-unstable-stable configuration by varying the rotation rate ($\mathbf{\Omega}$), the inclination of the rotation vector and the stability of the lower stable layer. The spatial and temporal average of kinetic energy flux (F_k) is computed for several turnover times after the fluid has thermally relaxed and is used to estimate the amount of penetration below the convectively unstable layer. Numerical experiments show that with the increase in rotational velocity, the downward penetration decreases. A similar behaviour is observed when the stability of the lower stable layer is increased in a rotating configuration. Furthermore, the relative stability parameter S shows an $S^{-1/4}$ dependence on the penetration distance implying the existence of a thermal adjustment region in the lower stable layer rather than a nearly adiabatic penetration region.

Complexity analysis of experimental and observational times series by using the tools of nonlinear dynamics has been an area of recent interest. H.P. Singh and collaborators have demonstrated a technique for the enhancement of chaos in a computational model of a periodically stimulated excitable neuron. "Anticontrol" of chaos is achieved through intermittent adaptive intervention which is based on finite–time Lyapunov exponents measured from the time series. The results suggest that an adaptive strategy for chaos anticontrol is viable for increasing the complexity in physiological systems which are typically both noisy and nonstationary

Sun and the Solar System

Sahijpal, Sandeep

The presence of some of the short-lived radionuclides, e.g., ^{26}Al, ^{60}Fe, ^{41}Ca, ^{36} Cl, ^{53}Mn and ^{7,10}Be (with mean-lives $<$ 5 million years) has been inferred in the early solar system on the basis of the isotopic studies of primitive meteorites. These radionuclides are used extensively to study various physico-chemical processes associated with the origin and the early evolution of the solar system. One of the greatest concerns associated with these short-lived radionuclides is to understand their production scenario(s). Dr. S. Sahijpal has recently developed for the first time an extensive numerical code for the irradiation production of these short-lived radionuclides in the early solar system by energetic (1-500 MeV/n) protons, ^{3,4}He from the active early sun going through T Tauri phase. Recently obtained X-ray flares observations of YSOs in the Orion molecular cloud by the *Chandra* X-ray satellite were used to calibrate the various parameters involved in numerically simulating the irradiation environment. Various physico-chemical processes associated with the dust grain condensation, coagulation were considered during the irradiation production of the short-lived nuclides within the protosun's magnetosphere. The developed numerical code would play a key role to understand the production of the short-lived nuclides and their implications to the early solar system processes. In general, the code would enable to understand the irradiation environment prevailing with the young stellar objects going through the T Tauri phase.

Dr. S. Sahijpal has been also developing numerical codes of the melting and planetary differentiation of accreting planetesimals with ^{26}Al and ^{60}Fe as the heat source. The decay energies of $\sim$3 MeV associated with these two radionuclides are considered to have resulted in the melting and the planetary scale differentiation of the planetesimals (the building blocks of planets) in the early solar system. Dr. S. Sahijpal has developed comprehensive numerical codes to simulate the accretion, heating and differentiation of planetesimals. The growth of an iron-core along with the formation of a silicate mantle with a crust has been simulated for the first time to understand the differentiation processes.

Saikia, Eeshankur

Eeshankur Saikia has studied stellar convection numerically in a Sun-type star at different depths. The code for the 3D simulation of the turbulent convective fluid is analyzed for a parallel platform. The interaction of the fluid with radiation near the solar surface and the dynamics near the subadiabatic layer is also studied. Besides, effort has been made to use the tools of non-linear dynamical theory to extract and analyze the information from the simulated data or any other astronomical time series.

Sen, Asoke K.

The polarization values observed for comets at various phase angles are in general explained by using Mie Theory, which has an underlying assumptions that the grains are compact solid spheres. However, based on spacecraft observations and other facts, it is well known that the grains are nonspherical and in most cases porous and irregular. But with spheroidal grains, it becomes difficult to reproduce theoretically the observed negative polarization branch, which comets exhibit at low phase angles. Recently Sen., A. K along with his Ph.D student studied the polarimetric behaviours of comet Levy and using prolate spheroidal crystalline olivine particles (with effective radius 0.218 micron and aspect ratio E=0.486) successfully reproduced the observed polarization values of comet Levy. They performed calculations based on T-matrix Theory and a good theoretical fit to the observed polarisation data for comet Levy was obtained, which could successfully explain the negative polarization values for comets as well.

Sen, A K along with his German collaborators (from DLR, German Aerospace Center, Berlin) have studied asteroids belonging to Karin family. There are evidences that asteroids belonging to this family, have been created out of a very recent (5-

6 Myr ago) catastrophic collision and hence their studies' provide important clues to the understanding of the dynamical evolution and aging of asteroids in our solar system. The light curve observations of these asteroids were made with the 2m telescope at Hanle Observatory, under IUCAA's guest observing programme. The photometric observations in the V-band of two asteroids belonging to the Karin family, (11728) Einer and (93690) 2000 VE21, were made during two nights (November 25 and 26, 2005) enabling information on rotational periods and the absolute magnitudes H. These derived values helped to understand several properties related to dynamical evolution of asteroids and were found to be useful to complement the IR observations obtained for a series of Karin family asteroids with the Spitzer satellite.

Shrivastava, Pankaj K.

Pankaj K Shrivastava has studied the characteristics of coronal mass ejections and their effects on cosmic ray intensity and geomagnetic field variation. CMEs are described as the mass ejection from sun into interplanetary space. These CMEs carry large amount of energy ($= 10^{25} J$), which produce perturbations to the density and magnetic structure in the solar wind. The signature of CME associated interplanetary disturbances are called as interplanetary coronal mass ejections (ICMEs). Dr Shrivastava has investigated transient decreases in cosmic ray intensity and increase in geomagnetic in associated with occurrence of ICME events. A systematic study has been done to derive the relationship between magnitudes of Forbush decreases (Fds) and solar wind velocity, temperature and density. Forbush decreases are transient and rapid decreases in cosmic ray intensity. Such decreases are followed by a slow recovery, typically lasting for several days. A positive and high correlation has been found between the magnitude of Fds and maximum velocity of solar wind during the Fd events.

Pankaj K Shrivastava and his co-workers have studied the relationship between cosmic rays and coronal index of solar activity (CI) for the periods of negative ($A < 0$), mix and positive ($A > 0$) polarities of the general magnetic field of sun. They have used first time coronal index as a new solar parameter in long-term cosmic ray modulation studies. Adopting the harmonic analysis technique, they have also studied average characteristics of diurnal and semi-diurnal components of cosmic ray daily variation using the hourly values of several neutron monitor stations covering the low and high cutoff rigidities for the period of 1996 to 2005.

Mathematical and Theoretical Physics

Gangal, Anil

Anil Gangal in collaboration with Abhay Parvate has studied spaces of fractally differentiable functions and fractally integrable functions on fractal subsets of the real line. Analogues of Sobolev spaces are defined and studied on such sets. These spaces are required in order to study fractal differential equations, which in turn are required for study of physical models of fractal structures and processes. Some aspects of fractal noise problems are also studied.

Goyal, Ashok

Ashok Goyal with S.R.Choudhury, Naveen Gaur , Sukanta Dutta and Mamta continue to investigate phenomena and processes likely to point towards new physics beyond the standard model. These include $K^0 - K^0 bar$ mass difference, lepton number violation and neutrino Majarona mass generation in Little Higgs model. Bounds on lepton number violation from neutrinoless double beta decay, meson and lepton decays, trimuon production in neutrino factory, anamolous magnetic moment of muons. In addition we are studying the signals of LH model with T Parity specifically Lepton Flavour Violation in gamma- gamma and electron positron colliders. Triple vector-boson anamolous coupling are some other phenomenon under consideration.

Kaushal, R.S.

The study of compact stars in terms of quark degrees of freedom has been the subject of great imortance in the recent past. In his ongoing project R.S. Kaushal, in collaboration with A. K. Sisodiya, D. Parashar and V.S. Bhasin has pursued his studies on both the nonstrange and strange diquark stars within the framework of an effective phi-4 theory. The role of two-diquark interaction energies is investigated in detail with reference to the mass-radius configuration of diquark stars. It is suggested that strange diquark stars are more compact and stable as compared to nonstrange diquark stars.

In another ongoing project Kaushal, in collaboration with Ranjit Kumar and wadhesh Prasad, has investigated the soliton content in the solutions of a certain class of nonlinear diffusion-reaction equations involving quadratic and cubic nonlinearities and a convective flux term. The existence of kink and anti-kink type solitons in the solutions is demonstrated.

Mukherjee, Pradip

Pradip Mukherjee has studied different theories on noncommutative space- time. With his Ph D. student Anirban Saha he has studied noncommutative gravity in the frame work of unimodular gravity where they have shown that there is no first order correction due to noncommutativity. They have also studied the possibility of regular soliton solutions in a noncommutative Maxwell - Chern - Simons - Higgs model.

With Anirban saha and Anisur Rahaman Pradip Mukherjee has formulated the 1+1 dimensional bosonised Schwinger model on a noncommutative platform and studied various characteristics of such models. With R. Banerjee and Sourav Samanta he has investigated a theory of noncommutative gravity with lie algebraic noncommutative structure.

Pandita, P.N.

Despite its great success, the gauge group $SU(3) \times SU(2) \times U(1)$ remains a completely unexplained feature of the Standard Model (SM) of electroweak and strong interactions. The idea of grand unification is, therefore, one of the most compelling theoretical ideas that goes beyond the Standard Model. In grand unified theories (GUTs), the SM gauge group can be elegantly unified into a simple group. The renormalization group flow of the gauge couplings leads to their unification at a very large scale. However, this picture wherein the SM is embedded into a grand unified theory (GUT) with gauge coupling unification at large scale leads to the well known hierarchy and naturalness problems due to the widely separated scales, the weak scale characterized by the mass of the Z-boson ($\sim M_Z$), and the large unification scale characterized by the gauge coupling unification. Supersymmetry (SUSY) is at present the only known framework in which the hierarchy between the weak scale and the large GUT scale can be made technically natural. This naturally leads us to the idea of supersymmetric grand unification.

P. N. Pandita, in collaboration with B. Ananthanarayan, has carried out a detailed study of the superparticle spectrum in supersymmetric grand unified theories in order to determine the parameters of the underlying theory at the large GUT scale, which can then be used to determine the grand unified gauge group. There is chain of group embeddings of the SM gauge group into a larger group

$SU(3)_c \times SU(2)_L \times U(1)_Y$
$\subset SU(5) \subset SO(10) \subset E_6 \subset E_7 \subset E_8$.

However, in four-dimensional grand unified theories the gauge groups E_7 and E_8 do not support a chiral structure of the weak interactions, and hence cannot be used as grand unified gauge groups in four dimensions. This leaves out only the three groups, $SU(5)$, $SO(10)$, and E_6 as possible unified gauge groups in four dimensions. In this investigation supersymmetric GUTs based on the gauge groups $SU(5)$ and $SO(10)$ were considered. It is shown how the underlying supersymmetry breaking parameters of these theories can be determined from a measurement of different superparticle masses. The impact of non-universal gaugino masses on the superparticle spectrum, especially the neutralino and chargino masses, which arise in supersymmetric grand unified theories with non-minimal gauge kinetic function, has also been studied. In particular, the interrelationships between the squark and slepton masses which arise in grand unified theories, and which can be used to distinguish between the different underlying gauge groups, were derived.

Rao, Nagalakshmi A.

While the original version of Klein Paradox concerns scattering situation of Dirac particles at a potential barrier, Nagalakshmi A. Rao, in collaboration with B. A. Kagali, has shown that an analogous puzzling situation arises with the Klein-Gordon equation for bound states. With the usual minimal coupling procedure of introducing the interaction potential, a paradoxical situation results when the "hill" becomes a "well", simulating a bound-state-like situation. This phenomenon for bound states is contrary to the conventional wisdom of quantum mechanics and is analogous to the well-known Klein Paradox, a generic property of relativistic wave equations.

In literature, scattering of an electron by a potential barrier is known to be one of the simplest solvable problems in non-relativistic quantum mechanics. However, a similar problem with the potential step or barrier in relativistic quantum mechanics often results in a paradox - with more particles reflected by the step than are incident on it. Such a puzzling situation contradicting non relativistic expectation was termed Klein Paradox. This phenomenon suggests the possibility of creation of particle-antiparticle pairs at the Klein step.

Unlike scattering, Rao has reported the appearance of a similar situation in the context of bound states by considering the one dimensional time independent Klein Gordon equation, which reduces to the Schrodinger form with an effective energy, $\mathbf{E_{eff}}$ and effective potential, $\mathbf{V_{eff}}$. For a potential barrier with well-defined boundaries, $\mathbf{V_{eff}}$

can either be positive, zero or even negative, depending on the barrier height. Interestingly, for $V_o < 2mc^2$, $\mathbf{V}_{eff}$ is positive and the problem is analogous to a typical scattering problem. In a situation where $V_o = 2mc^2$, the effective potential vanishes and the barrier becomes supercritical. A novel situation arises when the barrier height exceeds $2mc^2$. When $V_o > 2mc^2$, the effective potential becomes negative and the "hill" is transformed into a "well". Particles, instead of being scattered by the hill are trapped inside the simulated well, inferring that bound states are possible for strong barriers. Moreimportantly, a classic scattering problem is transformed into a bound state problem, aptly called the 'Klein paradox for bound states,.

Conclusively, the potential hill need not be only of the square type for such anomalous bound states. The actual number of bound states and the energies however depend on the shape and size of the hill. Further calculations show that a paradoxical situation like this does not arise for pure scalar repulsive potentials. In such a case, a barrier is transformed into another barrier, no matter how strong or weak the potential is.

(III) IUCAA-NCRA GRADUATE SCHOOL

IUCAA Research Scholar, Ujjaini Alam (Guide: Varun Sahni) has defended her thesis submitted to the University of Pune during the year of this Report. The abstract of the same is given below :

An Investigation into the Properties of Dark Energy

Ujjaini Alam

The enigma of dark energy has been a topic of hot debate over the last decade. The current supernova data, the cosmic microwave background and large scale structure clustering data all point consistently to the existence of this exotic energy form, but beyond that very little is known as to its nature. From the observational viewpoint, the facts known to us are as follows– a very tiny fraction of the total energy density of the universe is in baryonic matter, about one-third is in dark matter, and the remaining two-thirds comprises of a totally unknown energy form which has negative pressure and therefore causes the expansion of the universe to accelerate at present. These facts in themselves are startling enough. Also, the nature of this energy form is a topic of much debate and no consensus has yet been reached on a theoretical model of dark energy. The presence of dark energy is now based on sufficiently robust observational data. It is therefore time to probe its nature in greater detail. A host of theoretical models have been suggested to deal with the issue of dark energy. The simplest of all these models is the cosmological constant. Proposed by Einstein in 1917, the cosmological constant has had a chequered career. It was rejected by Einstein himself later, then revived in the 1960s when it was seen that it corresponded to the zero point vacuum fluctuation energy, and it received a further boost from observations in the nineties as the simplest model to explain the data. However, even today, the theoretical problems of this model (the cosmological constant problem, the fine-tuning problem) are not well understood. A host of other models have been suggested for dark energy, such as the tracker potential quintessence models, unified models of dark matter and dark energy, braneworld models of dark energy and so on. We need to explore means to examine the data in order to be able to choose between the different models of dark energy. In this thesis we probe the observational data using different techniques and attempt to draw conclusions on the properties of dark energy.

Layout of Chapters :

In the **first chapter**, we introduce the concept of dark energy. We trace the history of the evolution of the dark energy problem and describe the different dark energy models that have been proposed over time. We also give a short description of the different observational data (the supernova data, the cosmic microwave background, large scale structure data, etc.) which have been used to understand the riddle of dark energy. We attempt to give a flavour of the dark energy problem as it stands today. In this chapter, we also outline the plan of the rest of the thesis, and the substance of each chapter.

The **second chapter** deals with the observations and the techniques used to analyse the data. We have focussed primarily on supernova data since this data gives us direct evidence of the acceleration of the universe. In the last few years there has been a great increase in both the quality and quantity of supernova data available to us. It is now possible to reconstruct different cosmological parameters using the supernova data to quite a high degree of precision. We describe the different techniques we can use to analyse this data. One can fit different models of dark energy to the data and obtain constraints on the parameters of the model. In a more interesting approach, one can use model independent parameterizations to extract information out of the data without unduly biasing it in favour of any model. This approach gives us constraints on different cosmological parameters, using which we may decide which cosmological models are allowed by the data. This has the advantage that many cosmological models can be dealt with using a single analysis. We also discuss here the use of different observational and theoretical priors and how they can change the results.

In the **third chapter** we discuss model independent parameterizations of dark energy. We outline the basic philosophy behind the reconstruction approach and show the primary results obtained by the use of such a techniques. The basic question in front of us today is– whether dark energy density is a constant (the cosmological constant), or whether it varies. To answer this question, we attempt to obtain bounds on the different cosmological parameters, especially the dark energy equation of state. We may use different model independent ansatz to parameterize different cosmological parameters such as the dark energy density and the dark energy equation of state to obtain bounds on the different cosmological parameters. Several such ansatz have been proposed in literature. We use a polynomial fit to the dark energy density as our preferred ansatz. We first study the properties of this ansatz in some detail. This ansatz returns exact values for the cosmological constant and some quintessence models ($w = -1/3,\ w = -2/3$). For a host of other models, such as tracker quintessence models, and Chaplygin gas models, it is successful in reconstructing different cosmological parameters to a high degree of accuracy. We simulate different cosmological models using current supernova error specifications to show that the ansatz can reconstruct cosmological parameters and discriminate between models with a high degree of accuracy. Having assured ourselves of the efficacy of the ansatz, we now turn our attention to the real supernova data. Comparing the results of a maximum likelihood analysis with the theoretical values of the cosmological parameters for different models of dark energy, we draw our conclusions about the state of the universe. We find, surprisingly, that the current supernova data points to a dark energy model that is radically different from the commonest cosmological constant or even quintessence models. Dark energy equation of state appears to evolve from a super-negative value ($w < -1$) at present to dust-like behaviour ($w \simeq 0$) at high redshifts. Such an exotic model of dark energy appears to be at least as probable as the cosmological constant at a 2σ confidence level if only the supernova data are considered. This behaviour is so unexpected that we further explore this result to understand its significance. We find that the result is robust under changes in the matter density within a reasonable range and to the change of ansatz. Using an older dataset from the High-z Supernova Search Team (HZT), we find that the result is also stable to using different subsets of the data. However it is interesting that when we use the newest, high-confidence "Gold" dataset, which brings together all the data available from the different projects, we find that the amount of evolution of dark energy varies between the different subsets of data. The data from the Supernova Cosmology Project (SCP) shows minimum evolution while that from HZT shows the most evolution. This shows that we need a greater quantity and quality of supernova data in order to be certain of the results obtained in this analysis. We also check how the use of theoretical priors on the equation of state changes the results. If we impose the Weak Energy Condition ($w \geq -1$) by hand the evolution of dark energy becomes weak. This shows the importance as well as the perils of introducing theoretical priors. We also show how the presence of observational priors affects the results. If we use priors from the cosmic microwave background (CMB), then the degree of evolution depends upon the present values of the matter density ($\Omega_{0\rm m}$) and Hubble parameter (H_0). The CMB and supernova data taken in conjunction allow both strongly evolving and non-evolving (the cosmological constant) dark energy models for different choices of $\Omega_{0\rm m}$ and H_0.Therefore, it is imperative that observations determine the values of these two parameters to an accuracy of better than 5% in order that the reconstruction approach can provide an unambiguous conclusion about the nature of dark energy.

