IUCAA

INTER-UNIVERSITY CENTRE FOR ASTRONOMY AND ASTROPHYSICS

(An Autonomous Institution of the University Grants Commission)

Annual Report

(April 1, 2007 - March 31, 2008)

Editor

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HIGHLIGHTS OF 2007- 2008

This annual report covers the activities of IUCAA during its twentieth year, April 2007-March 2008. 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), 14 post-doctoral fellows and 22 research scholars. The core research programmes by these academics span a variety of areas in astronomy and astrophysics. These topics include quantum theory and gravity, classical gravity, gravitational waves, cosmology and structure formation, cosmic microwave background radiation, observational cosmology and extragalactic astronomy, active galaxies, quasars and IGM, magnetic fields in astrophysics, high energy astrophysics, stars and the interstellar medium, and instrumentation. These research activities are summarised in pages 16-64. The publications of the IUCAA members, numbering to about 68 in the current year are listed in pages 88 - 91. IUCAA members also take part in pedagogical activities like lectures, seminars, popularisation of science, etc., the details of which are given in pages 98 - 99 of this Report.

The extended academic family of IUCAA consists of about 78 Visiting Associates, who have been active in several different fields of research. Pages 65-82 of this report highlight their research contributions. The resulting publications, numbering to about 131 are listed in pages 92-96 of this report. A total of about 1348 person-days were spent by Visiting Associates at IUCAA during this year. In addition, IUCAA was acting as host to about 550 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 128 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, four students have successfully defended their theses and obtained Ph.D. degree from the University of Pune during the year 2007 -2008. Summary of their theses appears in pages 83 - 87.

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 6 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 5000 people visited IUCAA.

These activities were ably supported by the scientific and technical, and administrative staff (25 and 31 in number respectively) who should get the lion's share of the credit for the successful running of the programmes of the centre. The scientific staff also looks after the major facilities like library, computer centre, and instrumentation lab. A brief update on these facilities is given on pages 129 - 138 of this Report.

T. Padmanabhan
Editor

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The Council and the Governing Board

The Council
(As on March 31, 2008)

President

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

Vice-President

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

Members

Anil Kakodkar,
(Chairperson, Governing Board)
Chairman, Department of Atomic Energy, Mumbai.

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

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

Jishnu Dey,
CSIR Emeritus Scientist,
Presidency College, Kolkata.

Sanjeev Dhurandhar,
IUCAA, Pune.

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

Arun Grover,
Tata Institute of Fundamental Research, Mumbai.

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

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

Narendra Jadhav,
Vice-Chancellor,
University of Pune.

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

Vijay Khole,
Vice-Chancellor,
University of Mumbai.

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

Shyam Lal,
Vice-Chancellor
Patna University.

K. Ramamurthy Naidu,
Banjara Hills, Hyderabad.

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

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

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

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

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

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

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

Member Secretary

Naresh Dadhich,
Director, IUCAA, Pune.

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

R. K. Chauhan,
Officiating Secretary,
University Grants Commission.

T. R. Kem,
Secretary,
University Grants Commission, New Delhi.

T. Ramasami,
Director General [Officiating],
CSIR, New Delhi.

Y.C. Simhadri,
Vice-Chancellor,
Patna University.

The Governing Board
(As on March 31, 2008)

Chairperson
Anil Kakodkar

Members

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

Member Secretary

Naresh Dadhich

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

R. K. Chauhan

Honorary Fellows

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

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

Russell Cannon,
Anglo-Australian Observatory, Australia.

Jurgen Ehlers,
Max-Planck Institute for Gravitational Physics, Golm, Germany.

A. Hewish,
University of Cambridge, UK.

Gerard 't Hooft,
Spinoza Institute, The Netherlands.

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

Yash Pal,
Noida.

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

P.C. Vaidya,
Gujarat University, Ahmedabad.

Visiting Professors

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

Anvar Shukurov,
University of Newcastle, UK.

Alexei Starobinsky,
Landau Institute for Theoretical Physics, Russia.

Statutory Committees
(As on March 31, 2008)

The Scientific Advisory Committee (SAC)

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

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

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

Umesh C. Joshi,
Physical Research Laboratory, Ahmedabad.

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

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

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

Ashoke Sen,
Harish-Chandra Research Institute, Allahabad.

N.K. Dadhich (Convener)
IUCAA, Pune.

The Users' Committee

N.K. Dadhich (Chairperson, Ex-officio member),
Director, IUCAA, Pune.

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

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

T. Padmanabhan,
IUCAA, Pune.

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

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

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

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

The Academic Programmes Committee

N.K. Dadhich (Chairperson)
T. Padmanabhan (Convener)
J. Bagchi
D. Bhattacharya (from 01.06.2007)
S.V. Dhurandhar
Ranjan Gupta
A. K. Kembhavi
Ranjeev Misra
M. Parikh
A.N. Ramaprakash
S. Ravindranath
Varun Sahni
Tarun Souradeep
R. Srianand
K. Subramanian
S. N. Tandon

The Standing Committee for Administration

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

The Finance Committee

A. Kakodkar (Chairperson)
R.K. Chauhan (till 24 .02.2008)
N.K. Dadhich
S.V. Dhurandhar
C.S. Meena
R. Nityananda
A. Pimpale
Raju Sharma (from 19.02.2008)
K.C. Nair (Non-member Secretary)

Members of IUCAA (as on 31 March, 2008)

Academic

N.K. Dadhich (Director)
T. Padmanabhan (Dean, Core Academic Programmes)
A.K. Kembhavi (Dean, Visitor Academic Programmes)
J. Bagchi
D. Bhattacharya (from 01.06.2007)
S.V. Dhurandhar
R. Gupta
R. Misra
M. Parikh
A.N. Ramaprakash
S. Ravindranath
V. Sahni
Tarun Souradeep
R. Srianand
K. Subramanian
S. N. Tandon

Emeritus Professor

J.V. Narlikar

Scientific and Technical

P. S. Barathe (from 29.10.2007)
N.U. Bawdekar
R. S. Bhandare (from 21.02.2008)
S.S. Bhujbal
M.P. Burse
S.B. Chavan
V. Chellathurai
K.S. Chillal
P.A. Chordia
H.K. Das
S. A. Dhurde
G.B. Gaikwad
S.U. Ingale
A.A. Kohok
V.B. Mestry
S.G. Mirkute
V. Mohan
N. Nageswaran
A. Paranjpye
S. Ponrathnam
S.M. Prabhudesai (from 17.12.07)
V.K. Rai
C.V. Rajarshi (from 21.01.2008)
H.K. Sahu
Y. R. Thakare

Administrative and Support

K. C. Nair (Senior Administrative Officer)
N.V. Abhyankar
V.P. Barve
S.K. Dalvi
S.L. Gaikwad
B.R. Gorkha
B S. Goswami
R.S. Jadhav
B.B. Jagade
S.M. Jogalekar
S.D. Kakade
S.N. Khadilkar
S.B. Kuriakose
N.S. Magdum
M.A. Mahabal
E.M. Modak
K.B. Munuswamy
R.D. Pardeshi
R.V. Parmar
B.R. Rao
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. Waghela
K.P. Wavhal

Post-Doctoral Fellows

S. Barway
R. Gopal
C. Konar (from 06.08.2007)
S. Malu (from 17.12.2007)
K. Misra (from 28.02.2008)
B. Pandey
Subharthi Ray
S. Basak (till 14.09.2007)
S. Joshi (till 16.06.2007)
M. Joy (till 27.03.2008)
R. Koley (till 26.01.08)
S. Pal (till 20.12.2007)
A.K. Ray (till 27.4.2007)
R. Sinha (till 24.01.08)

Research Scholars

M. Aich
S. Ali (fom 09.08..2007 to 05.10.2007)
A. Bora
S. Chakravorty
S. Chatterjee

T. Ghosh
G. Goswami (from 23.07.2007)
D. Kothawala
G. Mahajan
S. Muzahid (from 01.08.2007)
A. Rawat
S. Kumar
P. K. Samantray
S. Samui
S. Sarkar
A. Shafieloo
I. Singh (from 27.07.2007)
M.K. Srivastava
S. Sur
A. Deep (till 13.06.2007)
H. Mukhopadhyay (deceased)
T. Naskar (till 31.07.2007)