In the **fourth chapter** we explore the possibility of using future supernova data. Large space based missions, such as the SuperNova Acceleration Project (SNAP), are being planned for the near future. These will result in the accumulation of about ten times the quantity of supernova data available now. If these experiments succeed, the study of dark energy will have achieved a quantum leap. We will therefore require to develop new tools to deal with the high quality data we expect to become available in a few years time. Traditionally, the equation of state of dark energy is used to draw conclusions about the nature of dark energy. This approach has a few drawbacks. Firstly, the equation of state is a physical parameter. For the more recent models of dark energy, for instance the higher dimensional braneworld models, it is difficult to define an equation of state. In this respect, geometrical parameters (such as the deceleration parameter) which depend only on the scale factor and its derivatives have a much more universal appeal since they can be applied to a wider class of cosmological models other than the cosmological constant and quintessence. Also, it is well known that the equation of state alone cannot break the degeneracy between different models of dark energy. It can be shown that scalar field models with very different Lagrangians can result in approximately similar equations of state in the range of redshift we are interested in. An important aspect of this thesis is the construction of new geometrical diagnostics of dark energy– the Statefinder pair $\{r, s\}$– which are based on the scale factor and its first three derivatives and which can reliably discriminate between different dark energy models. The Statefinder pair have the added advantage that the variables $\{r, s\}$ provide a phase-space portrait of dark energy. In particular, for the cosmological constant the Statefinder pair yields a fixed point at $\{r = 1, s = 0\}$. In marked contrast, the

$\{r(z), s(z)\}$ trajectory for all other dark energy models evolves with redshift. For quintessence models using a tracker potential, the Statefinder r decreases to a minimum value and then increases to unity, while the Statefinder s decreases monotonically to zero. For the Chaplygin gas models on the other hand, the behaviour is the exact opposite– here r increases to a maximum, then decreases to unity, while s increases from -1 to zero. We demonstrate that using the Statefinder pair in conjugation with future supernova data will make it possible to clearly discriminate the cosmological constant from other models of evolving dark energy. Therefore, with the advent of better quality data, it can be expected that the Statefinder pair will help shed light upon the nature of dark energy, especially on the issue of whether dark energy is evolving or not.

Having looked in detail at model independent parameterizations of dark energy, we now turn our attention on the physical models of dark energy. In the fifth and sixth chapters we discuss a few such theoretical models of dark energy and their compatibility to the data. In the **fifth chapter** we consider the higher dimensional braneworld scenario for dark energy. In these models, dark energy is not due to a scalar field or a fluid component. Rather, the acceleration of the universe is simply a manifestation of the fifth-dimension (or bulk) onto the four-dimensional brane. These models can provide us with various possibilities for dark energy. For instance, in some braneworld models, the effective equation of state of dark energy can become super-negative ($w < -1$), as in the phantom models. However, these models do not suffer from any of the instabilities present in the phantom scalar fields. In other braneworld models, the current acceleration of the universe can be a transient epoch sandwiched between two epochs of matter domination. A class of braneworld models can encounter a "quiescent" future singularity at which the scale factor and the Hubble parameter remain well-behaved but the higher derivatives of the scale factor diverge. In some of these models, the universe recollapses in the future, while in others it has a loitering epoch. We discuss the observational constraints on these different classes of braneworld models. Using the current supernova data to perform a maximum likelihood analysis, we find that many of these models are commensurate with the current data for a large range of the parameter space and more data in the future will help in telling us whether dark energy could indeed be a signature of a higher dimensional world.

In the **sixth chapter**, we deal with a different class of dark energy models, namely, the decaying dark energy models. In these models the density associated with dark energy decays slowly over time. Decaying dark energy is modelled using a homogeneous scalar field which couples minimally to gravity. Dark energy decays as the field rolls down its potential and this allows for several interesting possibilities, such as the current acceleration epoch becoming transient or the collapse of a spatially flat universe under the influence of a growing negative potential. These models of decaying dark energy also have no horizons, which is an attractive feature from the viewpoint of string/M-theory. We use the supernova data to determine whether these possibilities are allowed by the current data. We find that these models are commensurate with the supernova data for a reasonable range of parameters. These models of dark energy allow us to explore the possibility that the universe will collapse in a finite time. From the data we may also calculate the minimum time to the recollapse of the universe.

The thesis ends with a concluding chapter in which the major results are summarised.

(IV) PUBLICATIONS

By IUCAA Academic Staff

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

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Paul, B.C. (2006) Chaotic inflationary universe on brane in Proceedings of IAGRG, Rajastan Academy of Physical Sciences Jaipur, eds. R. S. Tikekar et al., p. 103

Supervision of Thesis :

Ambika, G (2006) Fractal Patterns and Stochastic resonance in coupled map lattices, Mahatma Gandhi University, Kottayam, Ph.D. thesis of *Kamala Menon*

Chandra, Suresh (2007) Study of anomalous absorption in interstellar formaldehyde molecules, SRTM University, Nanded, Ph.D. thesis of *Pramod G. Musrif*.

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Pandey, S. K. (2006) A study of stellar activity in chromospherically active stars, Pt Ravishankar Shukla Univ., Raipur, Ph.D. thesis of *Sudhanshu Barway.*

Prasad, Lalan (2006) Solar coronal loops and their heating mechanisms, M.B. Govt. P.G. College, Under Kumaun University, Nainital, Ph.D. thesis of *N.K. Lohani*.

Rastogi, Shantanu (2006) Study of polycyclic aromatic hydrocarbons in the astrophysical context, D.D.U. Gorakhpur University, Gorakhpur, Ph.D. thesis of *Amit Pathak.*

Shrivastava, Pankaj K. (2006) Role of solar wind interplanetary disturbances in long term modulation of cosmic rays. A.P.S. University, Rewa, Ph.D. thesis of *Neelam Singh*.

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Vishwakarma, J. P. (2006) A study of shock waves in radiating and non-radiating gases, D. D. U. Gorakhpur University, Gorakhpur, Ph. D. thesis of *Gorakh Nath.*

Books

Kumar, R., **N. Kumar** and J.P. Chauhan (2006) Fluid Dynamics, Shiksha Sahitya Prakashan, Meerut.

Chauhan, J.P., Kaviraj, **N. Kumar** and P. Kumar (2006) Discrete Mathematics, Shiksha Sahitya Prakashan, Meerut.

(V) PEDAGOGICAL ACTIVITIES

(a) IUCAA-NCRA Graduate School

Sanjeev Dhurandhar
Topical course on Statistics and Data Analysis
(14 lectures)

Ajit Kembhavi
Electrodynamics and Radiative Processes I & II

Ranjeev Misra
Extragalactic Astronomy II

J.V. Narlikar
Quantum conformal cosmology
(Topical course)

T. Padmanabhan
Methods of Mathematical Physics II

A. N. Ramaprakash
Astronomical Techniques I

Swara Ravindranath
Galaxies : Structure, Dynamics and Evolution

Tarun Souradeep
Extragalactic Astronomy I

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

Naresh Dadhich and Varun Sahni
Astronomy and Astrophysics II

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

R. Srianand and **K. Subramanian**
Astronomy and Astrophysics I
(18 lectures)

(c) Chennai Mathematical Institute, B.Sc. Course

R. Srianand and **K. Subramanian**
General Relativity and Cosmology
(18 lectures)

(d) Supervision of Projects

J. Bagchi

Siddharth Hegde, Fergusson College, B.Sc. project
Invisible Sun: Detecting solar radio activity at 20 MHz
Jaydeep Belapure, Fergusson College, B.Sc. project
Study of meteor showers through scattering of radio waves from FM radio stations

Nikhil Pawar, Fergusson College, B.Sc. project
Decametric radio emission from Jupiter-Io system

Nikhil Pawar and Vishal Gajjar,
Pune University, M.Sc. Space Science project
Mapping of galactic hydrogen and observation of 21-cm spin-flip transition

Viral Parekh, Fergusson College, M.Sc. Electronics Science project
Study of non-linear dynamics and chaos through electronic circuits

Jaydeep Belapure and Mayuresh Kulkarni
Pune University, M.Sc. Physics and Space Science Project
Faraday rotation effect: Laboratory experiment and as an astrophysical tool

Naresh Dadhich

K. Aswin, I. I. T. Madras, Chennai, VSP
Gauss Bonnet black hole

Sanjeev Dhurandhar

Suratna Das, M.Sc. University of Pune
Gravitational waves

Deepak Gopinath, I. I. T. Bombay, Mumbai.
General relativity and its applications

A. Keshwarjit, Ph.D. student, Delhi University.
Gravitational waves

Ajit Kembhavi

Jayshree Roy, Gauhati University
Sloan digital sky survey

Saurav Ashtamkar, Mumbai University, VSP, *Super massive black holes*

Santosh Jagade, Mayur Kumbhalkar and Nikita Tholiya, Fergusson Gollege, Pune,
Astronomical data interface tool (ADIT)

Ranjeev Misra

M. Srivastava, IUCAA Graduate School Project
Simulation of images in the focal point of a telescope

J.V. Narlikar

School Students' Summer Programme
Foucault pendulum.
Rohit Rakshe
Tushar Kale
Prerana Vidhate
Amruta Chavan
Jaydeep Deshpande
Vinay Chanvan
Ameya Patil
Mahesh Bhaltad
Rucha Jogaikar
Saleena Vaidya
Riddhi Kadam
Ashwini Chaphalkar

A. N. Ramaprakash

A. Shukla, Pune University.
Wavefront aberration from defocussed images

A. Vinodkumar, A. Attupurath and M. Barve, Vishwakarma Institute of Technology, Pune
RTC and countdown timer

M. Kalamkar, Fergusson College, Pune
Laboratory characterization of Princeton Instruments CCD camera system

A. Kumar, Graphic Era Institute of Technology, H. N. B. Garhwal University, Uttaranchal
Embedded control software for 2m observatory unified instrument control system

M. Kulkarni, Pune University
Polarization variation in T-Tauri stars

Rita Sinha

Mancee C. Pimputkar, M.Sc. Physics, Fergusson College, Pune
Quantization of quasar redshifts

Tarun Souradeep

Sumit Ghose Roy, IIT Kharagpur, VSP
Towards anomalies in the CMB anisotropy of WMAP data

Atmjeet Verma, Delhi Univ., VSP 2006
Reconstruction of inflation potential using primordial power spectrum

R. Srianand

Kunal Mooly, B.Sc. project
Age of the star clusters

K. Subramanian

Sushree Tripathy, Utkal University, Bhubaneswar, VSP-
Galactic dynamo

Kshitij Thorat, Pune University, MSc Project.
Sunyaev-Zeldovich effect

(e) Supervision of Ph.D.Thesis

Varun Sahni (Guide)

Ph. D. thesis by Ujjaini Alam
An investigation into the properties of dark energy

(VI) SEMINARS, COLLOQUIA, at IUCAA

(a) Seminars

Sanjit Mitra: *Making skymaps of CMB and GWB*, May 12.

Ue-Li Pen: *Rotation in gravitational lenses*, May 15.

Ajit K. Kembhavi: *Super massive black holes*, May 25 and 26.

Manoranjan Khan: *Characteristics of dust acoustics waves applicable to Saturn ring*, June 1.

Susmita Chakravorty: *Warm absorbers : The S-curve analysis*, June 19.

Hum Chand: *Constraints on the variation of fine-structure constant, based on HARPS and UVES/VLT data sample*, June 19.

Atul Deep: *Opto-mechanical alignment of near infrared PICNIC imager*, June 19.

Gaurang Mahajan: *Quantum effects in gravitational fields*, June 19.

Tapan Naskar: *Some aspects of wormhole*, June 19.

Abhishek Rawat: *My work in the last one year*, June 19.

Saumyadip Samui: *Combined semi-analytical models for star formation, reionization and galactic outflows*, June 19.

Arman Shafieloo: *Model independent reconstruction of the expansion history of the universe*, June 19.

Sudanshu Barway: *On the origin of Lenticular galaxies*, June 20.

Soumen Basak: *Statistical isotropy of CMB polarization maps*, June 20.

Priya Hasan: *Morphologies and colour maps of AGN host galaxies using HST/ACS in the CDFS-GOODs field*, June 20.

Santosh Joshi: *Variability among peculiar objects*, June 20.

Minu Joy: *From the spectrum to inflation : An inverse formula for the general slow-roll spectrum*, June 20.

Subharthi Ray: *Estimation of the CMB power spectrum*, June 20.

Suryadeep Ray: *Gravitational clustering in redshift space and the non-Gaussian tail of the cosmological density distribution function*, June 20.

Rita Sinha: *Science with virtual observatory*, June 20.

Durgesh Tripathi: Solar *coronal mass ejections: SOHO observations*, June 21.

G. Jogesh Babu: *Linear regression issues in astronomy*, August 3.

Dawood A. Kothawala: *A study of the Painleve-Gullstrand type metrics*, August 11.

Gianluca Calcagni: *Ghost conditions for Gauss-Bonnect cosmologies*, September 6.

Sudip Bhattacharyya: *What thermonuclear X-ray bursts can tell us about neutron stars*, September 7.

Sanjit Mitra: *Gravitational waves from inspiralling binaries and cosmological ramifications*, September 14.

Resmi L: *On the presence of hard electron energy spectrum in GRB afterglow*, September 26.

Atul Deep: *The design and fabrication of near infrared PICNIC imager (NIPI)*, October 18.

Vasudha Bhatnagar: *Knowledge discovery in databases*, November 24.

K. Avinash: *New type of astrophysical objects*, November 28.

Yogesh Wadadekar: *Bulge formation in Lenticular galaxies: Violent relaxation or secular evolution?,* November 30.

Lajos Balazs: *Angular distribution of GRBs*, December 1.

W.H. Kegel: *Line formation in media with stochastic velocity fields*, December 5.

Martin Lopez-Corredoira: *Galaxy-galaxy and galaxy-QSO discordant redshift associations*, December 7.

Atish Kamble: *Multiband modeling of GRB afterglows*, December 12.

Ashish Mahabal: *Science with synoptic sky surveys*, December 13.

Habib Khosroshahi: *Properties of fossil galaxy groups*, December 14.

William C. Saslaw: *Statistical mechanics of the cosmological many-body problem (and some of its implications)*, December 28.

Aparna Venkatesan: *The first stars in the universe: Formation, feedback effects and detections*, January 4.

Varsha Kulkarni: *Tracing galaxy evolution with quasar absorption lines*, January 5.

Gulab Chand Dewangan: X-*ray investigations of active galactic nuclei and ultraluminous X-ray sources*, January 23.

Achamveedu Gopakumar: *Inspiral dynamics of compact binaries: Its applications and implications*, January 25.

Sima Ghassemi: *Generalized Friedmann equations for a finite thick brane*, January 29.

Pankaj Jain: *Direct determination of astronomical distances and proper motions by interferometric parallax*, February 15.

K. Shivanandan: *Astronomy after retirement*, February 22.

(b) Colloquia

Hagai Netzer: *Cosmic evolution of black hole mass and metallicity in active galactic nuclei*, April 3.

Anvar Shukurov: *The origins of the European Neolithic*, April 6.

Amitava Raychaudhuri: *The changing face of neutrino physics*, April 24.

R. Sukumar: *Maneaters and rogues: The ecology of wildlife human conflicts*, May 29.

Ravindra E. Amritkar: *Spatial synchronization and extinction of species*, September 11.

Vinod K. Gaur: *Experiments on two unique Indian terranes designed to resolve an outstanding question about planet Earth's continental lithosphere*, October 9.

Nobuyuki Kanda: *The decade of TAMA300: From construction to searching for gravitational wave events*, November 14.

Jurgen Ehlers: *Mass in general relativity*, January 15.

Kishore Marathe: *Gravity and topology*, January 22.

Francois Bouchet: *Cosmological anisotropies: Status and perspective with Planck*, February 12.

(VII) TALKS AT IUCAA WORKSHOPS OR AT OTHER INSTITUTIONS

(a) Seminars, Colloquia and Lectures

Naresh Dadhich

Why Einstein [Had I been born in 1844!]? Department of Mathematics, University of the Punjab, Lahore, April 6.

Why Einstein? Dr. Babasaheb Ambedkar Technological University, Lonere-Mangaon, Dist. Raigad, May 6.

Four basic forces of nature : A unified view, Introductory Summer School on Astronomy and Astrophysics and Vacation Students Programme, IUCAA, May 29.

Does gravity really live in 4-dimensions?, An evening lecture, delivered at IUCAA, June 8.

Why there are four basic forces?, Inter-University Accelerator Centre, New Delhi, June 23.

New black hole solution : Matter without matter?, IUCAA, July 6.

Some amusing questions leading to profound understanding, Second Saturday Lecture Programme, July 8.

On Gauss-Bonnet gravity, Parallel session on braneworld gravity, 11th Marcel Grossmann Meeting on General Relativity, Freie University, Germany, July 26.

Kaluza-Klein black hole in negatively curved extra dimensions in string inspired gravity models, High Energy, Cosmology and Astroparticle Physics Section of ICTP, August 4.

Is higher dimension necessary for gravity? Max-Planck Institute for Astrophysics, Garching, September 4.

Are four dimensions sufficient for description of classical gravity?, National Conference-cum-Seminar, Department of Physics and Electronics, Sri Guru Tegh Bahadur Khalsa College, New Delhi, September 21.

Why Einstein [Had I been born in 1844!]? Department of Physics, Guru Nanak Dev University, Amritsar, October 24.

Why Einstein [Had I been born in 1844!]?, WSFC-II International Symposium, Centre for Philosophy and Foundations of Science, New Delhi, November 2.

On Einstein's message and method, (keynote address) "Relevance of Einstein's contributions in the 21st century", Department of Physics, Kumaun University, Nainital, November 10.

A unified view of basic forces, inaugural day seminar organized by the Centre for Theoretical Physics, Jamia Millia Islamia, New Delhi, November 27.

New black hole : Pure curvature creation, 5th Meeting on Field Theoretic Aspects of Gravity [FTAG-V] organized by BITS-Pilani (Goa), December 21.

Einstein and gravity, Students of Presidency College, Kolkata in IUCAA, January 31.

New black hole : An example of pure curvature creation, 24th Meeting of IAGRG, Jamia Millia Islamia, New Delhi, February 5.

New black hole : A pure curvature creation, International workshop on Theoretical High Energy Physics, Indian Institute of Technology, Roorkee, March 15.

Atul Deep

The design and fabrication of near infrared PICNIC imager (NIPI), Leiden Observatory, Netherlands, November 2.

The design and fabrication of near infrared PICNIC Imager (NIPI), Brookhaven Laboratory, New York, November 7.

Sanjeev Dhurandhar

Gravitational wave experiments: Current status, 24th IAGRG meeting, Jamia Millia Islamia, New Delhi, February 6.

Gravitational waves, (Introductory Summer School, IUCAA, May 29- 30, (2 lectures).

Search for inspiraling binaries: interpolated search, Albert Einstein Institute, Max Planck Institute for Gravitational Physics, Potsdam, Germany, August 1.

Seminars on group representations and antenna patterns of gravitational wave detectors, Mathematics Deptartment, Pune University, in the seminar series on Fourier transforms on finite groups, from December 1, (3 lectures).

Ranjan Gupta

Backend instruments at IGO, IUCAA Giravali

Observatory 2m Telescope Dedication Symposium, IUCAA May 14.

Stellar spectroscopy, Introductory Summer School on A & A and VSP, IUCAA May 24-25 (2 lectures).

Relevance of UVIT observations to interstellar extinction and its modeling, UV and Multiwavelength Astronomy with ASTROSAT, IIA, Bangalore, September 27 - 29.

Telescope and new technologies, International School of Corporate Management, Pune, September 30.

The University of Hawaii Wide-Field Imager (UHWFI), IDG, IUCAA, October 19.

Interstellar dust, extinction and its modeling, IOA, Cambridge, UK, December 6.

Interstellar extinction and dust modeling, Workshop on Physics and Astrophyics of Dust: Formation, Probes and Astrophysical Implications, Kavalur, February 24-27.