Temporary / Project / Contractual Appointments

T. Agrawal (from 14.06.2007)
C. Deshpande (VOI Project from 22.01.2007)
J. S. Joshi (from 19.11.2007)
M. S. Kharade (Project Officer, ERNET Project)
D. Nandrekar
N.Pokharkar (from 20.11.2007)
S. Punnadi (from 04.06.2007)
A. Rupner
S. Sagar
S. P. Zodage (from 07.01.2008)
P. Barathe (till 28.10.2007)
A. Durgade (till 09.07.2007)
P. Gaware (till 31.12.2007)
A.P. Kadam (till 18.05.2007)
V.P. Kulkarni (till 09.07.2007)
S. Panchal (till 20.2.08)
S.M. Prabhudesai (till 16.12.2007)
M. Shaikh (till 12.12.2007)
P. L. Shekade (System Engineer, till 10.01.2008)

Part Time Consultant

V. Mhaiskar (M.V.S.)
V. S. Savaskar (Medical Services)

Long Term Visitor

Arvind Gupta
Sailo Mukherjee
(formerly from North Bengal University, Siliguri, West Bengal)

Visiting Associates of IUCAA

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Alok Kumar Durgapal,
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Kumaun University, Nainital.

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

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

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

A.D. Gangal,
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University of Pune.

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

Sushant Ghosh,
Department of Mathematics,
BITS, Pilani.

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

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

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

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

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

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

Deepak Jain,
Deen Dayal Upadhyaya College, Delhi.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Saibal Ray,
Department of Physics,
Barasat Government College, Kolkata.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Till July 31, 2007

Sarbeshwar Chaudhuri
Department of Physics
Gushkara Mahavidyalaya, Burdwan

Ashok Goyal,
Department of Physics,
Hansraj College, Delhi,

S.S.R. Inbanathan
Department of Physics,
The American College, Madurai.

Sanjay Jain.
Guru Premsukh Memorial College of Engineering.
Delhi.

R.S. Kaushal,
Department of Physics,
Ramjas College, Delhi.

U.S. Pandey,
Department of Physics,
D.D.U. Gorakhpur University.

T. Ramesh Babu
Department of Physics
Cochin University of Science and Technology, Kochi

R. Ramakrishna Reddy,
Department of Physics,
Sri Krishnadevaraya University, Anantapur.

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

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

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

From August 1, 2007

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

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

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

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

Biplab Raychaudhuri,
Department of Physics,
Surya Sen Mahavidyalaya, Siliguri.

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

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

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

The eighteenth batch of Visiting Associates, who were selected for a tenure of three years, beginning August 1, 2007.

Himadri Sekhar Das

Anirban Saha

Ashish Asgekar

Paniveni Udayashankar

S.N.A. Jaaffrey

Sanjay Jhingan

The photographs of the following Visiting Associates from the eighteenth batch are not available: Biplab Raychaudhuri, and Anjan Anand Sen

Appointments of the following Visiting Associates from the fifteenth batch were extended for three years : G. Ambika, Narayan Banerjee, Pavan Chakraborty, Subenoy Chakraborty, Ranabir Dutt, Sushant G. Ghosh, K.P. Harikrishnan, Chanda J. Jog, Kanti R. Jotania, Nagendra Kumar, Pran Nath Pandita, Madhav K. Patil, Harinder P. Singh, Pradeep Kumar Srivastava, and Anisul Ain Usmani.

Organizational Structure of IUCAA's Academic Programmes

The Director

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)

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

One of the major developments in astronomy in the country would be the launch of ASTROSAT, a satellite entirely committed to astronomy observations with multi wavelength facilities, next year. IUCAA has contributed a good bit of its share in its development as well as in science facilitating projects. It would indeed be a remarkable observing facility which will give a great boost to space astronomy. The various observing facilities on board would generate an enormous amount of data, which has to be managed and tailored to a science user friendly mode. This is a huge and challenging task.

In view of IUCAA's experience with VO project and its very innovative and successful collaboration with one of the software companies involved in data management and handling, it was felt by the ASTROSAT Science Committee that IUCAA would be an ideally suited Centre for this task. On the advice of the Committee, ISRO had approached IUCAA to submit a comprehensive project for the establishment of an ASTROSAT Data User Centre at IUCAA. Apart from the data management, the Centre would also offer processing of the data to a user friendly mode. IUCAA looks upon it as yet another opportunity of taking the cutting edge astronomy facilities to university students and faculty, and get them involved in it. The project proposal is under review process and it is hoped that it would soon get off the table.

As we create new and challenging observing facilities, the need for trained human-power for their optimum use becomes stronger. That can only come from universities. This is precisely the vision of IUCAA and hence, it would always be involved in such projects.

On the telescope front, we are in the second year since regular operations began. I am happy to report that the Cassegrain motor problem and other early life hiccups have all been sorted out, and we restarted observing cycles in January 2008. A major facility upgrade during this period was the successful installation and commissioning on site of the mirror re-aluminization plant. The primary mirror of the telescope was re-aluminized in October 2007 using this plant. Observational capabilities of the telescope have been enhanced by making available an automated polarimetry mode as well as a set of narrow band filters for IFOSC. Technical hiccups of various kind are part and parcel of any instrument of this proportion, but what is assuring is that it has made the instrumentation team confident not only in troubleshooting and smooth running of the telescope, but also hungry for new challenging projects which are on the anvil.

In the SALT Board meeting of 24 October 2007, held at Durban, South Africa, IUCAA formally joined the Board. There was a small formal function at the dinner in the evening, which was also attended by the Indian Consul General to South Africa, Shri Harsha Vardhan Shringla, who spoke very well and enthusiastically on the occasion. He had subsequently also paid a visit to the SALT telescope and was also kind enough to write a nice note about it. There is also a good news on the image quality front as well as the new high resolution spectrograph. We are now all set for exciting science to come out of this challenging instrument.

Astronomical facilities require big outlays, both in kind and mind, it is, therefore, necessary to have large scale multi-national and multi-expertise collaborations. IUCAA is presently going through a brainstorming exercise in chalking out its research and development strategy in instrumentation. The idea is to identify one or two projects, which could be taken as institute or national initiative tagged on to a major international project like Extremely Large Telescopes or the next generation instruments for SALT or ASTROSAT II.

Once again, I would like to urge my university colleagues to join in the various exciting projects, which are being proposed. Your participation is sought on a wide all encompassing canvas including instrumentation, observation, data analysis, and theory. It would be wonderful to have a team of enthusiastic young students sweating out and learning the state of art skills and techniques.

A joint workshop between IUCAA and Brazil on cosmology was held at IUCAA during July 16 – 21, 2007 in which, about half a dozen colleagues from Brazil and a dozen or so from IUCAA, universities and other institutes participated. The second workshop in this series will be held in October this year at Natal in Brazil in which, a number of Indian participants will take part.

Finally, I should express my sincere thanks to the Governing Board, Council and Chairman, UGC and his team of officers for the understanding and consideration shown to IUCAA's programmes and needs, and for their wise counsel and support. It is widely acknowledged that IUCAA works smoothly and effortlessly as a well geared machine. It is all due to the untiring effort of the cohesive team of administrative and scientific staff, as well as the infrastructural support staff. It is to their spirit of commitment and dedication, I salute with admiration and thank them all warmly.

Naresh Dadhich

Congratulations to ...

Sanjeev Dhurandhar

*Elected **President of the Indian Association for General Relativity and Gravitation** in March 2008.*

Arvind Gupta

*Conferred with the **Harmony Silver Award** (A Dhirubhai Ambani Memorial Trust Initiative), Mumbai, 2007, and **Indira Gandhi Prize** for Popularization of Science, by Indian National Science Academy, New Delhi, 2008.*

Ajit K. Kembhavi

*Elected a **Fellow of National Academy of Sciences**, India.*

Jayant Narlikar

***Kalabhushan Award** by the Rajvaibhav Pratisthan, Aundh, April 1, 2007.*

***Doctor of Science (Honoris Causa)** from Assam University, Silchar, January 29, 2008.*

*Conferred with the **Suryadatta National (Lifetime Achievement) Award 2008,** by Suryadatta Education Foundation, Pune.*

T. Padmanabhan

*Conferred with the **INSA-Vainu Bappu Memorial Award** by the Indian National Science Academy, New Delhi, 2007.*

Swara Ravindranath

*Awarded the **SERC Fast Track Fellowship for Young Scientists**, by the Department of Science and Technology on May 29, 2007.*

Tarun Souradeep

*Conferred with the **B.M. Birla Science Prize in Physics,** by B.M. Birla Science Centre, Hyderabad, 2006.*

R. Srianand

*Elected a **Fellow of Indian Academy of Sciences**, India.*

Welcome and Farewell

Welcome to...