Modern astronomical telescopes and technologies of this millenium and *dust and its effects in astronomy and other areas,* Astronomy Refresher Course conducted at Delhi University, Delhi, March 15-16 (2 talks).

Development of artificial neural network scheme for application to TAUVEX satellite data, ISRO-RESPOND project review meeting, PRL, Ahmedabad, March 23-24.

Ajit Kembhavi

White dwarfs, neutron stars and black holes, Inaugural talk for Olympiad Students, Nehru Science Centre, Worli, Mumbai, May 3.

Future of higher education and convergence of media, participatory, technologies - Connect, converge, communicate, IUCAA, May 6.

Supermassive black holes, (Informal Talk) IUCAA, May 25 and 26.

Virtual observatory and grid computing, C-DAC, Garuda Grid Deployment Workshop C-DAC, Pune, June 22.

Gravitational lenses, Presidency College, West Bengal, July 19.

Virtual observatory paradigm and national projects (Invited talk), Special Session on Virtual Observatories, XXVIth General Assembly of International Astronomical Union, Prague, August 21.

Developing countries and the virtual observatory, Special Session on Astronomy in the Developing World, XXVIth General Assembly of International Astronomical Union, Prague, August 22.

Challenging the digital divide, Special Session on Astronomical Data Management, XXVIth General Assembly of International Astronomical Union, Prague, August 22.

Photometric identification of quasars from the Sloan survey, Special Session on Virtual Observatories (with Rita Sinha and N. Sajeeth Philip), XXVIth General Assembly of International Astronomical Union, Prague, August 22.

UGC Infonet - the scope and beyond, National workshop on Emerging Trends in University Management, West Bengal University of Technology, Kolkata, September 4.

Virtual observatory - A new data paradigm, National Workshop on Astronomy for Engineers, Siliguri Institute of Technology, Darjeeling, September 10.

From stars to black holes, Sikkim Government College, Gangtok, September 11.

Pluto : Is it not a Planet?, Pandit Ravishankar Shukla University, Raipur, September 22.

The planet Pluto, Department of Geography, University of Pune, October 5.

Supermassive black holes, Workshop on Frontiers of Physics, Department of Physics, University of Mumbai, Vidyanagari, October 10.

Suppression of star formation in early - type galaxies and a galaxy at a redshift z = 6.96, IDG, IUCAA, September 29.

Morphological correlations in galaxies, Cardiff University, UK, October 25.

Morphological correlations in galaxies, Queen Mary College, University of London, October 27.

Galaxy scaling and supermassive black holes, IOA, Cambridge, November 1.

Morphology of luminous compact and other galaxies, Observatoire de Lyon, France, November 8.

Planet : Near and far, (Science Week), (organized by Rotary Club) Garware College, November 22.

The space, Lecture series on Space, B. N. College of Architecture, Pune, November, 23

Bridging the digital divide - Empowering universities *in India*, INDEST Workshop and Fourth Annual Meeting, IIT Delhi, December 19.

Imaging the sky, Workshop on Introduction to Atronomy Programme, KTHM College, Nasik, January 17.

Career in astronomy, Workshop on Introduction to Atronomy Programme, KTHM College, Nasik, January 17.

Archival data - Use, abuse, Indo-French Training School in Optical Astronomical Observations, IUCAA, February 15.

Knowledge through information technology, UGC Academic Staff College, University of Burdwan, West Bengal, February 20.

Planets : Near and far - The story of Pluto, UNPG College, Padrauna, U.P., February 22.

Gravitation : Illusion and reality, Inaugural lecture at the DDU Gorakhpur University, February 23.

Planets : Near and far - The story of Pluto, DDU Gorakhpur University, February 23.

VO-Project demonstrations, IIA, Bangalore, March 5.

Warm absorbers in active galactic nuclei, IIA, Bangalore, March 6.

Digital divide and the UGC-Infonet, Pt. Ravishankar Shukla University, Raipur, March 12.

Ratna Koley

Braneworld models and phenemenology, Post-doc Fest, IUCAA, January 31.

Braneworlds in six dimensions : New models with bulk scalars, 24th Meeting of the IAGRG, Jamia Millia Islamia, Delhi, February 5.

Ranjeev Misra

The non-Linear behaviour of black hole systems, Discussion Meeting on Non-Linear Dynamics, IUCAA, November.

Transitions between cold and hot disks, High Energy Phenomena Around Compact Objects, TIARA, Hsinchu, Taiwan, July.

A laboratory experiment to study astrophysical accretion processes, Informal Discussion Group, IUCAA, December, 2006.

Jayant Narlikar

A critique of standard cosmology, The conference on Bernard's Cosmic Stories, Universidad Internacional Menendez Pelay (UIMP), Valencia, Spain, June 26.

Searches for extraterrestrial life, The Physics Department, University of Bremen, Germany, July 11.

TWAN : a way of networking third-world astronomers, Special Session 5 on Astronomy for the Developing World, XXVI General Assembly of the International Astronomical Union, Prague, Czech Republic, August 21.

Einstein and cosmology, School of Physics, Univerity of KwaZulu-Natal, Durban, South Africa, September 8.

A critique of standard cosmology, South African Relativity Society Meeting, Pretoria, South Africa, September 15.

S*earches for extraterrestrial life*, The University of Zululand, South Africa, September 22.

A critique of big bang cosmology, The Workshop on Physics: Atom to Galaxy, H.N.B. Garhwal University, Srinagar, October 9.

A critique of standard big bang cosmology, The Indian Institute of Science Education and Research, Pune, February 7.

The interaction between particle physics and cosmology (Second Abdus Salam Memorial Lecture), The Conference at the University of Chittagong, Chittagong, Bangladesh, March 14.

Research, teaching and development programmes of the International Astronomical Union, The Conference at the University of Chittagong, Chittagong, Bangladesh, March 17.

Research, teaching and science popularization programmes of the International Astronomical Union The University of Dhaka, Dhaka, Bangladesh, March 19.

T. Padmanabhan

The darker side of the universe, XXIII Texas Symposium on Relativistic Astrophysics, Melbourne University, Australia, December 15.

Entropy and dynamics of the spacetime, 24th Meeting of the IAGRG, Jamia Millia Islamia, New Delhi, February 5-7, 2007.

Gravity as an emergent phenomenon, TIFR, Mumbai

March 12.

Four curious pieces, HRI, Allahabad, September.

Gravity: an emergent phenomenon, International Workshop on Theoretical High Energy Physics, IIT, Roorkee, March 15 - 20.

Some open questions in astrophysics and cosmology, INSA-Hungarian Academy of Sciences, New Delhi, November 27.

Darkest side of the universe, IUCAA-MPA Workshop on Astrophysics and Cosmology, IUCAA, March 5

Supratik Pal

Gravitational collapse in braneworld gravity, Fifth Meeting on Field Theoretic Aspects of Gravity, BITS Pilani, Goa Campus, December 18-23.

Aspects of braneworld gravity : The effective theory and its prospects, Post-doc Fest, IUCAA, January 31.

Structure formation on the brane : A mimicry, 24th Meeting of the IAGRG, Jamia Millia Islamia, Delhi February 5-8.

Biswajit Pandey

Luminosity-bias relation from filaments in the Sloan Digital Sky Survey Data Release Four, IIT Kharagpur, December 7.

The luminosity, colour and morphology dependence of galaxy filaments in the Sloan Digital Sky Survey Data Release Four, Post-doctoral Fellow's fest, IUCAA, January 31.

Noninvariance of space- and time-scale ranges under a Lorentz transformation and the implications for the study of relavistic interactions' (J.L.Vay, 2007, PRL, 98, 130405), IDG, NCRA, April 27.

Maulik Parikh

Mach's Holographic Principle, Fifth Meeting on Field Theoretic Aspects of Gravity, Goa, December 2006.

Mach's Holographic Principle, Tata Institute for Fundamental Research (TIFR), Mumbai, February 2007.

A.N. Ramaprakash

IUCAA Girawali Observatory - now and soon, IUCAA internal meeting, Khandala, April 11.

Astronomical instruments of today, Training School for International Astronomy Olympiad, Nehru Science Centre, Mumbai, May 4.

Overview of IUCAA Girawali Observatory, Inaugural symposium of IGO, IUCAA, May 14.

Swara Ravindranath

Morphological diversities among the high- z galaxies in GOODS, the Conference "At the Edge of the Universe — Latest Results from the Deepest Astronomical Surveys, Sintra, Portugal, October 9-13.

Morphological diversities among the high-z galaxies in GOODS, MPIA, Heidelberg , October 16-18.

Morphological Diversities among the High-z Galaxies in GOODS, University of Nottingham,UK, October 20-24.

Morphological Diversities among the High-z Galaxies in GOODS, University of Exeter,UK, October 20—24.

Observational constraints on galaxy evolution from Deep Surveys, Harish-Chandra Research Institute, Allahabad , November 6-9.

Observational constraints on galaxy Evolution from multiwavelength surveys - the GOODS perspective, the 125th Astronomical Society of India meeting, Osmania University, Hyderabad, February 7-9.

Arnab Kumar Ray

Static and dynamic aspects of transonicity in Bondi accretion, IUCAA, Pune, November 3.

A time-dependent perturbative study of the shallow water hydraulic jump, Department of Physics, Pune University, Pune, February 3.

Static and dynamic aspects of transonicity in Bondi accretion, School of Physical Sciences, Jawaharlal Nehru University, New Delhi, February 14.

Application of dynamical systems techniques and perturbative methods in astrophysical fluid problems, Third SERC School on Nonlinear Dynamics and Turbulence, Indian Association for the Cultivation of Science, Kolkata, December.

Dynamic selection of a marginal solution in astrophysical hydrodynamics, (Journal club talk) Condensed Matter Physics Group, Harish-Chandra Research Institute, Allahabad, February 24.

Critical features of multitransonic pseudo-Schwarzschild accretion, Post-Doctoral Fellows'

Fest, February 2.

Varun Sahni

Dark energy: Puzzles and surprises, (Plenary talk), SF06 Cosmology Summer Workshop, Santa Fe, USA, July 3-21.

Dark matter and Dark energy, (Plenary talk), Workshop on Frontiers of Physics, Mumbai University, October 9-11.

Inflation after WMAP,
April 7, 2006
IDG talk, IUCAA/NCRA, Pune, India

The Accelerating Universe and Dark Energy,
September, 2006
Colloquium, Indian Institute of Science, Bangalore, India

The Big Bang,
November 2006,
Invited lecture on the occasion of the XI International Astronomy Olympiad IUCAA,Pune

Rita Sinha

DEEP-QSO: Clustering of galaxies around QSOs, US National Virtual Observatory Summer School at Aspen, Colorado, USA, September 6-14.

Virtual Observatory- An overview, Astronomy Department, University of Virginia, Charlottesville, USA, September 18-30.

Introduction to the Sloan Survey, Astronomy Department, University of Virginia, Charlottesville, USA, September 18-30.

VO- overview and VO-software demo, Workshop on Advanced topics in Data Analysis in Cosmology and Gravitational Wave Astronomy, IUCAA Reference Centre, Delhi University, October 4- 14.

Virtual Observatory, Introductory workshop on Astronomy and Astrophysics, K.T.H.M. College, Nashik, January 17-18 .

Virtual Observatory- An overview, Indo-French Training School on Astronomy, IUCAA, February 24.

Photometric identification of quasars and SED builder: A VO approach, Post-doctoral Fellow's Fest, IUCAA, February 2.

Tarun Souradeep

Statistics of CMB anisotropy, IUCAA-MPA workshop on Astrophysics and Cosmology, IUCAA, March 5.

Celebrating the Cosmic Microwave Background (Colloquium), TIFR, Mumbai, November 2.

Celebrating the Cosmic Microwave Background (Colloquium), HRI, Allahabad, October 27.

Statistical isotropy of CMB temperature and polarization, (Invited talk) Workshop on Non-Gaussianity, ICTP, Trieste, Italy, June 21-29.

A blind estimation of angular power spectrum of CMB anisotropy from WMAP, (Invited talk) the Planck group meeting at JPL (Caltech), Pasadena, April 5.

Hunting correlation patterns in the CMB anisotropy, (Invited seminar) CaJWGR (Caltech JPL Assoc. for gravity wave research), Caltech, Pasadena, April 4.

R. Srianand

Observational cosmology, Engineering College, Siliguri, September. (2 lectures)

Galaxies, Workshop on stars and galaxies: Observatioal Techniques and data analysis, North Bengal University, September (2 lectures).

On the variation of fine-structure constants (a review talk), University of Kwazulu, Natal. October.

Probing the variation of fundamental constants (colloquium), IMSc, Chennai.

Physical conditions in protogalaxies (Vainu Bappu medal talk), Astronomical Society of India, Hyderabad, February.

Probing the star formation history using DLAs (A review), IUCAA-MPA Workshop on Astrophysics and Cosmology, IUCAA, March.

K. Subramanian

Magnetogenesis in the universe, (Colloquium) Harish- Chandra Research Institute, Allahabad, April.

CMB anisotropies , Harish-Chandra Research Institute, Allahabad , April (2 lectures).

Magnetogenesis in the universe, Delhi University, July.

Magnetogenesis in the universe, (colloquium), Institute of Physics, Bhubaneswar, August.

The nonlinear alpha effect under double first-order smoothing, Newcastle University, UK, October.

Magnetogenesis in the universe, Institute of Mathematical Sciences, Chennai, January.

Magnetizing the universe, IUCAA-MPA workshop on Astrophysics and Cosmology, IUCAA, March.

S. N. Tandon

Observational techniques and data analysis, Workshop on Stars and Galaxies, North Bengal University, and Siliguri Institute of Technology, Siliguri, September 12-15.

(b) Lecture Courses

Sanjeev Dhurandhar

A course on gravitational waves and data analysis, Delhi University, October 3- 12 (10 lectures).

A course on gravitational waves, Introductory Workshop on Astronomy and Astrophysics, Utkal University, Bhubaneswar from January 9 - 11 (3 lectures) .

Fourier transforms over finite groups, Mathematics Department, University of Pune, December 1, 6, 8 (3 lectures)

Ranjan Gupta

(i) Modern Telescopes and *(ii) Atmosphere and its effect* and (iii) *Astronomical Spectroscopy,* Workshop on Physics from Atom to Galaxy: Theoretical and Technical Status, Srinagar, HNB Garhwal University, October 9-11 (3 lectures).

Ajit Kembhavi

Stars and compact objects, Introductory Summer School on Astronomy and Astrophysics and Vacation Students' Programme, IUCAA, Pune, May 19, 26, 29 - June 1(6 lectures).

AGN and quasars, Introductory Summer School on Astronomy and Astrophysics and Vacation Students' Programme, IUCAA, May 15 - 17 (3 lectures).

Stellar structure and evolution, North Bengal University, Siliguri, September 13 - 14 (3 lectures).

Stellar structure, evolution and compact Objects, Part of M.Sc Special paper in Astronomy at Presidency College, West Bengal, December 4 - 8 and IUCAA, January 22 - 31(14 lectures).

Ranjeev Misra

Radiative and accretion processes in astrophysics, Introductory Workshop on Astrophysics, Mohan Lal Sukhadia University, Udaipur, December 2006 (4 lectures).

Radiative and accretion processes in astrophysics, Introductory Workshop on Astrophysics, Utkal University, Bhubaneswar, Janury 2007 (4 lectures).

Radiative and Accretion Processes in Astrophysics, Introductory Summer School on Astronomy and Astrophysics, IUCAA, May 2006 (4 lectures).

Jayant Narlikar

Cosmology from sidelines, European Southern Observatory, Germany, May 23, May 30, June 2, June 6, June 9, and June 13 (6 lectures).

Cosmological models with space-time symmetries, Bhaskaracharya Pratisthan, Pune, December 11-13 (3 lectures)

T. Padmanabhan

Introduction to general relativity, Introductory Summer School on Astronomy and Astrophysics and Vacation Students' Programme, IUCAA, May 23 - 26 (4 lectures).

A.N. Ramaprakash

Astronmical telescopes and instruments, Introductory Summer School on Astronomy and Astrophysics and Vacation Students' Programme, IUCAA, May 18 - 22 (5 lectures)

Polarimetric techniques in Astronomy: Indo-French Training School on optical Astronomical Observations, IUCAA, February 2007 (4 lectures).

Swara Ravindranath

Galaxies, Introductory Summer School on Astronomy and Astrophysics, IUCAA, May (4 lectures) and 2 demo sessions on *Reduction and analysis of spectroscopic data.*

Galaxies, Introductory Workshop on Astrophysics, Mohanlal Sukhadia University, Udaipur, December 20 -24, (3 lectures) and 1 demo session each on the *Reduction and analysis of photometric and spectroscopic data*.

Galaxies, Workshop on Understanding the Universe, Utkal University, Bhubaneswar, January 8 - 10 (3 lectures).

Tarun Souradeep

Introductory course on cosmology and structure formation, North Bengal University, April -May (Part of theoretical Science course at North Bengal university.) (10 lectures).

Cosmology: towards observing the early universe, the First Asian winter school on String Theory, KIAS, Seoul and Pheonix Park, Korea , January 15-19, (4 lectures).

Analysis of CMB anisotropy, University of Delhi, October 4 - 8 (8 lectures).

Inflation and CMB anisotropy, Vacation Students' Programme, IUCAA, June 2-9 (4 lectures).

R. Srianand

Diffuse matter in space, Vacation Students' Programme, IUCAA, May-June (5 lectures).

K. Subramanian

Fluids and MHD, Introductory Summer School on Astronomy and Astrophysics and Vacation Students' Programme, IUCAA, May (4 Lectures).

Theory of CMB anisotropies, Delhi University, July (4 lectures).

Theory of CMB anisotropies, Max Plank Institute of Astrophysics, Germany, October-November (5 lectures).

(VIII) SCIENTIFIC MEETINGS AND OTHER EVENTS

Inauguration of the IUCAA Girawali Observatory

Professors Yash Pal and J. V. Narlikar lighting the lamp on the occasion of the inauguration of the IUCAA Girawali Observatory

Inauguration of IUCAA Girawali Observatory was on May 13-14, 2006. After a long and eager wait, installation and commissioning of the 2- metre telescope was completed in February this year. Soon after its commissioning, the telescope was put to use for photometric and spectroscopic observations; it delivered good images and on several occassions images sharper than 1" were obtained. The telescope was formally inaugurated and dedicated to the nation in a simple ceremony on May 13, 2006. In the morning, members of IUCAA, many astronomers from universities and other institutions, and people from Girawali and other villages from the neighbourhood assembled at the site to participate in the inauguration of the telescope by Professor Yash Pal. In the evening, the IUCAA Girawali Observatory was dedicated to the nation by him in a function held in Chandrasekhar Auditorium of IUCAA. In addition to the dedication speech by Professor Yash Pal, there were brief speeches by N.K. Dadhich, J.V. Narlikar, S.N. Tandon, N. Mukunda, and Russell Cannon - all of whom have been intimately connected with the telescope project. On the next day, there was a technical symposium, in which performance of the telescope and preliminary results obtained were reported by astronomers from IUCAA. In addition, there were several talks by other astronomers on astronomy with moderate size telescopes.

School Students' Summer Programme - 2006

The annual IUCAA School Students' Summer Programme was held from April 17 to May 26, 2006. This programme was started in 1993 for the school students of Pune. It is conducted for six weeks, which gives a glimpse of the pursuit of scientific research to the school-nominated students. Six batches of 20-30 students of class VIII and IX were invited to work on a project at IUCAA. During the period, every week, starting on Monday, teams of 2 - 6 students were attached to volunteering scientists at IUCAA, who guided them on scientific projects. In the spirit of true research, the students and guides worked together unfettered by a set syllabus and time schedules. The students were given access to the IUCAA library and the facilities of IUCAA's Science Exploratorium - the Muktangan Vidnyan Shodhika, like the library, computer section and workshop. To give a finishing touch to their work, on the last working day of every batch, the student teams made presentations about the work they did during the week and submitted a report. This year, the students carried out projects under the supervision of Susmita Chakravorty, V. Chellathurai, Samir Dhurde, Abhay Kohok, Gaurang Mahajan, Vidula Mhaiskar, Jayant Narlikar, Thanu Padmanabhan, Arvind Paranjpye, Ashok Rupner, Saumyadip Samui, Sudipta Sarkar and Kandaswamy Subramanian.

The projects were diverse, covering wide range of topics. Some students estimated the latitudes of various places seeing the IUCAA Foucault pendulum and by observing shadow of gnomon and learned to use trigonometry to measure heights. Two teams made a collection of rock and soil samples around IUCAA to find out various facts about geology. Others studied the properties of electromagnetism, scale of our solar system, Kepler's laws and our planets, earth's structure, tectonic plates, volcanoes, earthquakes, rocks and minerals, weather phenomena, finding time and location from the heavenly bodies, laws of optics, fractals, human anatomy – sensory, nervous, circulatory, pulmonary, skeletal and digestive system. Some of the teams constructed a set of instruments for a school weather station, working model of the human eye, an AC generator, a model depicting movements of the earth during an earthquake, a working model of the IUCAA Samrat Yantra, models of the Cassini space-probe, periscopes and some scientific toys. Besides the team project, the students also had time for joint activities in the Pulastya building such as, solving puzzles, making scientific toy, exploring the IUCAA science park and viewing popular science movies. Informal interactive sessions with young, budding scientists were organized in which the participants were, Abhishek Rawat, Mudit Srivastava, Sharanya Sur, who are working towards their Ph.D. in IUCAA. Hamsa Padmanabhan, a class XI student who has recently won the second prize in the Intel Science and Engineering Fair held at US was also invited for a session. Besides answering questions, these young scientists shared their experiences and the joy of doing research in science.

Participants of the School Students' Summer Programme in various activities

Introductory Summer School on Astronomy and Astrophysics

Lectures and practical sessions of the Introductory Summer School on Astronomy and Astrophysics

The Summer School funded by the Department of Science and Technology (DST) of the Government of India was conducted at IUCAA for a month beginning May 15, 2006. Twenty-eight students studying physics at the final year B.Sc. or first year of M.Sc. as well as students of engineering in their third year participated in the school. The programme consisted of a series of lecture courses, evening lectures on special topics, image processing and data analysis sessions and problem solving sessions.

The main areas on which lecture courses given were (i) Astrophysical Processes, (ii) Stars and Stellar Systems, (iii) Gravitation and Cosmology, and (iv) Telescopes, Instruments and Data Analysis. These lectures were given by IUCAA faculty as well as visiting associates of IUCAA.

The special lectures, which were delivered mainly in the evening, were on a variety of special topics ranging from neural networks to application of super computers to various areas of astronomy. Several of these special lectures were delivered by graduate students at IUCAA, and these were very well received by the participants, who got a flavour of the state-of-the-art-research carried out by young students at IUCAA with whom the participants could discuss ideas freely and productively. Students and post-doctoral fellows at IUCAA also conducted several problem-solving sessions, during which the summer school students were encouraged to solve problems on the blackboard for the benefit of all those present. The problem-solving sessions were proved to be very important in conveying finer points of the subject to young students without burdening them with a great detail during the lectures. A number of image processing and data analysis sessions with optical and X-ray data were conducted by students and postdoctoral fellows in a special computer laboratory set-up for the purpose. These again proved to be hugely popular with the participants. During the first few days of the school, participants were introduced to facilities at IUCAA like the library, computer centre and the instrumentation laboratory; participants were also introduced to the use of electronic journals and preprint services. A visit was arranged for the participants to the new IUCAA 2-metre optical telescope and infrared telescope at Girawali.

The reaction of the participants to the lecture courses and practical and problem sessions was very positive and it is hoped that the experience will stimulate some of them to take up a career in Astronomy and Astrophysics. The school was coordinated by Ajit Kembhavi who was ably assisted by the technical and administrative staff.

Vacation Students' Programme

Participants of the Vacation Students' Programme

The Vacation Students' Programme (VSP) for students in their penultimate year of their M.Sc. (Physics) or Engineering degree course was held during May 15 - June 30, 2006. 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 IUCAA Associates. They also did a project with one of the faculty members of IUCAA during this period. K. Subramanian was the faculty coordinator of this programme.

Workshop on Stars and Galaxies: Observational Techniques and Data Analysis

A workshop on "*Stars and galaxies: observational techniques and data analysis*" was conducted by IUCAA at North Bengal University, Silguri during September 12 - 15, 2006. In all, about 50 students and lecturers from nearby colleges and universities participated in the workshop. The lectures covered the topics on stars, galaxies, compact objects, telescopes, detectors, celestial co-ordinates, photometry, polarimetry and projects with small telescopes. In addition to these, practical sessions were held to impart training on LINUX, IRAF and image processing. Lectures were held in the morning session and afternoon sessions were devoted to practical training. Resource persons included A.K. Kembhavi, S.N. Tandon, R Srianand, Vijay Mohan, Sudhanshu Barway, Abhishek Rawat (all from IUCAA), Asoke Sen (Assam University), S. Chakraborty (Visva Bharati University) and Rabin Chhetri (Sikkim Govt. College, Gangtok). Vijay Mohan was the coordinator of the workshop from IUCAA, and S. Mukherjee was the coordinator from North Bengal University, Siliguri.

Participants and lecturers of the Workshop on Stars and Galaxies: Observational Techniques and Data analysis

Workshop on Astronomy for Engineers

The IUCAA and IUCAA Reference Centre, North Bengal University (NBU), organised a two-day workshop on "Astronomy for Engineers" at Siliguri Institute of Technology (SIT), Sukna, on September 10-12, 2006. About 100 undergraduate engineering students and faculty members attended the workshop. The local arrangements were made by SIT in their scenic campus at the foothills of the Himalayas. The lecturers included S. N.Tandon, A. K. Kembhavi, A. Bandyopadhyay, R. Srianand, Vijay Mohan, Abhishek Rawat and S. Mukherjee. There were two interaction sessions, where the participants held long and animated discussions with the speakers.

An interesting event during the workshop was the distribution of prizes to the winners of the essay competition organised by IRC, NBU in 2005, the Year of Physics. The first three winners, Malini Ghosal, Dipanjan Hore and Alokparna Roy, were given cash awards and certificates and the next 12 participants were awarded certificates of merit and special prizes. There was a popular talk on the *"Mysteries of the Universe"* by A. Bandyopadhyay, M.P. Birla Planetarium, Kolkata.

Workshop on Advanced Topics in Data Analysis in Cosmology and Gravitational Wave Astronomy

The Workshop on Advanced Topics in Data Analysis in Cosmology and Gravitational Wave Astronomy was held at the IUCAA Reference Centre at Delhi University during October 4 -14, 2006. The aim was to teach the interested participants the techniques of modern data analysis in Astrophysics. Most of the talks were on data analysis applied to Cosmic Microwave Background Radiation and to Gravitational Wave Astronomy. There were also talks related to dark energy, simulations of large-scale structures, virtual observatory, high-energy physics and error analysis of the observations using the medieval observatory, Jantar Mantar at Delhi. It was attended by more than 50 participants. The audience included B.Sc., M.Sc. and Ph. D. students and also a number of faculty members from colleges and the universities in Delhi. Speakers included Tarun Souradeep (IUCAA), Sanjeev Dhurandhar (IUCAA), Rita Sinha (IUCAA), Jasjeet S. Bagla (HRI), Harvinder K. Jassal (HRI), Satyaki Bhattacharya (Delhi University), and N. Ratnashree (Nehru Planetarium, Delhi). The sessions were very interactive with lots of discussions.

The program also included a lecture tour of Jantar Mantar, which is an observatory built by Raja Jai Singh. Here, under the supervision of N. Rathnashree, some of the participants had a hands on session taking measurements and doing calculations .

This workshop was coordinated by T.R. Seshadri (Delhi University) and Tarun Souradeep (IUCAA).

Participants and lecturers of the Workshop on Advanced Topics in Data Analysis in Cosmology and Gravitational Wave Astronomy

IUCAA-MPA Workshop on Astrophysics and Cosmology

The IUCAA-MPA workshop on Astrophysics and Cosmology was held at IUCAA during March 5 - 9, 2007. The aim was mainly to foster closer ties between the Max Planck Institute for Astrophysics at Garching, Germany, and IUCAA. About 40 people participated in the workshop, including Simon White (the MPA Director), Torsten Ensslin, Antonella Maselli, and Volker Springel from MPA, IUCAA academics and several astronomers from other Indian institutes. The format of the workshop consisted of 16 one hour talks, spread over four days, with extensive discussions during the talks. Mostly topics related to structure formation in the universe were covered. Overall, the workshop resulted in closer contacts being established between many of the participants.

Participants of the IUCAA-MPA Workshop

Discussion meeting on Nonlinear Phenomena and Techniques

A discussion meeting on Nonlinear Phenomena and Techniques was held at IUCAA, during Nov 2 - 4 2006. The broad motivation for this meeting was to discuss the recent trends of applying non-linear techniques to different kinds of systems and data, especially those related to astrophysical sources. The meeting, coordinated by Ranjeev Misra (IUCAA) and G. Ambika (IISER, Pune), was coincident with the long term visit of Y. Tanaka (Ibaraki University, Mito, Japan) to IUCAA.The lectures and discussions were spread over three sessions, viz., Recent Techniques in Nonlinear Physics, Nonlinear Phenomena in Astrophysics, and Collective Behaviour in Nonlinear Systems. The participants included, M. Lakshmanan (CNLD, Bharathidasan University,Tiruchirapalli), Y. Tanaka (Ibaraki University, Mito, Japan), R. E. Amritkar (PRL, Ahmedabad), G. Rangarajan (IISc, Bangalore), A. D. Gangal (University of Pune) M. K. Das (IIC, Delhi), G. Ambika (IISER, Pune), R. Misra (IUCAA, Pune), Arnab Kumar Ray (IUCAA,Pune), K. P. Harikrishnan (The Cochin College, Kochi) P. M. Gade (Centre for Modelling and Simulation, University of Pune), Renja Sarkar (University of Pune), Rajesh S. (CCMB, Hyderabad), K. Ambika (Maharajas College, Kochi), B. Dey (University of Pune) and Hemant Bhate (University of Pune). Apart from lectures, there were active discussions, which were expected to lead to inter-disciplinary research and interactions in future.

Indo-French Training School in Optical Astronomical Observations

An Indo-French Training School in Optical Astronomical observations was organised at IUCAA during February 12 - 26, 2007. The school was funded by the Indo-French Centre for Promotion of Advanced Research, New Delhi. The school was aimed at to provide efficient training to research scholars, and young faculty members in optical astronomical observations and data reduction directly at the telescope. In all, there were 16 participants, 13 from India and 3 from France. There were 4 lecturers from France and 7 from India.

The school consisted of a few basic lectures required for doing observational astronomy. These lectures were held for the first four days during morning sessions. During these four days, in the afternoon sessions, hands on practice of data reduction was imparted using the archival data taken at IUCAA Girawali Observatory (IGO).

The 16 participants were divided into 4 groups and each group was given an observational project, supervised by an astronomer. Each group observed at 2-metre telescope of IGO, for one night. The complete data reduction of these observations was carried out by each group. On the last day of the school, every participant presented the results obtained by him / her.

During the last week of the school, evening talks were arranged on current observational facilities. The topics were : GMRT by J. Chengalur (NCRA, Pune), From Galileo to ELTs by Michel Dennefeld (IAP, France), Astrosat and UVIT by S.N. Tandon (IUCAA, Pune), FUSE mission by Jean-Michel Desert (IAP, France) and Virtual Observatory by Rita Sinha (IUCAA, Pune).

The lectures included: Telescopes by S.N. Tandon (IUCAA, Pune), Detectors and their calibrations by A.N. Ramaprakash (IUCAA, Pune), Atmospheric effects on observations by T.P. Prabhu (IIA, Bangalore), Astronomical observations by Vijay Mohan (IUCAA, Pune), Astronomical spectroscopy by Michel Dennefeld (IAP, France), Astronomical photometry by N.M. Ashok (PRL, Ahmedabad), Surface photometry by S.K. Pandey (Pt. Ravi Shankar University, Raipur), Archival data by A.K. Kembhavi (IUCAA, Pune), Image analysis by Emmnuel Bertin (IAP, France), and Polarimetry by A.N. Ramaprakash (IUCAA, Pune).

The observational projects were: Active galaxies and deep fields by Henry-McCracken (IAP, France), Spectroscopy of planetary nebulae by Jean-Michel Desert (IAP, France), Surface photometry of elliptical galaxies by S.K. Pandey (Pt. Ravi Shankar University, Raipur) and Abhishek Rawat (IUCAA, Pune), and Polarimetry of T-Tauri stars by A.N. Ramaprakash (IUCAA, Pune).

Michel Dennefeld of IAP, France was the French coordinator of the school. Vijay Mohan of IUCAA and S.K. Pandey of Pt. Ravi Shankar Shukla University, Raipur were the Indian coordinators of the school.

Participants of the Indo-French Training School in Optical Astronomical Observations

Introductory Workshop on Astronomy and Astrophysics

Rita Sinha at one of the lecture sessions

Students of Nashik at a question-answer session

An Introductory workshop on Astronomy and Astrophysics was conducted by IUCAA at K.T.H.M. College, Nashik during January 17 -18, 2007. In all, about 100 students and teachers from host and nearby colleges in Nashik district participated in the workshop. Lectures covered the topics on Imaging the sky, Measuring the light from the stars, Virtual observatories for the 21st century, Science from Hubble Space Telescope, Sun: our own star and Careers in Astronomy. Each lecture was followed by question and answer session. In addition to these topics, there were demonstration sessions, devoted to practical training. Resource persons included A. K. Kembhavi, Santosh Joshi, Arvind Paranjpye, Rita Sinha, and Abhishek Rawat all from IUCAA. A. K. Kembhavi from IUCAA and A. S. Mandlik, Department of Physics, K.T.H.M. College were the coordinators of this workshop.

Public Outreach Programmes

IUCAA has an active Public Outreach Programme, the primary aim of which is to inculcate scientific interest among school students (especially underprivileged ones), encourage and help talented children to do scientific projects, promote amateur astronomy and inform the general public about the importance and excitement of recent scientific achievements, especially in astrophysics. To achieve these goals, several programmes were undertaken last year.

While some of these programmes are held all through the year, others were organised during the summer vacation. Apart from these regular programmes, the National Science Day and IUCAA Open Day were celebrated on February 24 and 28, 2007 respectively. These Public Outreach Programmes are housed in the Muktangan Vidnyan Shodhika.

Activities for school students

Second Saturday Lecture and Demonstration Programme: school students from class IX and X were invited from Pune, to attend Lecture and Demonstration Programme, held on the second Saturdays of the month. These lectures, which were given in English and in Hindi/ Marathi, aimed to inspire the students by informing them of recent developments in Science.

Science Activity Workshops

These workshops were conducted on every Monday, Wednesday, and Friday and each session was attended by about fifty school students. The students were shown how to make and appreciate several scientific toys, which were made of simple and easily available materials like matchsticks,film cans, ballpoint pen refills, etc.The aim of these workshops is to show students that science is fun and exciting. This programme is especially beneficial to under privileged student who may not have access to costly scientific apparatus. These workshops have become very popular and are often booked a month in advance by teachers and NGOs. Children with special needs are encouraged. The team was invited to Grahamstown, South Africa, where the workshops received the most Innovative Workshop Award.

Advanced Projects

MVS supports advanced projects for college students. Manini Datta,Cummins College of Engineering for-Women, did a project on making a sidereal clock drive as part of her Engineering programme and Komal Daga, Kakul Jain and Divya Gupta did short projects using an automated telescope to measure sky brightness.

Visits to IUCAA and Sky Shows

IUCAA organises visits to the campus, for interested people from different professional backgrounds and age groups. These visits, which are by invitation only, took place typically on Thursdays. On each of the nearly 50 occasions, about 30 visitors were given a brief introduction about IUCAA and were shown the various exhibits on the premises and the science park. Student visitors with more technical background were also shown the instrumentation laboratory.

Contribution to the Media

The members of the POP interacted with the print and wireless media by informing them about the activities at IUCAA and about celestial events. This has helped media-persons be aware of upcoming events and hence a more thorough coverage could be provided. Dedication of IUCAA's 2mTelescope on May 13, 2006 was widely covered across the country. The media also covered the POP programme in the rural area near the location of the telescope. The POP provided up-to date information during August 2006, when Pluto was re-categorised as dwarf planet.

Members have been contributing weekly science features to a local newspaper, The Maharashtra Herald. These articles explain scientific principles and describe do-it-yourself experiments, which young readers can perform. These features were published every Friday (for high schools students) and on every Saturday (for secondary schools students) till January 2007.

Outstation support

The POP has provided active support to various organisations especially those affiliated to the university sector for the maintenance and setting up of astronomical facilities. The 9 inch telescope operated by M.G. University, Kottayam was repaired at IUCAA and an 11 inch telescope was put into operation for Vigyan Prasar, Delhi. A digital imaging facility was created and telescope making workshops were conducted for a prominent amateur astronomy group in Goa. Advice on the type of astronomical facility that would be feasible and suitable was provided to Amravati University.

Public Outreach in Girawali region

Last year, a new initiative was undertaken by POP to popularise astronomy in the rural areas near the location of the IUCAA 2m Telescope. A one day workshop on astronomy and science toy making was conducted at Ghodegaon (the nearest major town) for school teachers. This was followed by regular weekly programmes of science teaching and mobile planetarium and live sky shows in several villages. Nearly twenty such programme were held and typically more than 300 children participated at each show.

Pu La Deshpande's Birth Anniversary Celebrations

The 87th birth anniversary of Pu La Deshpande was celebrated at the Muktangan Vidnyan Shodhika, the Science Centre of IUCAA by arranging a four day programme for school students and teachers. The "Pulastya" building for the Muktangan Vidnyan Shodhika was built from a donation received from Smt. Sunitabai Deshpande, relict of the famous P. L. Deshpande (Pu La).

The celebrations started on November 8, 2006, with a talk in Marathi by J.V. Narlikar entitled, "*Ganitachi Vividhrangi Rupe*". Ninad Sheode from the University of Bremen, Germany, gave a talk about, "*Kya hai Ozone Hole*?" On the last day, Rajaram Nityananda, the Centre Director of NCRA-TIFR, Pune, gave the talk titled, "*Science Outside Classroom: Water*". It was followed by an interactive session with school teachers on science teaching including easy scientific experiments and a mobile planetarium demonstration.

An exhibition on do-it-yourself (DIY) science experiments was set up for the school students. The unique feature of this exhibition was that the DIY experiments were demonstrated by the students of Huzurpaga and Aksharnandan schools in Pune. A day-time introduction to sky watching was carried out using an advanced interactive software. A session on *`telescopes'* was conducted by the members of Akashmitra, an association of amateur astronomers.

More than 1000 students and 100 teachers participated in these celebrations.

The various Science Popularisation activities

Taramandal, The Mobile Planetarium

Last year, IUCAA acquired a mobile planetarium, named Taramandal, which has proved to be extremely useful in promoting Astronomy in areas around Pune and Kohlapur. In all, around 25 programme were conducted including 15 shows in the Girawali region.

POP Associate Programme (MViSA)

A programme named MViSA (Muktangan Vidnayan Shodhika Associates) was started last year, where amateur astronomers (consisting of college students and mid career professionals) and school teachers were invited to be associates of MVS. Twelve amateur astronomers and four teachers participated in this programme and had weekly meetings in MVS on Wednesdays and Thursdays. The associates were given training in astronomical observations, in particular photoelectric photometry of variable stars, occultations and data reduction. For more than 50 nights, the IUCAA 14" telescope was used and the variable star zeta Geminorum (with a six day period) was successfully monitored. In addition, four junior associates did projects on wind and water mill. The school teachers were initiated in making models that illustrate scientific principles.