Dipankar Bhattacharya, who is the new addition to IUCAA Faculty.

Chiranjib Konar, Siddharth S. Malu, Kuntal Misra who have joined as Post-doctoral Fellows.

Suvayu Ali, Gaurav Goswami, Sowgat Muzahid, and **Indrajeet Singh,** who have joined as Research Scholars.

...Farewell to

Soumen Basak, who has joined as a Post-doctoral Fellow at Institut d'Astrophysique, Paris, France,

Atul Deep, who has joined as a Post-doctoral Fellow at Leiden Observatory, Netherlands.

Tapan Naskar, who has joined the Indian Association for Cultivation of Science, Kolkata.

Supratik Pal, who has joined the Indian Statistical Institute, Kolkata.

Santosh Joshi, who has joined as a Scientific Application Developer at Geophysics Company at Mumbai.

Arnab Kumar Ray, who has joined as a Scientific Application Developer at Geophysics Company at Mumbai

Ratna Koley, who has joined the Indian Association for the Cultivation of Science, Kolkata, as a Senior Research Associate.

Rita Sinha, whose project period was over.

Minu Joy, who has joined the Korea Astronomy and Space Science Institute, Daejeon, as a Post-doctoral Fellow.

Calendar of Events

2007

April 16 - May 25	**School Students' Summer Programme** at IUCAA
April 18 - 20	**Himalayan Relativity Dialogue** at Mirik, West Bengal
May 11	**IUCAA-NCRA Graduate School** Second semester ends
May 14 - June 15	**Refresher Course in Astronomy and Astrophysics for College and University Teachers** at IUCAA
May 14 - June 29	**Vacation Students' Programme** at IUCAA
May 14 - June 15	**Workshop on Data Analysis** at IUCAA
July 16 - 21	**Indo-Brazil Workshop on Cosmology** at IUCAA
July 21	**SALT and Advanced Computing Facilities: Dedication** at IUCAA
August 6	**IUCAA-NCRA Graduate School** First semester begins
August 29 - 30	**Workshop on Virtual Observatory and Data Analysis** at J.E.S. College, Jalna, Maharashtra
September 19 - 22	**Mini-school on Astronomy and Astronomical Data Analysis** at Newman College, Thodupuzha, Kerala
October 15-19	**Workshop on Astronomy with Virtual Observatories** at IUCAA
November 19-21	**Workshop on Observations with Small Telescopes** at Bhavnagar University, Gujarat
December 7	**IUCAA-NCRA Graduate School** First semester ends
December 17-21	**International Conference on Gravitation and Cosmology (ICGC 2007)** at IUCAA
December 18-20	**Conference on Measuring Spin and Mass of Black Holes** at YASHADA, Pune
December 29	**Foundation Day**

2008

January 7	**IUCAA-NCRA Graduate School** Second semester begins
February 4-6	**Workshop on Data Analysis and Data Reduction** at The American College, Madurai, Tamil Nadu
February 28	**National Science Day**

ACADEMIC PROGRAMMES

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

(I) RESEARCH BY RESIDENT MEMBERS

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

Quantum Theory and Gravity

Gravity: The inside story

Historically, we thought of electrons as particles and photons as waves, time as absolute and gravity as a force. *T. Padmanabhan* has suggested, while providing a key conceptual consolidation of the ideas he has been developing over the last several years, that we have similarly misunderstood the true nature of gravity, because of the way the ideas evolved historically. When seen with the 'right side up', the description of gravity becomes remarkably simple, beautiful, and explains features, which we never thought needed explanation!

To understand what is involved, one could compare the standard, historical development of gravity (see Table 1) with the approach developed by *Padmanabhan* (see Table 2). Historically, Einstein started with the Principle of Equivalence, and — with a few thought experiments — motivated why gravity should be described by a metric of spacetime. This approach gave the correct backdrop for the equality of inertial and gravitational masses and described the kinematics of gravity. Unfortunately, there is no equally good guiding principle, which Einstein could use leading in a natural fashion, to field equations, $G_{ab} = \kappa T_{ab}$, which govern the evolution of g_{ab} (or to the corresponding action principle). So the dynamics of gravity is not backed by a strong guiding principle.

Conceptually, strange things happen as soon as we: (i)let the metric be dynamical, and (ii) allow for arbitrary coordinate transformations or, equivalently, observers on any timelike curve examining physics. Horizons are inevitable in such a theory, and they are always observer dependent. This is because, the Principle of Equivalence implies that trajectories of light will be affected by gravity. So in any theory which links gravity to spacetime dynamics, we can have nontrivial null surfaces, which block information from a certain class of observers. Similarly, one can construct timelike congruences (e.g., uniformly accelerated trajectories) such that all the curves in such a congruence have a horizon. What is more, the horizon is *always* an observer dependent concept, even when it can be given a purely geometrical definition. For example, the $r = 2M$ surface in Schwarzschild geometry acts operationally as a horizon *only* for the class of observers who choose to stay at $r > 2M$ and not for the observers falling into the black hole.

Once we have horizons, which are inevitable, we get into a more peculiar situation. It is an accepted dictum that all observers have a right to describe physics using an effective theory based only on the variables (s)he can access. (This was, of course, the lesson from renormalization group theory. To describe physics at 10 GeV, one shouldn't need to know what happens at 10^{14} GeV in "good" theories.) This raises the famous question, first posed by Wheeler to Bekenstein: What happens if you mix cold and hot tea and pour it down a horizon, erasing all traces of "crime" in increasing the entropy, of the world? The answer to such thought experiments *demands* that horizons should have an entropy which should increase when energy flows across it.

With hindsight, this is obvious. The Schwarschild horizon, or for that matter any metric which behaves locally like the Rindler metric, has a temperature which can be identified by the Euclidean continuation. If energy flows across a hot horizon $dE/T = dS$ leads to the entropy of the horizon. Again, historically, nobody, in-

	Principle of Equivalence ($\sim$ 1908).
$\Rightarrow$	**Gravity is described by the metric g_{ab} ($\sim$ 1908).**
?	**Postulate Einstein's equations *without a real guiding principle!* (1915).**
$\Rightarrow$	**Black hole solutions with horizons (1916), allowing the entropy of hot tea to be hidden ($\sim$ 1971).**
$\Rightarrow$	**Entropy of black hole horizon (1972).**
$\Rightarrow$	**Temperature of black hole horizon (1975).**
$\Rightarrow$	**Temperature of the Rindler horizon (1975-76).**

Table 1: Conventional perspective of gravity

cluding Wheeler and Bekenstein, looked at the Euclidean periodicity in the Euclidean time (in Rindler or Schwarzschild metrics) *before* Hawking's result came! And the idea of Rindler temperature came *after* that of black hole temperature! So, in summary, the history proceeded as indicated in Table 1.

Padmanabhan has argued that there are several peculiar features in the theory, for which there is no satisfactory answer in the conventional approach described above and they have to thought of as algebraic accidents. He argues that there is an alternative way of approaching the dynamics of gravity, in which these features emerge as naturally as the equality of inertial and gravitational masses emerges in the geometric description of the kinematics of gravity. *His results also show that the thermodynamic description is far more general than just Einstein's theory*, and occurs in a wide class of theories in which the metric determines the structure of the light cones and null surfaces exist blocking the information.