International Heliophysical Year (IHY) 2007

POP is celebrating the IHY 2007 by preparing a mobile exhibition, which would highlight various scientific and ecological aspects of the sun. This will be displayed in schools and to the general public during the later part of the year.

National Science Day

The National Science Day was celebrated at IUCAA on February 24 and on February 28. On Saturday, February 24 science related competitions were held for schools students. The centre was opened to the general public on February 28, so that they may acquaint themselves with the research done at IUCAA and appreciate scientific temper and methodology.

Inter-School Competitions

Schools in Pune region were invited to participate in the inter-school science competitions. On February 24, five students each, from about 80 schools took part in the quiz, essay and drawing competitions organised at IUCAA. Topics for the drawing and essay competitions were suitably chosen to enable the students to exhibit their fertile imagination and scientific knowledge. Based on a preliminary written test held in the morning, three member teams from five schools took part in the final quiz contest. The students were tested for their scientific and technological knowledge and their ability to solve puzzles.

The Open House for Public

More than 6000 people from all age groups and different walks of life visited IUCAA on February 28, 2007.

The visitors viewed several posters describing the basics of Astronomy and Astrophysics and the fundamental research done at IUCAA and interacted with IUCAA members who demystified the technical details of the research activities. Senior scientists directly interacted with the visitors to clarify their doubts about astronomy and physics. Short interactive lectures on different topics were held. A public talk, which explained the importance of this year's Nobel prize in physics, in non-technical language, was presented in the evening.

Visitors were encouraged to get hands on experience of using do-it-yourself experiments set up in the Muktangan Vidnyan Shodhika. Students of Aksharnandan School volunteered to give the demonstrations. Members of the Akashmitra, Pune and MVS associates participated in explaining exhibits in the science park and later on carried out sky observing programme for general public.

Students receiving tropies at the hands of IUCAA Director

The do-it-youself experiments are being demonstrated by the students

Winners of Various Competitions held on the occasion of the National Science Day

Essay Competition (Marathi Medium)

1st Prize : No prize was given

2nd Prize : Prachi Vinaya Kshirsagar, Sadhana Girls High School.

Essay Competition (English Medium)

1st Prize : No prize was given

2nd Prize : Darshita Rajesh Raval, Vidya Bhavan High School.

Honorable Mention:

Vishakha R Damle, Dr. Kalmadi Shamrao High School.

Drawing Competition

1st Prize (shared by): Priyanka D. Joshi, H. H. C. P. High School , and

Gayatri S . Wavhal, Muktangan English School.

2nd Prize: Nilambari Pravin Tupe, Sadhana English Medium School.

Quiz Competition

1st Prize:
Vidya Bhavan High School
(Rohit Sant, Mugdha Todkar, Jaideep Pathak)

2nd Prize:
Vikhe Patil Memorial School
(Piyush Kulkarni, Ameya Deshpande, Rohan Biwalkar)

3rd Prize:
Army Public School
(Pranjal Mittal, Ashish Pande, Rohan S. Vangal)

(Army School, Kirkee and D. E .S. Secondary School were the other two schools which qualified for the grand finale)

Popular Talks and Articles by the IUCAA Faculty

(a) Popular Talks

Naresh Dadhich

Why Einstein (Had I been born in 1844!)? (a Public Lecture) Introductory Workshop on Astrophysics Mohanlal Sukhadia University, Udaipur, December 23.

Science and Society S.F.S. School, Aurangabad, March 1.

Ajit Kembhavi

Pluto : The story so far, Public lecture series, IUCAA, September 18.

Planets : Near and far, Raosaheb Thorat Hall, Nashik, January 16.

Gravitation : Illusion and reality, Janalaxmi Bank Auditorium, Nashik, January 17 (organized by Science Forum, Nashik)

Ranjeev Misra

Observational evidence for black holes, (Akhash-Mitra, Pune, February 2007.

Jayant Narlikar

Searches for extra-terrestrial life, (a public lecture) University of the Punjab, Lahore, Pakistan, April 3.

Searches for extra-terrestrial life, Sohrab Godrej Memorial Oration Award Lecture at Taj Mahal Hotel, Mumbai, April 18.

Science and superstitions (a lecture) Nehru Memorial Hall, Pune, organized by the Arya Samaj Pune, May 6.

Why study astronomy? (a public lecture) The workshop on Physics: Atom to Galaxy, H.N.B. Garhwal University, Srinagar, October 9.

Searches for extraterrestrial life, (a lecture) Dehradun Institute of Technology, Dehradun, October 13.

Pruthvipalikade jeevshrushticha shodh, Search for extra-terrestrial life, (in Marathi) (a lecture), In memory of the late Shri. L.N. Wadikar at Sainik School Auditorium, Satara, November 5.

Ganitachi vividhrangi rupe, The many facets of mathematics, (in Marathi), (a lecture) to the school students, IUCAA, November 8.

The role of science fiction in the present age of science, (a keynote address) Eighth National Conference for Science Writers jointly organized by Indian Association for Science Fiction studies Marathi Vidnyan Parishad - Aurangabad Vibhag and Vigyan Prasar, Delhi at the Maharashtra Mahasool Prashikshan Prabodhini, Aurangabad, November 11.

Astronomy : Past, present and future, (a lecture) to the participants of the XI International Astronomy Olympiad, IUCAA, November 14.

Search for life in universe, (a lecture) to the school students organized by the Indian Association of Physics Teachers in collaboration with Rotary Club, Metro,Garware College, Pune, November 21.

Nehru, science and the scientific temper, (Jawaharlal Nehru Memorial Lecture) Jawaharlal Nehru University, New Delhi, November 24.

The search for life in the universe, (a lecture) Armed Forces Medical College, Pune, January 11.

Learning to live with science and technology, (24th T.A. Pai Memorial Lecture) T.A. Pai Management Institute, Manipal, January 17.

Facts and speculations in cosmology, (a talk) During ‘Techfest 2007’ held at the Indian Institute Technology, Bombay, Mumbai, January 28.

Search for life in the universe, (a lecture) Defence Institute of Advanced Technology (DIAT), Pune, February 6.

Modern cosmology from a historical perspective (a lecture) Zakir Husain College, New Delhi, February 13.

Search for panspermia in space in the upper atmosphere (an Informal Discussion Group talk) St. Stephen’s College, Delhi, February 13.

Cosmic illusions (a lecture) Gujarat Council of Science City, Ahmedabad, February 22.

Cosmic illusions,(a lecture) to the school students, IUCAA, Pune, February 24.

Vidnyannishth Savarkar, (Savarkar’s devotion to science) (in Marathi) (a lecture) Swatantryaveer Savarkar Pratisthan, Sangli, February 26.

Searches for life in the universe, (a talk) Department of Physics, Presidency College, Kolkata, March 12.

T. Padmanabhan

Nobel prize in Physics 2006- Blackbody form and anisotropy of the cosmic microwave background radiation, Nobel Evening 2006, NCL, Pune, November 2.

Astronomy as a science and its excitements, City Montessori School, Lucknow, QUANTA- 2006, November 17.

Excitement of doing science, S.P. College, Pune, February 20.

Dark energy, the cosmological conundrum, Raman Memorial Conference, Physics Department, University of Pune, February 23.

Nobel prize in physics 2006, National Science Day, IUCAA, February 28.

Rita Sinha

Welcome to virtual observatory, Akashmitra-Amateur Astronomers Club, Pune, January 25.

Tarun Souradeep

Cosmic structure and content, QUEST-06, CMS, Lucknow, November 19.

Afterglow of creation, QUEST-06, CMS, Lucknow, November 20.

The afterglow of creation, Second Saturday lecture for school students, IUCAA, February 10.

K. Subramanian

The expanding universe, Deen Dayal College, Delhi, July.

(b) Popular Articles

Naresh Dadhich

Meeting of minds
Hindustan Times, June 15.

T. Padmanabhan

Authors a regular fortnightly column in the newspaper "The Telegraph" from February 2007.

Maulik Parikh

Authors a regular column in the magazine "Outlook" (December 2006 - March 2007).

J.V. Narlikar

The excitement of doing science, Trillium 2005.

Science without borders, The Times of India, May 9.

A challenge in the sphere of higher education, Vision and Values - Science.Defence.Education.Ethics, 252.

A search for life in the universe, Dissertatio cum Nuncio Sidereo III, 3.

The excitement of doing science, Shillong College Golden Jubilee Magazine 2007.

The culture of science, Science and Spirituality in Modern India, 65.

Darkness at noon, The Times of India, November 18.

Amal Kumar Raychaudhuri, Biographical Memoirs of Fellows of the Indian National Science Academy, Ed. V. Ramamurti, Indian National Science Academy, 169.

Modern cosmology from a historical perspective, Science and Culture, 72, 9-10, 277.

Truth imitates fiction, The Times of India, December 30.

The role of science fiction in the present age of science, Dream 2047, December.

Change your mindset, The Indian Express, January 1.

Memory plus, The Times of India, March 31.

Learning to live with science and technology, Journal of the Kanara Chamber of Commerce and Industry, 17.

Vidnyan me kariyar - Mera chunav (in Hindi) [Career in science - My choice], Samaz Zaroka, 35.

Taron ko chhu lene ki hasrat (in Hindi) [Reaching out to the stars], Vikas Sahyatri, 4.

Vidnyan, samaj aur patrakarita (in Hindi) [Science, Society and Journalism], Anchalik Patrakar, February-March, 2.

Spot (in Marathi) [An explosion], Aaisi Akshare, July.

Time machinechi kimaya (in Marathi) [Miracle of the time machine], Marathi Vidnyan Parishad - Patrika, Diwali Issue, November, 8.

Akraman (in Marathi) [Invasion], Dharmabhaskar, Diwali Issue, 6.

Suryacha prakop (in Marathi) [Sun's fury], Dhananjay, Diwali Issue, 8.

Vidnyan ani me : Me vaidnyanik kasa zalo? (in Marathi) [Science and me : How I became a scientist?], Souvenir - Jawaharlal Nehru National Science Exhibition, 12.

Vidnyan sanshodhanatil uttejana (in Marathi) [The experiment of scientific research], Aamhi shastradnya ase zalo, 187.

Davadu naka kshana he molache! (in Marathi) [These moments are precious, don't waste them!], Sakal, January 3.

Krishnakand (in Marathi) [Dark Matter], Chhatra Prabodhan, 3.

Kuthe shodhishi vidnyaneshwar? (in Marathi) [Where shall we find young scientific leaders?], Sakal, February 6 and 28.

Vidnyan ani me : Me vaidnyanik kasa zalo? (in Marathi) [Science and me : How I became a scientist?], Shikshan Sankraman, February, 13.

Mallikabodha (in Sanskrit) [Lesson for Mallika], Samarpanam, 28.

(c) Radio/TV

Ajit Kembhavi

The story of Pluto, UGC Countrywide Classroom done by EMRC, Pune, October 4.

Jayant Narlikar

Relativity (in Hindi), DD News, May 22.

Relativity (in English), DD News, May 24.

Quantum (in Hindi), DD News, May 29.

Quantum (in English), DD News, May 31.

FACILITIES

(I) IUCAA computing facility

The IUCAA Computer Centre continues to provide state of the art computing facility to users from IUCAA as well as IUCAA associates and visitors from the universities and institutions in India and abroad.

The use of the computer network has changed dramatically due to high availablity of online multimedia applications. Enhancing the security of the network heads the list of reasons for modernization. Other important reasons include: increased reliability; accommodating growth due to changing user needs; preparing for changes in networking technology; and staying competitive with peer institutions. In Feburary 2007, the network across the campus was upgraded to a gigabit network. The new revamped network has redundant firewall appliances for security, hotspot appliance for monitoring wireless access points and broadband connectivity for IUCAA guest house.

In December 2006, a centrallized SAN (Storage Area Network) storage was commissioned to meet the ever growing data storage demands. The new consolidated SAN storage at IUCAA comprises of two EVA 4000 Storage arrays, two brocade fibre switches, two EVA 4000 SAN storage controllers, two EFS cluster gateways, one management console and one MSL 6000 LTO3 tape library system from Hewelett Packard. Presently the storge array has 56 * 500 GB (28 TB raw capacity) FATA disks. The entire SAN is managed by a management console software. HP Data Protector Software automates high performance backup and recovery from tape library. The EFS cluster gateways serve as a file servers for all the Unix clients of IUCAA.

High performance computing has become an indespensible and enabling technology for modern astronomy and astrophysics. In March 2007, HP C3000 blade based "Cetus" was added to the exisiting HPC. The new facility consists of 16 compute nodes and one head node of similar configuration. Each node has quad AMD Opteron (Rev F) 2218 Dual Core Processors @ 2.60 Ghz, 16 GB RAM , Infiniband interconnect for faster inter process communication, XC software and Pathscale compilers.

A computer laboratory with 20 PCs, and wireless connectivity to accommodate laptops, has been set up for use during workshops on image processing, data analysis and virtual observatory techniques, which are being organised at IUCAA with increasing frequency. The aim here is to introduce the university community to using the wealth of observational and archival data available at IUCAA and elsewhere in their projects.

The Computing facility continues to offer technical support to visitors, project students and associates of IUCAA.

(II) Library and Publications

In the period under review, the IUCAA library added 283 books and 402 bound volumes to its existing collection, thereby taking the total collection to 21376. 130 journals were subscribed by the library. 86 books were added to the collection of the Muktangan Science Exploratory library.

The monthly table of contents service initiated by the library in the year 2001 is presently catering to 24 university academics. The profile of each academic has been made available on the library homepage, from where the table of contents of the respective journals can be accessed by them. Requests for full text of articles received by email are then sent to the requestee. The library dispatched 175 full-text articles in the period under review. Apart from the above service, 192 full-text article requests were received through e-mail and post from 37 requestees.

The IUCAA library is an active member of the Forum for Resource Sharing in Astronomy (FORSA), which comprises ten 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.

Library and Information Services in Astronomy (LISA) conferences are a series of scientific meetings for librarians and scientists worldwide that aim to provide a platform to discuss the state of the art of information maintenance, retrieval, delivery, and preservation. LISA conferences cover diverse topics such as organization and management of books, journals, and specialized materials; electronic publishing, bibliographic and full text databases of astronomical literature and reports on collaborative projects.

Four FORSA members affiliated to IIA, Bangalore, IUCAA, Pune, NCRA, Pune and PRL, Ahmedabad received full support from the organizers to attend and present oral and poster presentations at the 5th Library and Information Services in Astronomy (LISA) conference, co-hosted by the John G. Wolbach Library & Information Resource Center at the Harvard-Smithsonian Center for Astrophysics and the Libraries of the Massachusetts Institute of Technology, Cambridge, MA, USA, June 18-21, 2006.

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

The requirements of IUCAA Girawali Observatory primarily dominated the activites of the instrumentation laboratory over the period reported here. As the observatory entered operational phase, it became critical to minimize down time from technical and logistic causes. As part of the action plan to achieve this, standby replacements for three of the critical instrument systems namely, EEV CCD data acquistion, motion controller and calibration unit controller were developed and tested in the laboratory. P. Chordia, H. K. Das, K. Chillal and V. Mestry are involved in this work. In order to ensure true redundancy, a regime for periodic swapping between operating and standby units have been put in place. Further, considering the fact that the EEV detector is already a few years old, an equivalent 2Kx2K CCD from E2V was procured. This detector has now been mounted inside a Dewar, tested with the standby data acquition system and calibrated. It is expected that at the end of 2007A observing cycle, this detector system can be commissioned at the observatory and made ready to be used with IFOSC.

During the science verification phase of the telescope (January to May 2006) a large amount of feedback about the Observatory Control System (OCS) was obtained. Further responses were received when the observatory started catering to the astronomy community. All this lead to an on-going process of debugging, improving, testing and release of versions of OCS, the work for which was largely handled by M. Shaikh (on contract) and M. P. Burse.

Work has also been progressing in the laboratory with the design and building of next generation instrument control system called the Common Controller Unit (CCU). Such periodic rebuilds are necessary not only to fight obsoloscence, but also to exploit new technologies which become available. The CCU system is built to current standards and keeping the future requirements of the observatory in mind. Once implemented, identical, configurable subsystems in the CCU will replace the different control units currently used for various instrument control requirements. From the maintenance point of view, it will be greatly beneficial to have only one type of card and code. The CCUs provide for feedback mechanisms to give the operator a good visibility of the status and modes of instruments. In addition to the hardware development (M. Srivastava, M. P. Burse, K. Chillal, V. Mestry), a considerable amount of software design and development have been undertaken, both for the embedded microcontrollers (A. Kumar, as part of his diploma project) as well as for the user interface (A. Kadam, M. Shaikh both on contract).

A USB data acquisition system which was initially developed on a Windows platform for testing CMOS Star-250 detectors for the Ultra-Violet Imaging Telescope (UVIT) on Astrosat, has now been ported to Linux based machines. The existing observatory control system (OCS) software package was rewritten to exploit the USB-based data acquisition system by M. Shaikh and M. P. Burse (with help from R. K. Singh). This eliminates the need to use PCI (5 volt) based hardware and proprietary device driver for it, which has become increasingly difficult to support on new computers and operating systems. With this change, the detector data acquisition system (hardware and software) is fully in-house developed and uses the standard and popular USB interface working with the built-in LInux device drivers. It is also better in terms of speed and flexibility. This new system has been deployed under test at the observatory. As the initial results have been very satisfactory, its operational release, is to be made soon, after some feedbacks and suggestions have been implemented.

The above USB based data acquisition system takes image data over a single fiber link and downloads it to a host computer. This system meets the present day requirements as the telescope can handle only one Cassegrain station (direct or side) at a time and at present only one instrument (with one Controller which can handle upto four simultaneous CCD readouts) is attached to a telescope port. A. Deep and M. P. Burse have been working on a new Data Acquisition Board which has been designed to meet the requirements of future generation instruments that might have more than four data outputs (eg. a mosaic of CCDs, multi band imager etc). It interfaces with five fiber links each of which may be connected to a Controller at the telescope end. Simultaneous data transfer through four fiber links would be possible with this board. It has 1GB flash memory on-board and image data through fiber links can be acquired either to the flash memory or to the USB port. A minimum data rate per fiber link of 1MBps would be sustainable for simultaneous data transfer through multiple fiber links and a maximum data rate per fiber link of at least 8MBps is sustainable for data transfer through single fiber. This board has a COM port also for command interface to controllers that do not take fiber input, like Common Control Unit. Design of this board is complete now and the PCB is being fabricated.

A. Kohok and H. K. Das have been working on designing and fabricating an automated arrangement for switching IFOSC between polarimetry and normal modes. The main difficulty of realizing this was due to the very limited amount of space available within the IFOSC framework. This mechanism is now ready and has undergone trials on the telescope after being mounted inside IFOSC. The final installation will be carried out during the next available service time on the telescope.

A group of three students from Sinhgad Engineering College, Pune have been working on making a single board computer with TCP/IP, serial and USB ports. Running the freely available Nut/OS operating system, this card can be configured using a web interface and can act as a bridge (Ethernet to Serial port). A USB to serial port bridge also has been added on this card which can be used to log information at the telscope end using standard PC USB interface. M. P. Burse, K. Chillal are the laboratory staff mainly invloved in the project.

(IV) IUCAA Girawali Observatory

The observatory was formally inaugurated and the telescope dedicated to the astronomy community by Prof. Yash Pal on May 13th, 2006. It was already reported last year that a core team at IUCAA had been conducting science verification programmes since January 2006. The science verification phase ended in May 2006 just before the arrival of the monsoon. Post-monsoon, in October 2006, IGO started operating for the benefit of the astronomy community.