So, instead of the historical path, he suggests proceeding as indicated in Table 2 reversing most of the arrows. The procedure uses the local Rindler frame (LRF) around any event P with a local Rindler horizon $\mathcal{H}$. When matter crosses a hot horizon in the LRF — or, equivalently — a virtual displacement of the $\mathcal{H}$ normal to itself engulfs the matter, some entropy will be lost to the outside observers unless displacing a piece of local Rindler horizon itself costs some entropy S_{grav}, say. Given the correct expression for S_{grav}, one can demand that $(S_{matter} + S_{grav})$ should be maximized with respect to all the null vectors, which are normals to local patches of null surfaces that can act locally as horizons for a suitable class of observers, in the spacetime. This puts a constraint on the *background* spacetime leading to the field equations.

To the lowest order, this gives Einstein's equations with calculable corrections. More generally, the resulting field equations are identical to those for Lanczos-Lovelock gravity with a cosmological constant arising as an undetermined integration constant. One can also show, in the general case of Lanczos-Lovelock theory, the on-shell value of S_{tot} gives the correct gravitational entropy, further justifying the original choice. Several peculiar features involving the connection between gravity and thermodynamics are embedded in this approach in a natural fashion. In particular:

- There *are* microscopic degrees of freedom ("atoms of spacetime"), which we know nothing about. But just as thermodynamics worked even before we understood atomic structure, we can understand long wavelength gravity arising possibly from a corpuscular spacetime by a thermodynamic approach. It must be stressed that metric g_{ab} is *not* a dynamical variable in the theory in the sense that it is not varied in the extremum principle to get the dynamical equations.

- Einstein's equations *are* essentially thermodynamic identities valid for each and every local Rindler observer. In spacetimes with horizons

	Principle of Equivalence
⇒	**Gravity is described by the metric g_{ab}.**
⇒	**Existence of local Rindler frames (LRFs) with a horizon $\mathcal{H}$ around any event.**
⇒	**Temperature associated with $\mathcal{H}$ is obtainable from the Euclidean continuation.**
⇒	**Virtual displacements of $\mathcal{H}$ allow for flow of energy across a hot horizon hiding an entropy $dS = dE/T$ as perceived by a given observer.**
⇒	**The local horizon must have an entropy, S_{grav}.**
⇒	**The dynamics should arise from maximizing the total entropy of horizon (S_{grav}) plus matter (S_m) for all LRF's leading to field equations!**

Table 2: Alternative perspective of gravity

and a *high level of symmetry*, one can also consider virtual displacements of these horizons (like $r_H \to r_H + \epsilon$) and obviously we will again get $TdS = dE + PdV$.

- If the the flow of matter across a horizon costs entropy, the resulting gravitational entropy has to be related to the microscopic degrees of freedom associated with the horizon surface. It follows that, any dynamical description will require a holographic action with both surface and bulk encoding the same information. For the same reason, the surface term in the action will give the gravitational entropy. Both these features have been investigated in detail by *Padmanabhan* and collaborators in the previous years.

Most importantly, this is not just a reformulation of Einstein's theory. Shifting the emphasis from Einstein's field equations to a broader picture of spacetime thermodynamics of horizons leads to a general class of field equations, which includes Lanczos-Lovelock gravity. It is now no surprise that Lanczos-Lovelock action is also holographic, and is related to entropy and has a thermodynamic interpretation.

Hawking radiation as tunneling: A generalized treatment

Understanding Hawking radiation is one of the key issues in any effort to unify gravity with quantum rules. In the last few decades, we have witnessed several independent attempts to comprehend the fact that black holes radiate and therefore behave very much like thermal systems. The original derivation of Hawking radiation involves calculating the Bogoliuyobov coefficients between asymptotic in and out states in a collapsing geometry. Another approach uses Euclidean quantum gravity techniques, where the thermal nature of horizons arises from the periodicity in Euclidean time.

There exists another popular, and possibly more physically appealing, approach to Hawking radiation based on quantum tunneling. The main ingredient in this case is the consideration of energy conservation as a thin shell of matter *tunnels* across the horizon. This idea has been used to derive Hawking-like radiation from virtually all known solutions of general relativity with horizons. Despite this, *there is no general approach for the tunneling of matter from a horizon which is independent of the specific solution.* Recently, *Sudipta Sarkar* and *Dawood Kothawala* have carried out a detailed analysis of tunneling of matter from static spherically symmetric horizons. Their work reveals that not only such a generalization is possible, but it also inevitably involves the thermodynamics of horizons, as should have been expected. More specifically, this approach reveals a direct relationship of tunneling, with the first law of thermodynamics for horizons, written in the form $TdS = \mathrm{d}E + PdV$. The connection between tunneling and first law of thermodynamics for horizons is also to be expected from the fact that the basic input behind both of them is same, namely, energy conservation. In fact, the method is *independent of the theory of gravity and makes no assumption of entropy being proportional to area.* Hence, the approach is more generally applicable as long as the first law of thermodynamics holds in the form $T\mathrm{d}S = \mathrm{d}E + P\mathrm{d}V$.

Sub-leading contributions to the black hole entropy in the brick wall approach

The concept of black hole entropy was originally introduced by Jacob Bekenstein to resolve certain thermodynamical paradoxes that arise in the presence of the black holes and, in particular, to preserve the universal applicability of the second law of thermodynamics. Soon after Bekenstein's proposal, based on their classical, macroscopic behavior, he thermodynamic properties of black holes were formalized as the four laws of black hole mechanics. Specifically, it was argued that, as the area theorem of classical general relativity closely resembles the statement of the second law of thermodynamics, the area of the black hole event horizon ($\mathcal{A}_{\rm H}$) can be considered analogous to the entropy. This association, in turn, led to the identification of the surface gravity (κ) of the black hole (which, for a stationary black hole, is a constant all over the horizon) as the temperature of the hole.

The laws of black hole mechanics were placed on a firm footing when, Hawking showed that, in the presence of quantum matter fields, a body that collapses into a black hole emits thermal radiation at the temperature

$$T_{\rm H} = \left(\frac{\hbar\, c}{k_{\rm B}}\right), \left(\frac{\kappa}{2\pi}\right), \tag{1}$$

where $\hbar$, c and $k_{\rm B}$ denote the Planck constant, the speed of light and the Boltzmann constant, respectively. The above Hawking temperature fixes the constant of proportionality between the temperature of the black hole and its surface gravity and, therefore, between the entropy and the area of the hole. One finds that the entropy of black holes are given by the following Bekenstein-Hawking area law:

$$S_{\rm BH} = \left(\frac{k_{\rm B}}{4}\right)\left(\frac{\mathcal{A}_{\rm H}}{\ell_{\rm Pl}^2}\right), \tag{2}$$

where $\ell_{\rm Pl} = \left(G\,\hbar/c^3\right)^{1/2}$, denotes the Planck length with G being the Newton's constant.

Black hole entropy assumes considerable importance due to the fact that it may provide us with an insight to the microscopic structure of the gravitational theory through the microcanonical, Boltzmann relation, $S = k_{\rm B} \ln \Omega$, where Ω is the total number of quantum states that are accessible to a black hole that is described by a small set of classical parameters. The different approaches that have been adopted in the literature to understand the microscopic origin of black hole entropy can be broadly classified into two categories. (i) Count the "microstates" by assuming a fundamental structure like D-branes, spin networks or conformal symmetry. (ii) Associate the black hole entropy to the quantum fields propagating in the fixed black hole spacetime and count the microstates of these quantum fields. Although, neither of the above approaches can be considered to be complete; both of them — within their domains of applicability — yield the semiclassical result in all spacetime dimensions $d \geq 3$. However, these approaches seem to lead to different sub-leading corrections to the Bekenstein-Hawking entropy. For instance, (i) The prefactor to the logarithmic corrections obtained using the spin-networks and conformal symmetry are different from the one obtained using the statistical fluctuations around thermal equilibrium. (ii) The power-law corrections obtained using the Noether charge approach are different from those via entanglement of the modes between inside and outside the horizon. In other words, even though different degrees of freedom lead to the universal Bekenstein-Hawking entropy, they lead to different sub-leading terms. This indicates that the key to the understanding of the statistical mechanical interpretation of Bekenstein-Hawking entropy may lie in the form of the sub-leading contributions.

The brick wall model is a semi-classical approach to understand the microscopic origin of black hole entropy. In this approach, the black hole geometry is assumed to be a fixed classical background on which matter fields propagate, and the entropy of black holes supposedly arises due to the canonical entropy of matter fields outside the black hole event horizon, evaluated at the Hawking temperature. Apart from certain lower dimensional cases, the density of states of the matter fields around black holes cannot be evaluated exactly. As a result, often, in the brick wall model, the density of states and the resulting canonical entropy of the matter fields are evaluated at the leading order (in terms of $\hbar$) in the WKB approximation. The success of the approach is reflected by the fact that the Bekenstein-Hawking area law, viz. that the entropy of black holes is equal to one-quarter the area of their event horizon, say, $\mathcal{A}_{\rm H}$, has been recovered using this model in a variety of black hole spacetimes.

It is, therefore, important to study the sub leading terms in a brick wall approach to obtain a better understanding of its relationship with the other approaches for black hole entropy. This is the motivation behind the work by *Sarkar* in collaboration with S. Shankaranarayanan (ICG, Portsmouth) and L. Sriramkumar (HRI, Allahabad), where they develop a technique to determine the sub-leading contribution to brick wall entropy order by order in the WKB approximation. Their work shows that along with the leading term, which is proportional to area, brick wall entropy also contains sub-leading terms of the form $\left[\mathcal{A}_{\rm H}^m + \mathcal{A}_{\rm H}^n \log \mathcal{A}_{\rm H}\right]$, where $(m,n) < 1$. Interestingly, one also find, at least in $(3+1)$ dimensions and in the zeroth and second order of WKB approximation, there are no power-law corrections to $S_{\rm BH}$ for the Schwarzschild black hole, while, for all other black holes there are power-law corrections to the Bekenstein-Hawking entropy. This leads to the following conclusion: *The power-law corrections to the entropy occur for any non-vacuum solutions.*. Similar power law corrections arise on evaluating the entanglement entropy of black holes. This behaviour seems to suggest a possible relationship between the brick wall model and the approach due to entanglement entropy. Their work also indicates the importance of sub-leading terms to understand the key issue of microscopic origin of black hole entropy.

Planck scale effects on quantum scalar field around a BTZ black hole

Hawking radiation from a black hole primarily arises due to asymmetry in the extent of redshift and the blueshift of the modes of a quantum field as they propagate through matter that is collapsing gravitationally and, eventually, would become a black hole. A typical mode that constitutes Hawking radiation at the future null infinity $\mathcal{I}^+$, when traced back to the past null infinity $\mathcal{I}^-$ (where the initial conditions are imposed on the quantum field), is found to have energy way beyond the Planck scale. As this radiation mostly consists of modes that leave the future event horizon just before its formation, such a phenomenon essentially occurs due to the enormous red-shifting of modes near the horizon. This behaviour then raises the question as to whether, and how, the *Planck scale physics* might modify the spectrum of Hawking radiation and the associated stress-energy tensor of the quantum field. In the absence of a workable quantum theory of gravity, most efforts concentrate on phenomenological models constructed by hand, which purportedly contain one or more features of the *effective theory*, obtained by integrating out the gravitational degrees of freedom. These models either introduce modified dispersion relations, or work with a classical fluctuating geometry, or assume that the spacetime coordinates are non-commutative. Often (though not always), these high energy models do not preserve local Lorentz invariance.

Hawking radiation is one instance, where we expect Planck scale physics to leave its imprints, thanks to the presence of the *infinite redshift surface.* However, quite generically, simple arguments based on fundamental concepts of general relativity and quantum mechanics (such as the *principle of equivalence* and *the uncertainty principle*) seem to indicate that it may not be possible to probe spacetime intervals smaller than the Planck length $L_{\rm P}$, which, therefore, acts as some thing like a 'zero-point length' of spacetime. To obtain an effective theory for a scalar field in a given background spacetime, one needs to appropriately account for quantum fluctuations of the metric and obtain the modified quantum propagator for the scalar field. This modified propagator would then capture some of the effects of Planck scale physics through its dependence on L_P. An approach that introduces such a 'zero-point length' in standard quantum field theory, while preserving local Lorentz invariance, is the so-called hypothesis of *path integral duality*. This hypothesis introduced by *Padmanabhan* in the early nineties, essentially leads to an exponential suppression of amplitudes of processes involving length scales smaller than L_P. Interestingly, it has been shown that, at low energies (compared to the string scale), the modified propagator of matter fields obtained through such an approach is equivalent to taking into account the string fluctuations propagating along compact extra dimensions.

The duality hypothesis yields a specific prescription to construct the modified propagator from the unmodified one. The calculations, however, are intractable in a generic 3+1 dimensional spacetime, since even the unmodified propagator is not known exactly. In contrast, the spacetime around a 2+1 dimensional, rotating Banados-Teitelboim-Zanelli (BTZ) black hole provides a situation where it *is* possible to calculate the two-point function exactly. The duality modified propagator and stress-energy tensor for the scalar field can, therefore, be obtained in a closed form. Such an analysis was recently carried out by *Kothawala*, in collaboration with S. Shankaranarayanan (Univ. of Portsmouth) and L. Sriramkumar (HRI, Allahabad). Their work shows that the duality modified propagator is finite in the coincidence limit. The form of the propagator also indicates that L_P indeed acts like the zero point length of spacetime intervals. Another feature to note (which is actually a characteristic of the duality hypothesis itself), is that the modification is *non-analytic* in L_P. A perturbative expansion in L_P will, therefore, not yield such a correction. Analysis of the quantum stress-energy tensor, $\langle T^{\mu}_{\nu} \rangle$, of the field shows that Planck scale effects introduced by duality hypothesis do not modify it to any appreciable extent, nor do they alter its *qualitative* behaviour. Moreover, these modifications prove to be most significant only very near to the horizon, $r = r_H$. Even for L_P as large as 0.9 r_H (a nearly *Planck-sized* black hole!), the maximum change (i.e., at $r = r_H$) in $\langle T^{\mu}_{\nu} \rangle$ is of the order of 3 - 5%. For any smaller value of L_P, the modified case turns out to be completely indistinguishable from the unmodified one. Therefore, one can conclude that, for any realistic L_P, these corrections are completely negligible. This result corroborates similar conclusions that have been arrived at earlier in the literature.

Black hole information paradox

The black hole information puzzle has for decades been one of the thorniest problems in theoretical physics. One of the proposed resolutions of it involves the idea of observer complementarity, in which, both an observer who falls into the black hole as well as an observer who stays outside and measures the Hawking radiation have, in principle, complete information about any system that falls into the black hole with the infalling observer. This duplication of information seems at first sight to be in conflict with the no-cloning principle of quantum mechanics, but a series of careful thought experiments show that observable paradoxes do not arise.

These thought experiments, however, do not extend to de Sitter space which faces a similar kind of information paradox. With Jan Pieter van der Schaar (University of Amsterdam), *Maulik Parikh* has showed that no observable violations of the no-cloning principle occur in de Sitter space either. The key idea is that the backreaction of the geometry restricts the maximum amount of energy that can be contained in de Sitter space. This energy is insufficient to encode even a single bit of information for a subsystem entangled with the horizon. Thus, an observer inside the horizon can never, in a low-energy experiment, recover any information to set up a potential conflict with the laws of quantum mechanics.

Classical Gravity

Gravitational dynamics from Bianchi identity

It is well known that for any field there is a defining property in terms of vanishing of the Bianchi derivative, $D^2 = 0$, which marks the derivative closure. The obvious examples are the vanishing of curl of gradient and divergence of curl. The former defines a scalar field, while the latter a vector field. Wheeler paraphrased this fact as 'boundary of boundary is zero'. That is a field always satisfies the Bianchi identity.

What happens when we go to tensor field like gravity? Here Bianchi identity is satisfied by the fourth rank Riemann curvature tensor. Let us take its trace which would, unlike for scalar and vector field, now be non-zero. That is, it gives rise to a second rank symmetric tensor (the Einstein tensor, G_{ab}) with identically vanishing divergence. This is a non-trivial statement which leads to determining gravitational dynamics - the Einstein equation. This happens because, trace of Bianchi identity remains non-zero and hence it would impose an equation on the field, which could be nothing other than its equation of motion. Thus, follows a very important statement that for a tensor field the Bianchi identity also determines the dynamics of the field, as argued by *N. Dadhich.*

It can be said that gravitational dynamics follows from the Riemann curvature through the trace of the Bianchi identity. On the other hand, the trace of Riemann curvature gives the Einstein-Hilbert Lagrangian, which on variation with respect to the metric leads to the same equation of motion. That is, the action as well as the Bianchi identity lead to the same differential operator on the left hand side of the equation of motion.