Observational proposals are accepted and time allocation carried out in two cycles - from October to January and from February to May. During each cycle, 60 % of the nights are available through open competition for proposals generated by principal investigators from the Universities, IUCAA and other places. At present, the remaining 40% of the time is set aside for scheduled maintenance, Director's Discretionory Time, Targets of Oppurtunity, Training schools, Observatory projects etc. A time allocation committee (TAC) consisting of three external members (including the Chairperson) and two IUCAA members has been constituted for evaluating the proposals received under the 60% open category. All the proposals received are peer reviewed by at least two referees, whose comments are considered by the TAC while allocating time. Scheduling of observing nights for each proposal is carried out by the telescope committee as per the allocated time.

In the accompanying table, the "requested" column show the number of nights which were requested by investigators under the three categories. The "allotted" column contain the corresponding number of nights which were allotted after the peer review process. The numbers in the brackets in both columns show the number of proposals under each case. The last column indicates the approximate fraction of time which could be utilized out of the allotted time. About 33% of the total scheduled time was lost due to various factors like technical faults etc. Cycle 2007A is currently under way at the time of preparing this report.

During February 2007, an Indo-French workshop on optical astronomical observations was conducted at IUCAA. About fifteen (ten Indian and four French) participants were selected for the two week long programme from among applications received from graduate students as well as junior faculty with interest in observational astronomy. After a series of preparatory talks and sessions in the beginning, the programme moved on to hands-on training for carrying out astronomical observations, data analysis, report preparation and presentation. V. Mohan, IUCAA and M. Dennefeld (IAP, Paris) were the main coordinators of this programme.

	Cycle 2006B	Requested	Allotted	% used
	Universities	46(7)	22(7)	90
	IUCAA	46(10)	26(9)	41
	Others	83(13)	15(7)	60
	Total	175(30)	63(23)	67

The instrument control IT-hardware and network at the observatory underwent a substantial make over before the beginning of the 2006B cycle. Also pressed into action was a revamped observatory control system (OCS) after the experiences gained during the science verification phase. The data acquistion system for IFOSC as well as the OCS has since been upgraded to a more portable, robust and fast USB-based one recently. Details of this and other hardware development work related to the observatory have been presented in the section in this report which deals with the instrumentation laboratory.

An order was placed last year with Mssrs. Hind High Vacuum Company, Bangalore for setting up a mirror re-coating plant at the observatory. The fabrication of this plant was completed earlier this year and the factory acceptance tests were carried out successfully. At the time of writing this report, installation of the plant at the observatory has progressed to an advanced stage and is expected to be completed over the next couple of weeks. Once the on-site tests are completed leading to the commissioning of the plant, it is planned to re-aluminize the primary mirror at a suitable time slot available, avoiding the peak monsoon. R. Gupta, along with H. K. Das, A. Kohok and others led the effort for realizing the mirror coating plant.

(V) Virtual Observatory - India

Virtual Observatory-India - The Next Generation

A virtual observatory (VO) makes possible the storage of vast quantities of astronomical data, which can be retrieved over the internet and used by astronomers, wherever they may be located in the world. Virtual observatories have become indispensable tools in a situation where vast quantities of data at different wavelengths are produced every night by major observatories on the Earth and in space. Data obtained at different wavelengths requires quite different techniques or analysis and expertise which takes a long while to develop. However, the modern astronomer needs to take a multi wavelength approach to the study of astronomical objects, and it is necessary to have computational tools and resources for meeting this requirement.

A network of virtual observatories, each with large data mirrors in one domain on the other, and transparent and easy to use tools or analysis, will therefore prove to be a great boon to astronomers. With this in mind, virtual observatories have been set up in several countries over the last few years, and significant progress has been made in developing standards, data formats, query languages and software for analysis, visualization and mining.

The Virtual Observatory-India-The Next Generation (VOI-TNG) project is a collaboration between IUCAA and Persistent Systems Pvt. Ltd. (PSPL), which is a major software development company in Pune, with expertise in data mining and related areas. The project is funded by the Ministry of Communication and Information Technology (MCIT) and PSPL. The hardware platform for the project is located at IUCAA, while the software development is undertaken in close collaboration at PSPL and IUCAA. VOI-TNG has developed several tools, which have found wide acceptance in the international virtual observatory community, and have been used in making new and exciting scientific discoveries, including black holes in galaxies and rare kinds of stars.

The projects undertaken by VOI-TNG during the period of the report are as follows:

1. VOPlot family: The family of tools constitute a plotting and visualization package with two and three dimensional versions and a two dimension version which can be used with large datasets and many millions of objects. The two dimensional version, VOPlot, has been upgraded to have multiple windows with sophisticated interaction possible between them. It is possible to transfer selected points from one window to another, to have common selections across the windows, to overlay plots in different windows and so forth. With these improvements, VOPlot has become a powerful research tool.

2. VOMegaplot : VOMegaplot has now been made available in a client server version. In the past it was available only as a stand alone tool, so that the user needed to have the data and the tool available on the local machines, which imposed requirements on the hardware. In the client server version the software and the data can be located on remote machines so that the user can manage to do sophisticated work with modest hardware and reasonable bandwidth. While the tools are all now fully developed, it is necessary to integrate them with each other so that a seamless package becomes available. The design of such a generic tool is in progress and a first version should become available towards the end of 2007.

3. VOCat : A rudimentary version of this tool had been developed in early stages of the project but now a fully integrated tool for working on catalogue data has been released. This enables data selection from large catalogues, with the graphic user interface reconfiguring itself to accommodate this selection. It is possible to carry out visualization and statistical studies of the selected data using VO-I tools, as well as tools available through other Virtual Observatory projects. For example, it is possible to use the cone search tool and services like SIMBAD, NED and ALADIN through VOCat.

4. VOStat : This was first developed as a VO compatible tool for statistical analysis on large datasets, as a collaboration between groups in Caltech and Penn State University. In collaboration with these groups VO-I has developed the next generation VOStat with many statistical tests and a new graphical interface. VOStat has been integrated with other tools like VOPlot to increase its power. VOStat is presently available only as a web based version, but a stand alone tool is in development. VOStat uses the statistical package 'R'.

Databases

SDSS-DR5 : VO-I has acquired a copy of Data Release of the Sloan Digital Sky Survey. For the first time it was possible to ftp the dataset which has about 2.5 terabytes in size, using the high bandwidth internet connectivity which is now available at IUCAA. Transferring the data using the available resources was a difficult and prolonged undertaking and was made possible because of the support received from the SDSS group at John Hopkins University. It will now be possible to acquire new data releases in the same manner, so that the astronomers working in India have excellent access to the datasets.

(VI) IUCAA Radio-Physics Training and Educational Facility

During 2006-07, in accordance with plans, significant work was completed towards the final commissioning phase of the *'IUCAA Radio-Physics Training and Educational Facility'* . The main goal of this novel facility, which is targetted mainly towards the university students and teachers, is to provide hands-on training and education in radio astronomy instrumentation, techniques, and observational disciplines. The main components, which are being developed as part of the facility include a dedicated laboratory for conducting educational radio-physics experiments, and several outdoor radio telescopes and antennas for making hands-on, high-quality and accurate solar/planetary (in radio-continuum), galactic (21cm hydrogen line, pulsars, 6.6 GHz Methanol masers etc.) and extragalactic radio source observations. Some major achievments of the past year are briefly highlighted here:

1. Steps were taken for widening the scope of the activities envisaged for the facility through a tripartite collaboration involving IUCAA, NCRA/TIFR and Pune University's Dept. of Electronics Science.

2. At the end of Xth plan, almost all of the funds allocated for the project were spent in building up core infrastructure. This includes a 4-mt radio telescope for solar and galactic 21-cm hydrogen line observations, a 408 MHz pulsar receiver, 1420 MHz VLBI enabled receivers for interferometry, low frequency antennas for solar and Jupiter observations, low-noise amplifiers, feeds and many other subsystems. For the laboratory, a number of physics and radio-science experiments, test and calibration instruments, computers and other electronics hardware were procured.

3. Significant efforts were made by *J. Bagchi* along with collaborators B.C. Joshi (NCRA) and M.R. Sankararaman (PU Dept. of Electronics Science) to promote Radio Astronomy in schools and colleges by way of lectures and many creative hands-on type observational and instrumentational projects for univesity students. For example, we describe the "Faraday Rotation Effect" experiment and "Nonlinear Dynamics and Chaos in Electronics" experiments recently performed in the IUCAA laboratory by a group of M.Sc. students:

An optical Faraday Rotation Experiment

In 1845 Michael Faraday, while searching for signatures of unity of light waves with electric and magnetic forces, discovered that the plane of polarization of a beam of ligh, traversing an optical medium like glass, rotates in the presence of a powerful magnetic field aligned with the beam. In other words, a nonabsorbing or weakly absorbing medium in which a polarized beam of monochromatic light propagates, shows circular birefringence in the presence of magnetic field. The angle of rotation θ can be expressed as $\theta = VB_{\|}L = \pi \Delta n L/\lambda$, where $B_{\|}$ is the component of magnetic field along the propagation, L is path length, Δn is circular birefringence (difference of refractive index for right and left circularly polarized beams in the medium), and λ is wavelength. The material property inducing Faraday Rotation is denoted by V, known as the Verdet constant.

In the experimental setup shown in Figure 15, a highly polarized, monochromatic beam of light of a diode laser (650 nm) was passed through a 10-cm rod of high Verdet constant lead-Silicate glass (Schott glass no. SF-59), which was kept concentric with a solenoid containing 1400 turns of Cu wire. A DC current of 1 ampere through the solenoid resulted in a field strength of ∼100 Gauss at its center. The rotation of the plane of polarization of the light beam emerging from other end of glass was analyzed by means of a rotatable polaroid filter in a calibrated mount and a photodiode. A clear rotation of plane of polarization was noted in the presence of magnetic field, which increased in proportion to the magnetic field strength, in accord with the Faraday rotation effect. For achieving a higher sensitivity for detection of small rotation angles ($\sim 1-2$ minutes of arc), the solenoid was next driven by an alternating current of $\sim$ 200 Hz frequency. The output voltage of the photodector and the driving current waveforms were both displayed on an oscilloscope for various positions of polaroid filter (see Figure 15). The modulation of the polarization of light beam due to an alternating current in the solenoid demonstrates the Faraday rotation caused by an alternating magnetic field. Since this method is much more sensitive compared to the constant magnetic field effect, we could detect the Faraday rotation and estimate the Verdet constants of water, salt or sugar solution, alcohol, monochloro-benzene (CH_5Cl) and many other organic and inorganic liquids. An important radio astronomical application of the Faraday rotation effect, in which a linearly polarized radio wave traversing a magneto-ionic plasma medium undergoes a rotation of the polarization angle, is in the study of magnetic fields in galaxies, clusters of galaxies, radio jets and in the cosmic plasma. Such studies are feasible with radio telescopes such as Giant Meter Wave Radio Telescope (GMRT) in India and other large telescopes of the world.

Study of nonlinear dynamics and chaos through electronic circuits

The essential properties of a chaotic system were investigated by means of Chua's circuit, discovered by Leon O. Chua. It is a nonlinear simple electronic network, which exhibits a variety of bifurcation phenomenon and "attractors". The experimental circuit (shown in Figure 16) consists of two capacitor (C1, C2), an inductor (L), a variable linear resistor (R) and a nonlinear resistor. This nonlinear resistor is made up of two negative resistance op-amps (N_{R1}, N_{R2}). Here, we are using piecewise-linear characteristic of Chua's diode (nonlinear re-

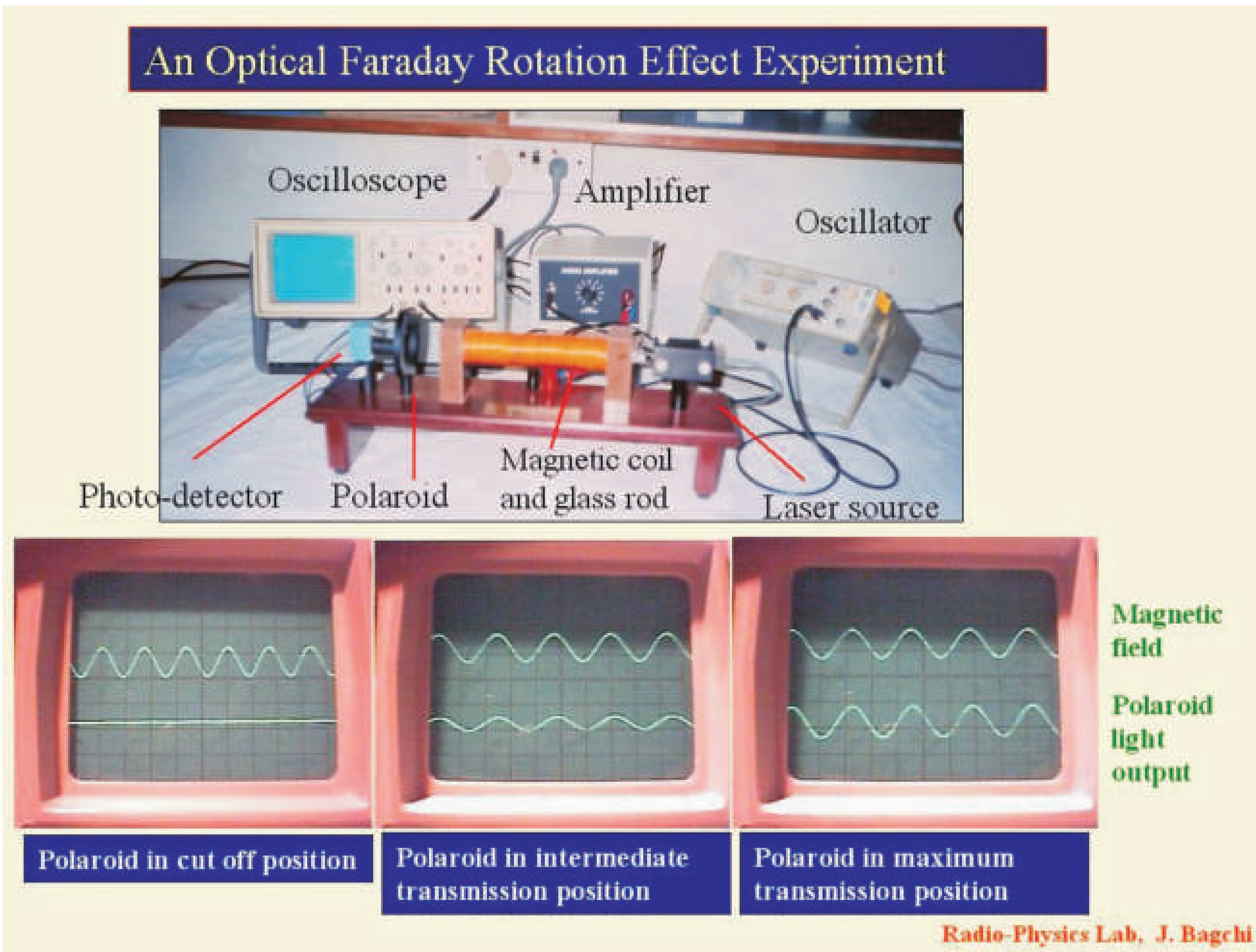

Figure 15: An optical Faraday Rotation experiment performed in the IUCAA radio-physics lab. The experimental setup is shown on top along with the waveforms of solenoid current (magnetic field) and the transmitted light from the polaroid filter used as an analyzer (bottom row). The optical medium kept within the magentic field is a rod of lead-silicate photonic glass SF-59 (Viral Parekh, Jaydeep Belapure, Mayuresh Kulkarni and J. Bagchi. See text for more details).

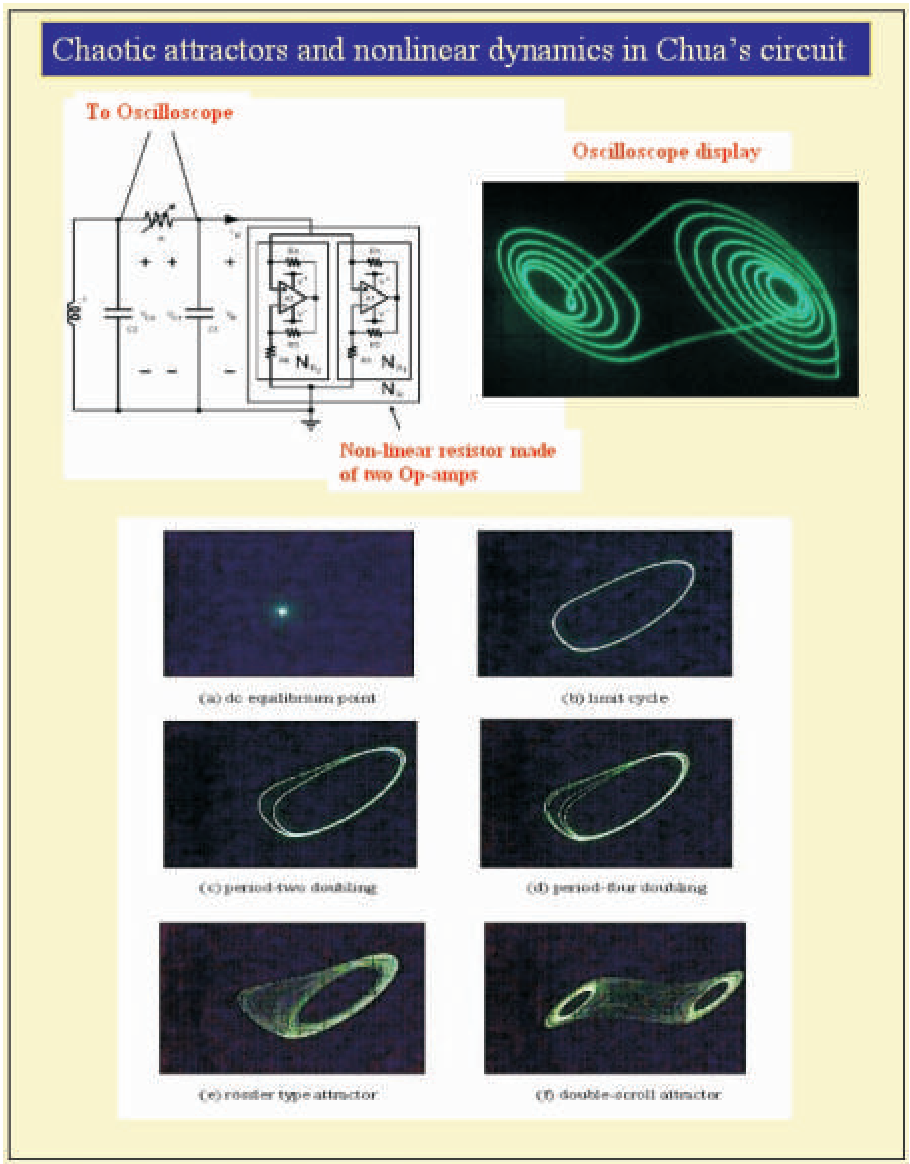

Figure 16: An experiment for study of nonlinear dynamics and chaos by means of an electronic circuit. We have used the Chua's circuit designed by Leon O. Chua. It is a nonlinear simple electronic network, which exhibits a variety of bifurcation phenomenon and "attractors". The phase-space evolution of the system; starting from stable equilibrium, through period doubling and bifurcation, and finally leading to spectacular chaotic attractors, is shown in a sequence of waveforms captured from the oscilloscope screen (Viral Parekh and J. Bagchi)

sistor). It is an autonomous circuit, means it does not require any external input signal except only power supply to two op-amps. An oscilloscope in X-Y mode of operation was connected across the variable resistor, thus monitoring the phase-space (state-space) behavior of the system.