This is all fine for dimension $n \leq 4$, while for $n > 4$, higher order terms like Gauss-Bonnet term should be included and more generally one needs to include the Lovelok polynomial. The linear Einstein-Hilbert term is adequate for $n \leq 4$, the quadratic Gauss-Bonnet for $n = 5, 6$ and so, the relevant order in the Lagrangian depends on the dimension. The variation of Gauss-Bonnet term gives the analogue of Einstein tensor, a second rank symmetric tensor (H_{ab}), which is quadratic in curvature and has vanishing divergence.

As Riemann curvature leads to G_{ab}, similarly there should also exist a quadratic analogue of Riemann leading to H_{ab}. *Dadhich* has identified this tensor and has obtained H_{ab} from the trace of its Bianchi identity. As expected, the trace of this tensor gives the Gauss-Bonnet Lagrangian just as Einstein-Hilbert Lagrangian is the trace of Riemann. Similarly, there would exist a Riemann analogue for the each term in the Lovelock Lagrangian giving the corresponding Einstein analogue a divergence free second rank tensor. This derivation automatically ensures quasi-linearity of the equation of motion.

Riemann curvature could be viewed as Bianchi potential for the Einstein tensor. Then *Dadhich* has given a new characterization of the Lovelock Lagrangian in existence of Bianchi potential for each term in the polynomial. Non-Lovelock Lagrangian will not have Bianchi potential. It is a purely differential geometric characterization. Since, gravity is entirely governed by spacetime curvature and so must its dynamics. The higher order terms in the Lagrangian attain physical meaning only in dimension greater than 4. Though there are some strong motivating arguments for higher dimension even for complete realization of classical gravitational dynamics, however, it is an open question. *Dadhich* has, for past couple of years, been articulating some of these physical considerations for higher dimension.

Gravitational Waves

Current status

A number of large-scale interferometric gravitational wave detectors, with optimal sensitivity in the frequency window $\sim$ 10 Hz $-$ 1 kHz are nearing desired sensitivities world-wide. The projects include the LIGO, composed of two Laser Interferometer Gravitational-wave Observatories situated in the United States, each with arm lengths of

4 km, VIRGO, an Italian/French project located near Pisa with a baseline of 3 km, GEO600, a British/German interferometer under construction near Hannover with a baseline of 600 m; in Japan, the TAMA project is currently running a medium-scale laser interferometer with a baseline of 300 m and plans exist for constructing a full scale detector (LCGT) in the near future. The LIGO detectors have already achieved their initial design sensitivity, amply demonstrated by the two year science run from 2005 to 2007. This run was carried out with the *realistic goal of directly observing gravitational waves* (GW's) *for the first time.* There are also separate proposals for space-based detectors e.g., LISA: the Laser Interferometer Space Antenna, a cornerstone project of the European Space Agency and NASA.

The key to gravitational wave detection is the ability to make a very precise measurement of small changes in strain. For laser interferometers, this is achieved by monitoring the distance between pairs of mirrors suspended at either end of two long, mutually perpendicular evacuated arms. Gravitational waves passing through the instrument will shorten one arm while lengthening the other. By interferometric means, the relative change in length of the two arms can be measured as a relative phase change of the light beams propagating down the arms, thus, signaling the passage of a gravitational wave at the detector site. Long arm lengths, high laser power, extremely well-controlled laser stability, and mechanical isolation of suspended test masses are the essential ingredients needed to reach the requisite sensitivity.

Although the initial design of the interferometers currently under construction has been fixed, it is universally recognised that more technologically advanced detector designs, in a globally distributed network, will be needed in order to confidently detect, locate and characterise sources of gravitational waves. Therefore, the first observational phase now is being followed up by hardware upgrades on most of the instruments, whose purpose is to reach better sensitivity over wider frequency bands. These will be the enhanced detectors of the near future.

Gravitational wave detectors produce a large volume of output data. For example, LIGO alone will generate approximately TB/day, of which only 1% is the noise-limited interferometer strain output. The other 99% of the data correspond to a large number of other interferometer channels and environmental sensor channels that are used to qualify the noise characteristics of the operating detectors. Signals of astrophysical origin will be buried in the noise and sophisticated data analysis techniques are required to optimally extract the physics information encoded in the waveforms. Experience in handling large volumes of data and the development of appropriate analysis algorithms play a vital role in the eventual successful detection of gravitational waves. The scale of the challenge is such that a concerted international effort has been mounted in order to develop data analysis techniques, that are sufficiently robust to ensure that detection is possible.

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 (LISA). The IUCAA group has had collaborations with all major gravitational wave groups around the world and now a large number of past students and postdoctoral fellows of IUCAA are part of these groups, some of whom hold key positions. The IUCAA group has collaborations with, AEI, Germany (GEO), US (LIGO), Japan (TAMA) and France (LISA). These collaborations have been carried out with the sponsorship of NSF (US), DST (India) and IFCPAR (Indo-French).

Described below are the main activities, the IUCAA group has focussed on during the past year:

(i) Cross-correlational search for periodic sources:

Long lived quasi-periodic GW from rapidly rotating non-axisymmetric neutron stars are among the promising sources of detectable GW for ground-based detectors. A number of such searches for long-lived periodic GW have been carried out using data from ground-based GW detectors. These include searches using data from interferometric and bar detectors. These searches are of two kinds depending on the size of the parameter space that is searched:

Targeted searches for sources whose parameters are well known from other astrophysical observations. Such searches are not computationally intensive, and use statistically optimal matched filtering techniques.

Wide parameter space searches are conducted either for neutron stars in binary systems whose parameters are poorly constrained from prior observations, or blind searches for as yet unknown neutron stars.

While none of the above searches have yet resulted in a detection, there have been some notable successes. For the searches targeting known pulsars, the limits on the gravitational wave emission and the corresponding limits on the deformation are starting to become astrophysically interesting.

Similarly, a lot of the groundwork has been laid for meeting the computational challenges for the wide parameter space searches. Computationally efficient methods and hierarchical data analysis pipelines have been developed, which allow us to vastly improve the ratio of sensitivity to computational cost. Most of these are semi-coherent methods, i.e., combinations of coherent analyses combined together by excess power techniques, and they come in two main flavours. The first combines short segments of simple Fourier transformed data. The baseline of the short Fourier transforms is chosen such that the signal manifests itself as excess power in a single frequency bin, and the excess power is combined by various methods. The simplest is the StackSlide method, which adds the normalized excess power from the short segments, taking care to "slide" the frequency bins to account for the Doppler shift and intrinsic spindown. The PowerFlux method is very similar; it performs a weighted sum of the normalized power using weights which take the sky-position and polarization dependent sensitivity of the detector into account; the weights serve to improve the sensitivity. Finally, there is the Hough transform method, which performs a weighted sum of binary-number counts calculated by setting a threshold on the normalized excess power. This is more robust and computationally efficient, though at the cost of being somewhat less sensitive. All three methods have been used to analyze LIGO data in all-sky wide frequency band searches for GWs from isolated neutron stars, and these are so far the most sensitive wide parameter space GW searches of their kind published so far; we shall refer to them as the "standard" semi-coherent searches in the rest of this report.

A variant of these standard semi-coherent techniques are the so-called hierarchical searches, which aim to search deeper by increasing the coherent time baseline. This requires a sky-position (and spindown) dependent demodulation to be performed before calculating the excess power statistic. The extra demodulation step significantly increases the computational cost and such a search pipeline is currently being employed on larger computational platforms such as *Einstein@Home*.

In addition to the above surveys for isolated neutron stars, searches have also been carried out for gravitational waves from neutron stars in binary systems. A plausible argument for why some neutron stars may be emitting detectable GWs applies to neutron stars in binary systems, and in particular, to the Low Mass X-ray Binaries (LMXBs), which consist of a neutron star and a low mass main-sequence star. The observed X-ray flux from these systems is due to the high rates of accretion of matter onto the neutron star. It is observed that the rotation rates of neutron stars in LMXBs is significantly lower than that might be expected on theoretical grounds; the highest theoretically possible rotation rate is significantly larger than 1 kHz, while the current observed record is $\sim$ 620 Hz. It was suggested that this apparent upper bound on the rotation rate might be due to a balance between the spin-up due to accretion and the spindown due to the emission of gravitational radiation; there is virtually a "wall" created by the flux of GW radiated, which increases as Ω^6, where Ω is the angular rotational frequency of the spinning neutron star and this limits its spin-up. There are a number of other suggested explanations, which do not involve gravitational radiation, but accreting neutron stars are clearly promising sources of detectable gravitational radiation. So far, two searches have targeted Sco X-1, the brightest LMXB. These have used very different techniques; the first used a coherent integration on 6 hours of data from the second science run of the LIGO detectors, while the second used a cross-correlation statistic on data from the more recent fourth science run.

Almost all of these searches mentioned above have been based on techniques which look for signals of a given form in a single data stream, i.e., either matched filtering techniques or semi-coherent power summing methods. While both matched filtering and semi-coherent techniques have been generalized and used to analyze data from multiple interferometers, the starting point for these methods is always the analysis of a single data stream.

For a stochastic background, we use the facts that the statistical properties of the signal are time independent and that the two polarizations are statistically independent. For periodic GWs from neutron stars, these assumptions do not hold. The signal is deterministic and non-stationary (because of the Doppler shift), and the two polarizations are not independent. There is yet another ingredient present for periodic signals that is not present for stochastic sources. In principle, since the signals we are looking for have long term phase coherence, it should be possible to cross-correlate any pair of data segments to extract the signal, regardless of how far apart the segments are in time and regardless of whether they are from the same interferometer or not. It will turn out that the sky-resolution is much coarser than for the standard periodic searches; the appropriate baseline is not the Earth-Sun distance but rather the distance between the two detectors. This leads to a much lighter computational burden for a blind search.

S. V. Dhurandhar, B. Krishnan, *H. Mukhopadhyay* and J. Whelan have generalized the cross-correlation statistic, traditionally used for the stochastic gravitational wave background searches, to periodic gravitational waves. The features of periodic waves, not present in the stochastic background signals, are non-stationarity and long-term coherence. The non-stationarity may need to be taken into account depending on the frequency resolution, and the long-term coherence implies that in principle, the data segments from arbitrary times and arbitrary detectors can be cross-correlated. In this framework, a network consisting of an arbitrary number of detectors can be naturally considered. Because of the freedom in choosing which data-segment pairs to correlate, the method is very flexible, and these are some of the possibilities:

All possible short data segments can be cross-correlated. This is then very close to the $\mathcal{F}$-statistic corresponding to a full matched filter statistic. In this case, the parameter space resolution becomes very fine and consequently while this is ideally the most sensitive method, it's computational cost becomes prohibitive for wide parameter space searches.

At the other extreme, one can choose to correlate only data segments taken from distinct detectors at the same (or very close) times. This is the closest in spirit to the standard directed stochastic background searches using aperture synthesis. In this mode of operation, the search is not computationally intensive, and is very robust against signal uncertainties. However, this also implies poor resolution in parameter space, and thus, more expensive follow-ups to verify possible detections and to estimate the signal parameters.

The standard semi-coherent searches, such as PowerFlux, StackSlide and Hough all correspond to the special case, in which we consider only self-correlations.

In intermediate regimes when we correlate data segments separated by a maximum coherence time, the cross-correlation search is similar to a hierarchical search in which we combine segments of demodulated data.

Conceptually, this method, thus, provides a unified framework for all the known periodic wave searches, and this might be useful in various calculations and applications. Each of the above modes of operation corresponds to tuning the maximum coherence time all the way from small values to the total observation time. The precise value chosen for a specific application depends on the trade-offs between computational cost, sensitivity, and robustness against signal uncertainties. The additional parameter which figures importantly in this trade-off is the length of the short data segments.

(ii) Coherent versus coincidence search for inspiraling binaries:

Inspiraling binaries are one of the most promising candidates for first detection of GW. The compact objects can be treated essentially as point particles leading to sufficiently adequate description of the system in terms of the post-Newtonian formalism. The great accuracy of the post-Newtonian approximation of the phase, about a cycle for a wave train $\sim 10^4$ cycles long, renders it amenable for matched filtering analysis. Inspiraling binaries are astrophysically important, because they will not only carry detailed information about the binary system, but also general relativistic deviations from Newtonian gravity in their orbit which can experimentally be measured. The best available estimates suggest that at 1% false alarm probability, the expected number of neutron star(NS)-NS binary coalescence seen per year by ground based interferometers is $3 \times 10^{-4} - 0.3$ for initial detectors and $1 - 800$ for advanced detectors. In recent years, a number of ground based detectors are collecting quality science data and are collaborating together, thus, the time is ripe to consider analysis of network data for the detection of inspiraling binaries. The advantages of multidetector search for the binary inspiral is that, not only does it improve the confidence of detection, but it also provides information about the direction and polarization state of the source.

Two strategies currently exist in searching for inspiraling binary sources with a network of detectors: the coherent and the coincident. The coherent strategy involves combining data from different detectors phase coherently, appropriately correcting for time-delays and polarization phases and obtaining a single statistic for the full network, that is optimized in the maximum likelihood sense. On the other hand, the coincident strategy matches the candidate event lists of individual detectors for consistency of the estimated parameters of the GW signal. A coincidence search with real data from LISM and TAMA 300 has been carried out by TAMA group and a trial data analysis on S5 data of the LIGO detectors has recently been performed.

There is a long standing debate as to which strategy performs better. In the first work, *Mukhopadhyay*, H. Tagoshi, *Dhurandhar*, H. Takahashi and N. Kanda compared the performances for the simple case of coaligned detectors located in the same place. The coherent statistic was improved in second work by the same team. This analysis is applicable to the case of existing detector pairs H1-H2 and planned future detectors LCGT. The coincident strategy has the advantage of reduction of false alarm, however, this is at the price of reduced detection efficiency. On the other hand, in the coherent strategy, the false alarm rate is not reduced and the sensitivity is enhanced, which in turn results in higher detection efficiency. Which of these two competing effects wins was determined by looking at the detection efficiencies of the two strategies at the same false alarm rate. *Receiver operating characteristics* (ROC) curve, which is the plot of detection efficiency versus false alarm rate, was drawn for both the strategies and from those curves it was inferred that for the viable false alarm regime the coherent strategy performs much better than the coincident strategy.

Currently *Mukhopadhyay*, Tagoshi, *Dhurandhar* and Kanda have analysed the general case of two widely separated detectors on Earth. Since the detectors are situated on the globe and have their arms lying parallel to the Earth's surface, they necessarily have different orientations. However, the general problem of detectors with arbitrary locations and orientations is considered, since this does not greatly add to the mathematical complexity of the problem. The coherent statistic for non-aligned detectors is completely different from that of the aligned case. One cannot naively generalise the earlier results to the general case of widely separated detectors. The comparison of the strategies is based on ROC curves, obtained analytically as well as via simulation. An enhanced coincidence strategy is analysed, which is basically an improvement on the simple coincidence strategy for, it is seen that when the detectors are not aligned, the performance of the simple coincidence strategy is very poor. In enhanced coincidence, although the two detectors are considered in isolation and the candidate event lists compared for consistency in the estimated signal parameters, the two statistics from individual detectors are added in quadrature and a single threshold is placed upon the resulting statistic. This strategy, for the case of two detectors only, renders a statistic identical in form to that of the coherent strategy.

The bottom line here is that, the coherent strategy of detection is superior to the coincidence strategies either simple or enhanced. The ROC curves display this fact quantitatively for all the cases considered.