In Figure 16 we show the oscilloscope displays showing the phase-space trajectory of; (a) an equilibrium point (b) a limit cycle, forming a closed loop in phase space (in the area of dynamical systems a limit cycle describes stable oscillations, such as the motion of a pendulum clock or the beating of a heart. A limit-cycle on a plane or a two-dimensional manifold is a closed trajectory in phase space having the property that at least one other trajectory spirals into it either as time approaches infinity or as time approaches minus-infinity); (c,d) the system at the onset of chaos, visible in its period doubling by factors 2 and 4, and finally, (e) a chaotic Rossler type attractor and, (f) a chaotic double-scroll attractor. In a non-linear system such as the one we studied and other dynamical systems, an attractor is a set to which the system evolves after a long enough time. For the set to be an attractor, trajectories that get close enough to the attractor must remain close even if slightly disturbed. Geometrically, an attractor can be a point, a curve, a manifold, or even a complicated set with fractal structures known as a "strange attractor". Chaos theory and chaotic systems have wide ranging potential applications in random number generation for cryptography, computer simulations, stability analysis of solar system (can planets ever collide ?), accretion flows on black holes and in x-ray binaries, weather prediction, study of human heart and numerous other extremely interesting areas full of surprises.

IUCAA REFERENCE CENTRES (IRCs)

[1] Delhi University
(Coordinator: T. R. Seshadri)

The IRC, Delhi University has organized two workshops, where a number of people from within Delhi and from outside participated. In addition to the speakers and visitors who came for the workshop, talks were given by several other visitors.

Talks

M. Varadharajan: *Quantum Gravity and Hawking Radiation*, April.
B.C. Paul: *Chaotic Inflationary Universe on Brane*, June.
Subir K. Das: *Critical Dynamics in fluid*, August.
K. Avinash: *Liquid Vapou Phase Transition in Complex Plasmas*, November.
Samir Mathur: *Fractional Brane State in the Early Universe*, December.
M. Varadharajan: *Quantum Fields at Any Time*, December
Smita Mathur: *The Missing Baryons Problem*, January.

Visitors

Sanjay K. Pandey (L.B.S. College, Gonda, UP), B. C. Paul (North Bengal University, Siliguri), K. Subramanian (IUCAA), Ranjan Gupta (IUCAA), Madhavan Vardharajan (Raman Research Institute, Bangalore), Samir Mathur (Ohio State University, USA), Smita Mathur (Ohio State University, USA).

Lecture Series:

Cosmology with the CMB Anisotropies: This was a series of lectures delivered by K. Subramanian (IUCAA) in July 2006. This was at a pedagogical level.

[2] Pt. Ravishankar Shukla University, Raipur
(Coordinator: S. K. Pandey)

The faculty members, research scholars and students in the department as well as visitors have made use of the facilities available at the centre in strengthening their teaching/research activities in the field of A & A.

Teaching

Final year students of the department, who offer A & A as the specialization for their M.Sc. course used IRC facilities (INTERNET and library) in carrying out their project work. The number of students who opt for Astronomy and Astrophysics as their specialization is almost 50% of the student strength in M.Sc. final year. New telescope CGE800 was used by M.Sc. students to carry their observational projects in Astronomy.

Research : The research activity of the faculty members and the research students is mainly focused in following areas:

(i) Dynamical modeling of elliptical galaxies carried out by D. K.Chakraborty and his research students. Chakraborty along with his research students, namely, Arun Kumar Singh, Firdaus and Arun Diwakar has been engaged in finding out variation in intrinsic shapes of individual elliptical galaxies using their photometric data. It is expected to provide additional results as compared to previous works in determining an overall shape. The work is in progress and will be communicated shortly for publications. Part of this work was presented in the meetings of ASI and YAM during the period 2006-7.

(ii) Multi-wavelength surface photometry of early-type galaxies carried out by S.K. Pandey and his research students as a part of collaboration with A.K. Kembhavi and people from other institutes/observatories. The main objective of the research programme is to study properties of dust in extragalactic environment, and also to examine relationship of dust with other forms of ISM in these galaxies. A few nearby dusty early-type galaxies were imaged in BVRI bands using the 2m Telescope of IUCAA at IGO during 2006-07. Laxmikant Chaware, S. Kulkarni have been involved in this project. Significant progress was made in further investigation of galaxies from LFC survey fields. One of the LFC fields, SDSS1208 was observed for one hour in service mode, on June 22, 2006 using AAT. Compactness of the field and constraints of fiber allocation limited the target allocation to 135 galaxies. Reliable redshifts were obtained for 55/135 (40%) of the galaxies targeted to get the low resolution spectra in wavelength range 370 nm to 880 nm. The same field was again observed on March 27, 2007 in service mode for 1.5 hours. The spare fibers, after allocation of target from the field were used to allocate the galaxies selected from the SDSS survey. This observation yielded spectra of 235 galaxies, for which data analysis is in progress. This is collaborative research programme with A.K. Kembhavi, Russell D. Cannon, Ashish Mahabal and a research student, Laxmikant Chaware working at Raipur.

Talks

M.Sc. students of the department made use of IRC facilities for the preparation/presentation of weekly

seminars organized in the department. Following lecture was organized:
Ajit Kembhavi: *Pluto: is it not a planet?* September 22.

Lectures given by S. K. Pandey

Multiband photomteric studies on dusty early-type galaxies, IUCAA 2m Telescope Dedication Symposium, IUCAA, Pune, May 14.

Lectures on (i) *Studying variable stars using small telescopes*, and (ii) *Galaxies* at the workshop on Physics from Atom to Galaxy : Theoretical and Technical status, Physics Department H. N. Bahuguna Garhwal University, Srinagar-Garhwal, October 10 and 11.

Surface photometry of galaxies, Indo-French Training School in Optical Astronomy, IUCAA, February 14.

Popular Lectures delivered by the Coordinator, IRC in and around Raipur city.

Universe as the biggest physics laboratory, Teacher's Training Programme, Raipur, May 20.

Stars: their structure and evolution, Bhilai Mahila Mahavidyalaya, Bhilainagar, February 25.

Radio talk/interview

Radio talk in Hindi on " Prithvi aur Dhoomketu me Takkar; Vinash bhi hai aur Jeevan ki utapti bhi"(National broadcast,Vigyan Bharati) April 19.

Visitors

H. P. Singh (University of Delhi), Ranjan Gupta (IUCAA), S Barway (IUCAA), Ajit Kembhavi (IUCAA).

Other activities

The important activity of the centre has been to encourage M.Sc. and research students of the department to participate in summer schools/workshop, etc., conducted at IUCAA/ARIES, etc. During the year some of the research scholars participated in YAM-2006 held at IIA, ASTROSAT workshop. It is indeed a matter of pride that Laxmikant Chaware was selected for participation in International School of Young Astronomers (ISYA), Malaysia, March 4-24, 2007.

[3] North Bengal University, Siliguri (Coordinator: S. Mukherjee)

Since its inception, the IRC at North Bengal University has provided facilities for research work in cosmology and theoretical astrophysics. During this year, the centre has introduced some additional facilities for astronomical data analysis. Books, computers and some relevant softwares are now available in the IRC. Two workshops, organized jointly by IUCAA and IRC, have helped in popularizing this field of research among the faculty and students of the colleges and universities of the region. A number of research papers have been published using the IRC facilities.

Visitors

S. N. Tandon (IUCAA), A. K. Kembhavi (IUCAA), A. Bandyopadhaya, (Positional Astro. Centre, Kolkata), V. Mohan (IUCAA), R. Srianand (IUCAA), S. Chakraborty (Visva Bharati, Santiniketan), A. Sen (Assam University, Silchar), S. Barway (IUCAA), A. Rawat (IUCAA), P. S. Joarder (Bose Institute), Rabin Chhetri (Sikkim Govt. College), Mehdi Kalam (Netaji Nagar College for Women, Howrah), Farook Ahmed (Jadavpur University), Chandana Acharyya (A. College, Jalpaiguri), Pradip Chakraborty (Alipurduar College), Ivan Dorjee Lepcha (P.N.G. School, Gangtok), Praveen Puri (Centre for Computers and Communication Technology, Sikkim), Shibshankar Karmakar (Parokata Jr. High School, Alipurduar), Mustafizur Rahaman (Kalpani Rajmohan High School, Kalpani, Coochbehar), Supriyo Dey Sarkar (Islampur High School), Sandip Swarnaker (St. Mary's Higher Secondary School), Madhuja Ghosh (Stepping Stone Model school), Sanghamitra Sen Gupta (Suniti Bala Sadar Girls' High School), Shayeri Moitra (Suniti Bala Sadar Girls' High School), Achal Lama (Stepping Stone Model School), Dipanjan Hore (M.T.B. High School), Surajit Pathak (St. Mary's H.S. School), Partha Sarathi Debnath, Dilip Paul, Prasenjit Thakur.

Other activities

Seminar /Workshop Organized :

Workshop on Stars and Galaxies: Observational Techniques and Data Analysis, September 12-15.

Workshop on Astronomy for Engineers, Siliguri Institute of Technology, September 10-12.

Public outreach programme : A special public lecture by A. Bandyopadhyay, Positional Astronomy Centre, Kolkata was organized on September 12, 2006 in the physics department of the North Bengal University. Bandyopadhyay explained why Pluto is no longer recognized as a planet. The winners of the essay competition conducted by the IRC in the year of Physics, 2005, were among the invitees. Prizes and certificates were awarded to them in the meeting.

[4] Cochin University of Science and Technology, Kochi (Coordinator: V. C. Kuriakose)

The facilities available at IRC have been regularly used by both M.Sc. students for their project work and Ph.D. students and the faculty members. Talks, seminars and colloquia were conducted under the joint auspices of IRC and the department. The IRC library contains 56 books. Internet connectivity is also provided in the IRC room. A number of research papers have been published using the IRC facilities.

Talks/Colloquia

Watson P. Varikkat *: Modern astronomical telescopes*, April 7.
C.S. Unnikrishnan: *Is the special theory of relativity for ever* ?, May 26.
P.P. Divakaran: *What we can learn from Yuktibasha*, July 17.
K.P. Moosad: *Under water transducers*, August 25.
M.K. Radhakrishna: *Physics of nano devices: Technology limitations and research challenges*, September 28.
M.A. Ittyachan: *Search for extraterrestrial intelligence*, November 2.
K. Manzoor: *Nanotechnologies for cancer detection and therapeutics*, January 31.
V.C. Kuriakose: *On no-hair theorem*, November 25.
K. Babu Joseph: *Entropy in lattices*, November 25.
P.I. Kuriakose: *Violation of generalized second law of thermodynamics*, November 25.
K. Ambika: *Synchronisation in GM map*, November 25.
Kamala Menon: *Lattice stochastic resonance*, November 25.

Visitors

C.S. Unnikrishnan (TIFR, Mumbai), P.P. Divakaran (IMSc., Chennai), Moncy V. John (St. Thomas College, Kozhencherry), T.R. Govindarajan (IMSc., Chennai), E. Krishnakumar (TIFR, Mumbai), R. Vijaya (IIT, Bombay).

Other activities

National Seminar on "Gravity and Light" was organized in collaboration with the Department of Physics during February 23-24, 2007 which was mainly intended for post graduate students, and a large number of students from neighbouring colleges participated in the programme. Post graduate students also participated in the IRC colloquia. Series of lectures on Quantum Field Theory in Curved Spacetime and Nonlinear Dynamics have been arranged for the benefit of research scholars and post graduate students.

IRC in collaboration with the Department of Physics, CUSAT and SPIE CUSAT student chapter, organized a ten day Workshop for School students in an around Kochi city, who have completed class X, during June 5-16, 2006. Sixteen students from different schools attended the workshop. The purpose of the workshop was to make aware of the importance of learning basic sciences and the role of basic sciences in technology. In this workshop students were introduced to the fundamental concepts in physics, they got opportunities to do some fascinating experiments in physics and to visit different laboratories in the Physics Department to see the research work being going on. Experts from IUCAA gave them training in making small telescopes.

[5] Jadavpur University, Kolkata (Coordinator: Narayan Banerjee)

The IRC has organized regular weekly seminars, attended by faculty members, research students and colleagues from neighbouring universities and colleges. There were around 30 seminars conducted during this period. In addition to the lectures by regular members, three talks were delivered by visitors. The centre also provides a scope for college teachers to get involved in part-time Ph.D. studies. At least two teachers are now utilizing the facilities of the centre for this purpose.

Visitors

Supratik Pal (IIT, Kharagpur), Ajit Kembhavi (IUCAA), Sunil Maharaj (University of Kwa-Zulu Natal, South Africa), Anian Ananda Sen (Jamia Milia Islamia, New Delhi)

Talks

Supratik Pal: *On brane-world cosmology*, July.
Sunil Maharaj: *Simple relativistic Solutions in astrophysics*, January 2.
Anjan Ananda Sen: *Reconstructing k-essence models*, March 20.

Other Activities

Narayan Banerjee delivered a semi-popular talk on Cosmology at the Department of Mathematics, Jadavpur University for M.Sc. students.

[6] D.D.U. Gorakhpur University (Coordinator: D. C. Srivastava)

Seminars by visitors, faculty members and research scholars were organized at the IRC. These provide an opportunity for interaction and exchange of ideas. At present dial up internet facility is available. IRAF; an image analysis software and AIPS for analysis of radio data are being used at the centre. Film shows were organized for the benefit of school students.

Talks:

A.N. Singh: *Role of Nitrogen in life and death*, April 4.
M. K. Harbola: *Density functional theory of ground and excited states*, October 28.
R. Sagar: *Research activities at ARIES*, December 6.
A.N. Singh: *Pain and common pain killer bridubrofen: Effect of environment on electronic structure and properties*, December 23.
A. K. Kembhavi: *Planets: Near and far- The story of Pluto*, February 23.
A. K. Kembhavi: *Gravitation: Illusion and reality*, February 23.

Visitors:

A.N. Singh (B.H.U., Varanasi), M. K. Harbola (I. I. T. Kanpur), Ram Sagar (ARIES, Nainital), A. K. Kembhavi (IUCAA).

Other activities :

Public Outreach programme (Film Show)

On lives of P. C. Vaidya and A. K. Raychaudhuri (Vigyan Prasar Bharti and IUCAA) February 21.

Eighteenth IUCAA Foundation Day Lecture

Many Indias : Search for a Centre*

U. R. Ananthamurthy

I feel deeply touched by the introduction. Because he put me in a community and I have begun to believe, particularly in literature, we look like distinct, different, people; but everyone is doing what someone else had not done, so we complement one another. Not only the present day writer, but in some way you complement your ancestors also. So it goes on in every Bhasha. I am particularly happy to be here because I have been an admirer of Narlikar. I have read many of the articles that he writes in newspapers. I feel proud that he writes in Marathi too. Then when I met Professor Dadhich, I found that he is a poet in Hindi. You know the kind of courtesy I received, Tarun brought me from the airport and I talked to him about the creation of knowledge in our languages, not merely transferring knowledge from another language to our language, but *creation*. He told me of a recent Bengali book which it is not merely a translation but somebody does original thinking. Today what I want to speak about is in somewhere in that sphere: whether we can be not merely a vehicle of adult literacy, but can these languages also produce knowledge?

I will tell you a few stories. When I was very young, I was in a village surrounded by a forest and the school was not nearby and it was my mother who made me write on sand and I began learning letters on sand. My father used to be a village accountant. The first poem that I heard from him was a very moving one called, *Govinahadu* in Kannada - that is, the song of a cow. It appears that there is a Sanskrit version of it and also a Kannada version, which most children read. It is the story of a cow which moves into the territory of a tiger. The tiger sees the rich prey and is hungry and wants to eat the cow. But the cow tells the tiger: "I have not yet fed my calf, I will go home, feed my calf and I will become food for you". The cow comes to its shed and talks to the little calf – very moving words when the cow talks to the little calf - and goes back to the tiger and the tiger is so moved by the honesty of this cow. In the Kannada poem the tiger jumps from a precipice and kills itself. In the Sanskrit poem it appears the tiger has a change of heart and begins to do *tapas*. I think Kannada version is better because the tiger cannot really change its nature. It can only kill itself. The bhasha people have been more realistic than the Sanskrit people

The whole poem begins with a verse. I will tell you how it begins. It is almost like a camera looking at the whole globe from high above and then the camera begins to focus on one cow herd in one village and it begins like this *Dharani mandala madhyadarage* - Dharani is the whole globe; Madhya is the centre of it. This poem puts Karnataka in the centre of the globe. The world is a globe. Any one of us can be a centre. Maharashtra can be a centre and not only in Karnataka but even a little village.

I will tell you the story and I believed that Karnataka was the centre of the world. But I was not at fault. Because 1000 years ago our first book in Kannada language was by a poet called Shri Vijaya and he called it Kavirajmarga. My friend Subbanna, who Professor Dadhich talked about, has written an excellent book on this first book, which was written a thousand years ago, and he uses *Dandi* - a Sanskrit theoretician. But he just does not use Dandi but begins to create his own poetics, which is appropriate to the Kannada language but has *Dandi* as an inspirer. I want you to note it because, when I say there are many Indias, think what kind of connection makes it possible for us to be ourselves and also to relate to others. So what he does is that he says there is a *bhargava marga* , which is the high path and there is a *deshi*. He defines the Kannada language not as devbhasha or the language of Gods, but a Bhasha spoken in a particular geographical area.

So this is a language which does not travel. English travels now. Sanskrit used to travel in the sense that you would find a Sanskrit scholar anywhere in India and they could talk to each other. But Kannada was defined in the first book as a language which does not travel but there is no inferiority complex arising from that. He says it does not travel but there is a great verse there. He says that it can mirror the whole world and that a language which does not travel but is a mirror of the whole world.

The first poet was Pampa, who wrote Mahabharata and again trying to relate himself to the great India he makes many changes in the Mahabharata. He cannot make Krishna the hero, because Pampa was a Jain and being a Jain he could not extol the virtues of Krishna. But he makes Arjuna the hero. And because he was a court poet he could also extol his King, who was a Hindu. So here is a Jain writing about a Hindu King, making use of Mahabharata and he takes excellent passages from Mahabharata. He does not translate it but appropriates it to the language. And this is something very interesting. Now we know that the great rivers which flow into Mahabharata for years - some of the pure Karnataka

**This is transcribed from the audio recording of the lecture with minimal editing in order to retain the original informal flavour of the lecture - Ed.*

rivers also flow into Mahabharata. So it is our Mahabharata. He makes it our own.

Who are his ideals? In Karanataka a thousand years ago, here is a poet for whom the ideal was Kalidasa. He thinks that he can do better than Kalidas. In some places he can excel. How can he excel? By combining the qualities of Sanskrit with the qualities which are indigenous to the Kannada language. Marga and Deshi. And one more thing that is very interesting. Tamil is older than Kannada by a few 500 years or so; I don't know, scholars have different opinions. But Tamil has its own poetics, its own writing form. From the Brahmi, it takes only those alphabets which are necessary to speak Tamil sound. Whereas Kannada accepts all the 52 alphabets although they are not necessarily required to write Kannada. What are the advantages? Kannada began to receive words from other languages more easily because they could be written in Kannada. I don't think I can write Clinton in Tamil: it is Glinton, you have to know that it is Clinton. I don't think they can write Gandhi, they write Kanti, and you have to know that it is Gandhi. Whereas in Kannada I can write anything. So the ***sweekar*** became the hallmark of the Kannada language. It can take anything from anywhere. Thousand years ago somebody decides this! Tamil has its own strength because it is strictly Tamil but Kannada has a different kind of strength because it has taken a lot from Prakrit, Sanskrit, and now English, and European languages. It is open.

I said I will tell you a few stories. Just before I came here, a week before, a young writer who writes in Maithili came to see me. He said Vidyapati, who wrote in Sanskrit, and then began to write in Maithili. Maithili again is a language like Kannada which does not travel. It is aligned only in its own place. There have been very great writers in our own times like Nagarjuna, who wrote in Sanskrit, Hindi, and also in Maithili. I asked this young man: "What is the state of Maithili now? Is it used in any school?" No. Because it is Hindi, which travels much wider than Maithili does. Then I asked him what guaranty is there that Maithili will survive as a language , because it has a rich history of its own, rich literature of its own.

This is what worries me. All languages in India will survive, one feels, if there are people who speak only that language. I once met Nemade, a Marathi writer. He told me that some people from Bihar came to Bombay to sell vegetables. They speak only their language, they refuse to learn any other language. So all our women who go to buy vegetables, because they want to buy fresh good vegetables, have learnt to speak their language. And who are these people who know only that language and no other language? They are not literate, they are backward, they are untouchables and also people who have not come up, in the modern sense, anywhere. I sometimes think that our languages have survived because of such people who knew only that language. They did not think that ruler's language is our language. People who have done well in life think that the ruler's language is their language.

Today if I am a Kannada writer, it is because they have preserved that language. It is very alive not only in written form but in oral form. There are oral epics in this language. There are women who can recite a thousand page oral epic even today. These oral epics are also different from the upper caste epics. They are different versions. They are very imaginative; they are very creative. And it is another world altogether.

You know Ramanujan, once came to Karnataka and did some research on the Ramayana in Kannada. Not the written Ramayana but the oral Ramayana. He found nearly a thousand oral versions. In one version, Sita is not literate and is a village girl and Rama is also not a literate. They argue and the question is whether she should go to the forest with Rama. Rama argues that you are a princess, your feet are very tender, you should not be going to the forest with me and there are wild animals, etc. etc. and Sita also argues that I am your ***Dharmapatni*** and you can't leave me. But Rama is cleverer and he puts another argument. You know in oral epics you can make your own argument, they don't recite what is given to them. Then Sita says: "In every Ramayana, Sita goes to the forest, so how can you deny it to me?"

This is what I call inter-textuality. There are many Indias but there is still one India because there is an inter-textuality. Every work in India - even the folklore - has some insight into another text. Subanna, again in one of his books, says that we have many languages but we also have two other languages common to the whole country, which makes many Indias into one India. And they are Ramayana and Mahabharata. They are really like two languages. A lot of meaning is conveyed by referring to it. As you are aware most of us know our Ramayana and Mahabharata not for the first time by reading them; we just know them before we have read these two epics. We just know them through ***nataks***, performances, village performances, ***hari-kathas***. If you have come from a village world you would have heard these two epics and then you will read them later on. So, that was a device by which we are connected with each other.

I will say something about myself now. I became a Professor of English. I did my English from my high school days but I grew up in Kannada and my medium of instruction was Kannada and later on I had to switch over to English. I still remember the trauma when I had to learn my Physics, Chemistry in English and for a long time I could not understand what was happening but then I taught myself how to do that. I was highly motivated because I came from a poor family but a Brahmin family. It is said that the Brahmins are like cats;

even if they are poor, throw them anyway they will land on their feet! So I was highly motivated. I struggled hard, learnt English, but I could always go back to Kannada. Why? Because as I said I come from a Brahmin family and if you are a Brahmin you think that you are apart from others - particularly if you are orthodox you don’t even touch the people when you are washed. How did I become a writer? I went to a common school where other children also came. It was a Kannada medium common school. How I have become a writer; I say it through a metaphor: I had to wear a little piece of cloth on myself and when I came back home from school my grandfather wanted me to wash and wear it. But there was a shirt and I always put the shirt on a nail. I wore the shirt to school. So I always say that I became a writer because of that shirt. Otherwise my world would not have really expanded.

What is happening now? In our desire to have a strong India, one India where everyone can speak one language that is English, we are so nervous that our children will not learn their English, will be backward; so even a Government peon, who is in a Government service would like to send his child to an English medium school. And they don’t go to common schools. These schools are very expensive that it is only for those who can afford that kind of expense; they are not going to grow up like I have done, mixing with the rest of India.

So in a caste-ridden society, (I am speaking of days before India became independent and the caste system in villages was still strong) the common school took me across into a bigger world. I became a writer because I went to a common school and I wore that shirt into that school. Many of us who have done creative work in many of the fields have gone to common schools. And now in India the common school is almost dying out. In Kerala, Mr. Antony wanted me to write a report on status of Education. He thought that the government schools were empty because the population had gone down but I found that it was not just that reason. Many parents don’t send their children to Government schools. They send them to special schools and they are very expensive. Hence, we are having children who belong to Bharat who go to Government schools; those who belong to India, go to very expensive schools.

The many Indias and one India was possible because of many of us who could genuinely become bilingual, without losing our own language. But I think the middle classes will slowly lose their languages; they may not completely lose it. I have a different way of understanding the language, which made this many Indias and one India knit together. I would not use the word mother-tongue. I think it is a dangerous word which creates all kinds of problems. I use three words in my language. I will tell you what the words are. One word is *Manyamathu* - House tongue. The other word I use is *Bidimathu* - Street tongue. And the Third is *Attarmathu* - Upstairs tongue.

We have always used these three tongues. There is a poem by Ramanujam. He says: I was mischievous and played pranks I used Kannada; when I was hungry I spoke Tamil (because his mother was a Tamil Brahmin woman in the kitchen); and when I went upstairs to my father who was a mathematician - I talked in English. So he grew up in three languages. Manemathu is very important for most of us, because if you are a Muslim in Karnataka you speak Urdu. If you are an Iyer Brahmin, you speak Tamil. The girl may be married to somebody, somewhere else and so Manyamathu is always kept for cultural purposes. But a large number of writers in my language are not people who spoke Kannada Manyamadhu. It was only Bidimathu for them, the languge of the street.

Take for instance, the very great poet in my language - Bendre. Bendre spoke Marathi at home. He was a Maharashtrian Brahmin. But he was a great poet. Bendre has a kind of dhwani something like Blake had, very very subtle. He is one of the great poets of the world in that kind of subtlety. I asked him once, "When did you start learning Kannada? " He told me: "Until I was thirteen or fourteen I did not even know that I was speaking two languages". See, he did not even know! It was just bhashas. When he was telling me that, his daughter-in-law came and whispered something in his ear and he talked back to her in Marathi not knowing that he was doing the same thing then when he was talking to me!

So they dealt with two languages. In Karnataka, you can speak Tulu and Kannada, Tamil and Kannada, Kodawa and Kannada. Our great short story writer Masti Venkatesh Iyengar was a Tamil. Puth Narasimharcher, a great poet, was again a Tamil. Many of our writers are either Tamil-speaking at home or Marathi speaking at home or Konkani speaking at home. Many of our very fine writers, young writers, are Konkani. Karanth wrote a great novel *Chomana dudi* (Choma the untouchable). Choma is hungry for land and does not get land; it is a tragic story but the first of its kind in Kannada making us feel that an untouchable has a great hunger in his heart for equality. The whole novel actually takes place in Tulu - because when Choma is talking to his daughter, he must be talking to her in Tulu - but it is written in Kannada. So Kannada is a language through the Tulu experiences in it.

Now many Indian writers in English - although they are good writers, like Roy, who wrote an excellent novel - are translating something that is taking place in an Indian language into English. Otherwise who can ever write a creative work in English - in the BBC English or CNN English. No. Because English resides somewhere in India. English is a very hospitable language and can take the experience of our languages and change the medium in a very subtle manner. That is why either Salman Rushdie or anyone like him writes, their English has a special quality; that special quality comes from the ambience of an Indian language, because it resides in the ambience of an Indian language.

But I think we are slowly losing this - which means that we may have international writers or writers who write for export. Now we have more and more writers who have begun to write for export. We have lost the confidence of Shrivijaya who thought that the language does not travel but it can mirror the whole world. Rightly so because when Shakespeare was writing in English, it was not a language which traveled but Shakespeare came.

I have a feeling that what is happening in India is something that is happening all over the world also. A thousand years ago, when Latin dominated Europe, even Newton wrote in Latin because that was the language through which they could talk to one another. Later on, the great book on evolution came in English language and it created a big stir in Britain. Darwin wrote in English and Newton wrote in Latin. But English was not a language which traveled but it produced great writers. Why? because when Latin, the language of Cosmopolis, made way for the languages of Europe - the ordinary languages, the Bhashas of Europe which were always there.Then we have a Dante, Shakespaere, Tolstoy and a number of great creative writers. Again when Sanskrit, which was the language of Cosmopolis, made way for the Indian languages, we had a Tulsidas, we had a Kabir and a number of great Marathi writers like Gyandeo and many others. Sanskrit, thus, made way for them. It was a great period of decentralization of our kind of knowledge - the literary, the poetics, and similar kind of knowledge. But now it looks as if the whole world is centralizing now. I met a great Physicist in Germany. He said that he no longer publishes anything in German now, but in English. It is not because you can express it better in English but because it is commercially a more successful language. It is not because the British speak English but it is because Bush speaks English. So there too it is a game of power. But I heard another woman who was talking about this, one Dr. Radha. She said that when she went to Sweden she found that Europe is also taking to one language. The Swedish people, it appears, don't mix the two languages but most of them know English and they can happily use English and also Swedish and create knowledge in Swedish. Not in English but in Swedish.
Create knowledge - that is more important for me. Many of us have not troubled ourselves to learn Hindi in the South. If Hindi had created knowledge in Hindi, we will have related to Hindi. But Hindi only translates it from English so why not I also translate it from English. So all of us have been translating from Europe. We don't feel that there is another language which has a great knowledge in that language. So something else is happening in the world now. I will come to this question again. I am talking in a confused manner. I am not confused but I want to talk from experiences and not make any statement rigidly.

Take this whole question of unity and diversity. You know, that is what we use - India is one but also diverse. Even Tagore talked about it. For Tagore, the diversity was as important as unity; for Gandhi again the diversity was as important as unity. That is why both of them rejected the idea of a nation. They thought of India as a civilization because they had known that in Europe nationalism had led to two bloody wars, First World War and Second World War, meaningless wars. I feel very troubled when the great man who created such a wealth in Infosys said that we should have only English. I think it is wrong. You know what has happened with only English. I was sharing it with Professor Dadhich. As a teacher, this is a problem for me. Now in Bangalore, if there is a middle class young man or a woman and you learn your English well enough - with that American accent better enough - you just change your name into shorter name which can easily be pronounced by others, you get a job in the call centre and make Rs. 20,000. But if you do a B.A. and become a teacher or if you do an M.Sc. and become even a scholar in an institution like this you will not make more than 10000 rupees. English at one time was a gateway to knowledge but today it is so commercialized that English has become a curse. If you know it well enough you have to come from a different kind of a family system altogether. You know very bright people can be lost because no other knowledge is necessary as much as spoken English.

So we have gone into a kind of an illusionary world. If you know English you are intelligent; you need not know anything else. Slowly, that is the way young people are growing up; certainly in Bangalore and it is happening in smaller towns also because of ***no common schools*** but special schools. This should worry us; especially all of us who want to create intelligence and knowledge in this country.

Hence, I proposed in Kerala a ***upayam*** – a way out . I told them that if for the sake of English they all go to private special schools, then why don't you start teaching them some English from the first standard. But the medium of instruction should be their language. Medium should be Malayalam, medium should be Kannada, medium should be Marathi, but empower them with some English, because that is what creating this kind of an ***angst*** in people. So give them some English. Like the Swedish, we are comfortable in two languages if it is necessary. There was a time when Pampa wrote in my language, and he knew his Sanskrit. Those who created knowledge in Kannada, knew their Sanskrit. And our great 12th century poet knew Sanskrit. For instance Basava - Bhartava was a great ***veershaiva*** poet; I think one of the greatest poets of the world. There are some good translations from Ramanajan and they are just extraordinary poems. The strange thing is an Englishman cannot read Chaucer any longer. Chaucer has to be translated. He was 15th century or so. But I can read a 12th century *Vachana* poet today, without any problem. So a thousand years are still alive and speak in our languages. And much of that is kept intact by people who are not educated in our sense. The whole idea of development and so on is making a kind of one India, a strong national India. Every capital will look like a five star hotel and you do not even know where you are. We will jump from one hotel to another and we lose our identities.

What is the way out? If I reject nationalism and if our languages develop their own nationalism, it can be as bad as the other nationalism. That is why you know the linguistic chauvinism can be as dangerous. But sometimes to fight this kind of obliterating of these languages, wiping of these languages, may produce movements of that kind. Now people like me, find it very difficult to mediate this. For instance the Belgaum Mayor decided that Belgaum should go to Maharashtra and then passed a resolution. He came to Bangalore, people went and put black ink on his face. I said later that this was wrong, you should not have done that. For a few days, my wife was afraid that I may be attacked by people who were very angry. And that can happen to a Marathi writer also, if he speaks against that kind of activism here. It will happen everywhere. But that again will not help for the kind of thing I want. Where you are like in my poem *Dharani mandala madhya darage*. India is multicentered, many centered, everyone of us is a centre. And we need the language of the atta – upstairs, it used to be Sanskrit at one time, then Persian and now it may be English as well. But the language of the house, the language of the street and the language of upstairs - all the three are important. There was no problem of connecting one with the other.

I would now come to the unity and diversity. This is how then I will put it. If somebody thinks in India that unity is very important, all this diversity, your own heritage, your own language, all this is wrong, we should all be Indian, then Assamese people will say Assamese is important, Punjabis would like to say Punjabi is important, the Tamils would like to say Tamil is important. If you overdo unity then diversities begin to assert. But if you overdo diversity what happens? We all begin to think of unity. I generally find there is something common between me and Narlikar and Dadhich and others, and if there is nothing common have we not inherited something common? Unity become important if diversities are overdone and diversities become important if unity is overdone. Particularly in a political sense if unity is overdone, then the diversities will begin to assert themselves. So unity in diversity means it is a process. Our elders knew how to keep this process alive. Without losing your Indian identity as well as your own identity. When Advaniji went around taking bricks from all over India to build a temple in Ayodhya, everyone said you should be Indian. Then I wrote a poem, which I roughly translate to English. When do I say I am an Indian? I thought of my mother. My mother never perhaps used a sentence like “I am an Indian, Naanu Bhootiyalu”. No. I don’t think she ever had an occasion to say I am an Indian.

I wrote like this - I say I am an Indian only in London so that someone may not mistake me for a Pakistani. When I come to Delhi, and they ask "who are you". I say I am from Karnataka. In Bangalore if they ask "who are you", I say I am from Tirthahalli from where all the great writers came. In Tirhtahalli, I don’t have to say who am I because they even know my subcaste. Because our identity is not only in your caste but in your subcaste also. Yandyavalka never had to say that he was an Indian. He was a great sage. He did not have to be conscious that he was an Indian. He was just creating knowledge for the whole world -that is what he thought. But now we are forced to say that we are Indians. Most of us have several identities, but they are not contradictory identities. But politics can make one identity a contradictory one to another identity. To say that "I am a Kannadiga"; if it means that I am not an Indian there is a conflict. You don’t have to assert one thing in order to lose the other. So every Indian has several identities - identity of his language, identity of his caste, of his subcaste and the traditional world and many other identities. But still he lives with all those identities; they are not contradictory identities. But the modern world system is forcing you to lose these identities in order to be effective and efficient in one. Many parents think that, "if my child can imbibe some English even when the child is in my stomach that will be good". They would give an injection so that he will be born with an American accent. It is as foolish as that. When we were in college there was a joke – One of our ministers went to London, came back and in great wonder he said, "even little children speak English there". We are getting back to that state of mind now. Particularly because of these call centres. It is harming a lot of science and young people taking up really challenging courses and so on.

I will come to the last point. I think what distinguished 20th century, which made us a nation, was that we did not think of ourselves as a nation in the European sense of the word "nation". We thought of ourselves as a nation in a civilized sense and hence all our languages were honoured. Gandhi wrote in Gujarathi, in Hindi and in English and he loved English literature. I am told that Narlikar writes in Marathi, Hindi and English. If only all our children become literate in our own languages, there would be five crore Kannada people. It is like European nation. If only they can read and write, if you make them literate, the language is empowered. And if you begin creating knowledge in this language, making use of every other language in the world, like the English people have done, the Germans have done, like all over the world like Pampa did in my own language, like all the saint poets did in their own languages. They took the essence of the Upanishads into their poetry.

There was a writer in my language who in the 16th century said ***Sanskrit vel innene*** - What else is there in Sanskrit ? We have also now imbibed a lot of Europe in our languages. I use a term for the Indian languages. I call them "genagni"- that is digestive fire. The Indian languages have a digestive fire. Marathi in its great medieval period when Tukaram and Gyandeo were there, they took whatever had to be taken - from the essence of Indian knowledge and Indian spirituality. That was translated by the Dasas and the Shivacharans in Kannada and it happened everywhere - through Kabir, Tulsidas. The medieval movements were not just religious. They were movements which empowered our languages, men and empowered women. In the 12th century if you became a lingayat, if you took the Basava part, the women when they menstruated did not have to go and sit outside. It empowered women. So all our languages empowered women. The first fight against caste system was by Basava who got a Brahmin girl married to a Dalit boy in the 12th century.

So it happenend through all these languages. These languages, were also vehicles of revolutionary thought, and change. There were also languages, which were like receptacles. Through their Genagni, they digested whatever had to be digested from the cosmopolis like all the European languages did.

I would like to end my lecture with the thought: Is it possible for us to have richer knowledge in India? A language is not merely a vehicle of thought. I think language also influences the way you create thought. I don't know how it does in science; it may do it in science. I was so happy when you use so many Indian words here to call different centres. I am not an Indianiser in the sense of - "Go back to Vedas and get all the knowledge" - no, not that. I mean create modern knowledge.

Why do I say it? In the 20th century, there were three hungers. Hunger for equality. I think it was born in Gandhiji when he was thrown out of the railway carriage. The second hunger was hunger for the spiritual, because we wanted to go beyond religions and its rituals. So you had an Arbindo, you had Ramana, a number of people who talked in a universal kind of language so far as God was concerned. That is because, we had an adwaita parampara - a wonderful way of relating to the mystery of the world. India was always in search of a spiritual consciousness without the need for a God. Whereas the semetic religions cannot have spiritual consciousness without a God. But India experimented a kind of a spiritual realm without the need for a personal God. So the spiritual hunger was there in Ramana, Arbindo - even Gandhi, to some extent. The third was hunger for modernity. It is a very great hunger.

You refer to Kuvampu; he was a shudra and came from a farmer caste. There was no education in his house except to read and write. He comes from a rich family but not the upper caste. He said, "If I did not get the 26 alphabets of English, I would perhaps be working in a cattle shed. English liberated me". English liberated Ambedkar. The hunger for modernity was as intense and it was related to the hunger for equality. So I say that the two other hungers - spiritual hunger and hunger for modernity - came from the womb of hunger for equality. But in today's India, the globalising India, the hunger for equality is gone and it is expressed only by popular politicians in a language to which we cannot respond. It is spoken of only to get votes. It is a votebank politics - hunger for equality.

Hunger for spirituality has created a number of Gurus for all the NRIs. They are very rich, they speak English as faultlessly as anyone else; expedential so then again it is vulgarized. I don't like any of them who speak the English language and give Psychotherapy. What is the hunger for modernity? It has degenerated into call centre. It does not mean where you are. But work as a part of the whole world and your language has also changed.

But can we again relate the three hungers to the hunger for equality? There is lot of potential in Indian people who speak different languages. Can they be brought into the world of knowledge with confidence? Because I know many people who even know English well, are afraid to talk in a class. If someone gets up and speaks very good English, this boy or girl, who has a deep knowledge, does not have the confidence to speak. Can we instill confidence again in our languages, can we make the common school come back again so that although we have different identities we get an all India identity by going to a common school?

Thank you very much.

Photo courtesy: Ninan Sajeeth Philip, Visiting Associate, IUCAA.

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