The main reason behind the poor performance of the simple coincidence strategy lies in the coverage of the sky. For a particular source at a fixed distance, the intrinsic signal-to-noise ratio (SNR) of the GW emitted depends crucially on the location and orientation of the source. For a single detector, such a source would be "visible" for particular orientations and only a part of the sky is "seen" by the detector; for differently oriented detectors, different parts of the sky would be "seen". When the detectors are aligned, the sky coverage of the coincident detector is the same as that of the single detector. The sky coverage of the coincident detector is essentially the intersection of the sky coverages of the two individual detectors. This is worse than any one of the single detectors if the detectors are oriented differently. However, the coincident detector may still perform better than the single detector, because the false alarm rate is less. On the other hand, the sky coverage of the coherent detector is more than the union of the sky coverages of the two detectors. So a coherent detector can "see" more part of the sky and also further away. Thus, the volume of the sky "seen" by the coherent detector is greatly enhanced and the detection probability is larger. In other words, the coherent strategy can detect more sources than the coincident one.

For the purpose of illustration, a binary is taken at a distance 15 Mpc. The mass of each individual star is 1.4 times the solar mass. The binary is taken to be optimally oriented and its position is varied throughout the entire sky. The intrinsic SNR is calculated for LIGO (L1) and VIRGO and a threshold of 7 is set on the SNR. Then the coverage of a single detector is 49%. The coherent strategy covers almost 92% of the sky, while the simple coincidence strategy covers only 18%. This is shown in the figure 1 below:

(iii) A general relativistic analysis of LISA dynamics and optics:

A number of ground-based large-scale interferometric gravitational wave detectors, with optimal sensitivity in the frequency window $\sim$ 10 Hz – 1 kHz are operational world-wide. A natural limit occurs on decreasing the lower frequency cut-off of 10 Hz because, it is not practical to increase the armlengths on ground and also because of the gravity gradient noise, which is difficult to eliminate below 10 Hz. The solution is to build an interferometer in space, where such noises will be absent and allow the detection of GW in the low frequency regime. LISA is a proposed mission, which will use coherent laser beams exchanged between three identical spacecrafts forming a giant (almost) equilateral triangle of side 5×10^6 kilometres to observe and detect low frequency cosmic GW. The ground-based detectors and LISA complement each other in the observation of GW in an essential way, analogous to the optical, radio, X-ray, γ-ray, etc., observations do for the electromagnetic waves.

In ground based detectors, the arms are as symmetrical as possible so that the laser light experiences nearly identical delay in each arm of the interferometer. This arrangement reduces the laser frequency/phase noise at the photodetector. This reduction of noise is crucial, since, the raw laser noise is orders of magnitude larger than other noises in the interferometer. But perfect symmetry is not possible, and an efficient system of servo loops is necessary for reaching a noise level compatible with the required sensitivity. The required sensitivity of the instrument can, thus, only be achieved by near exact cancellation of the laser frequency noise plus a good symmetry of the arms. However, in LISA, the lack of symmetry will be much larger than in terrestrial instruments, and the laser noise, though reduced by stabilisation techniques (still to be demonstrated), will probably be still too high. LISA consists of three correlated interferometers, which produce redundancy in the data, and this can be used to suppress the laser frequency noise. In LISA, six data streams arise

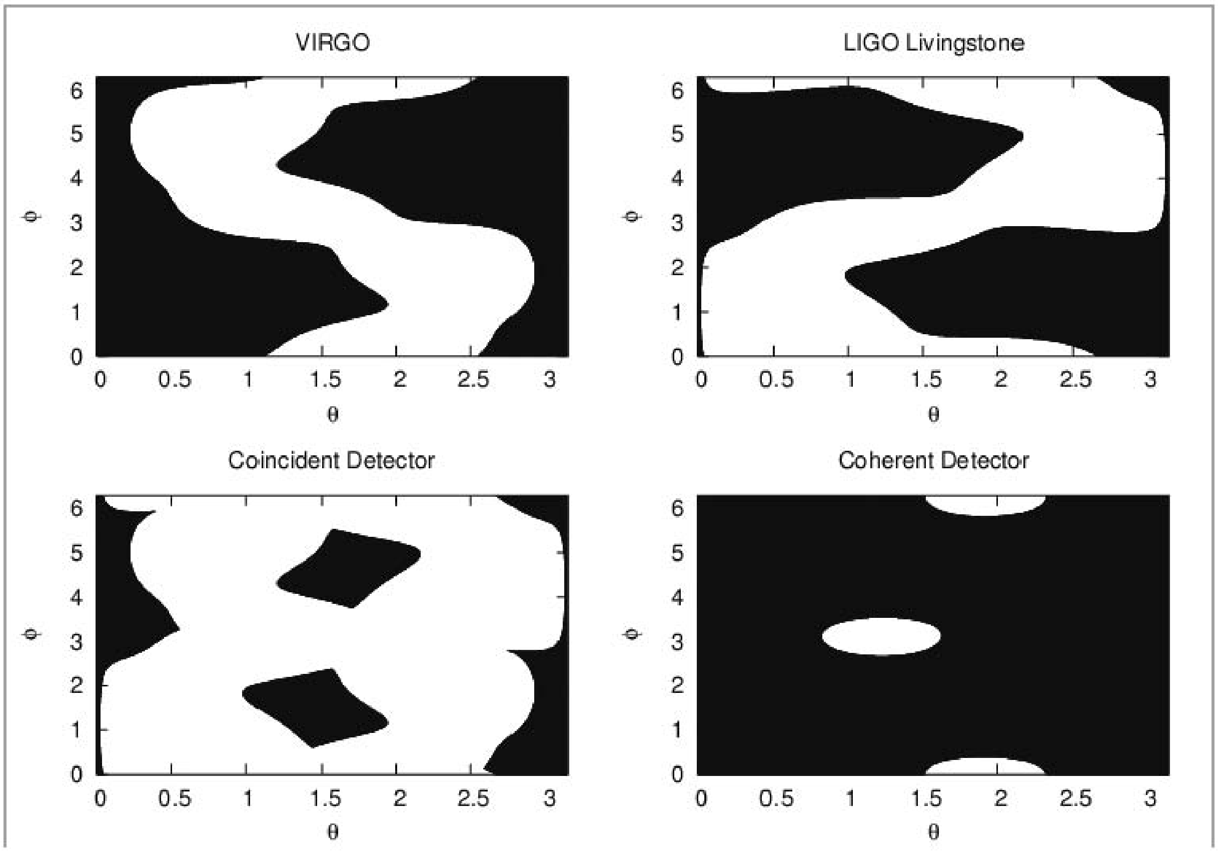

Figure 1: The top figures show sky coverages of individual detectors, while the bottom ones show the sky coverages of the coincident and coherent strategies. The dark areas in the figures depict the portions of the sky covered by the detectors.

from the exchange of laser beams between the three spacecrafts and it is not possible to bounce laser beams between different spacecrafts, as is done in ground based detectors, because after 5 million km propagation, the intensity of light reaching the target spacecraft, is reduced by 10 orders of magnitude; but in the target spacecraft a laser is locked in phase on the received wave, so that the secondary beam is re-emitted without loss of phase information to the primary source. This is analogous to the RF transponder scheme, as was done in the early experiments for detecting GW by Doppler tracking a spacecraft from Earth.

Laser frequency noise which dominates the other noises by 7 or 8 orders of magnitude must be removed if LISA is to achieve the required sensitivity of $h \sim 10^{-22}$, where h is the metric perturbation caused by a gravitational wave. This cancellation is achieved by time-delay interferometry (TDI), where the six data streams are combined with appropriate time-delays. This is possible because of the redundancy present in the data. This work was put on a sound footing by showing the data combinations had an algebraic structure; the data combinations cancelling laser frequency noise formed the *module of syzygies* over the polynomial ring of delay operators. This work was done for stationary LISA in flat spacetime, where the motion of LISA as well as the ambient gravitation field, mainly that of the Sun, was ignored. These were the so-called the Ist generation TDI. However, LISA spacecraft execute a rotational motion and also the background spacetime is curved, all of which affect the optical links and the time-delays. Thus, the Sagnac effect, Einstein effect, Shapiro delay, etc. are important and must be incorporated into the analysis if the laser frequency noise is to be cancelled. *Dhurandhar*, R. Nayak, J-Y Vinet and B. Chauvineau have posed this problem in a self-consistent framework of general relativity. The final goal is to determine the data combinations cancelling laser frequency noise taking into account near exact general relativistic model of LISA so that the LISA simulator can be built based upon this complete model. Preliminary work on optical links shows that the LISA configuration has some symmetries, which may be used to simplify the TDI problem for flexing arms which as it stands is quite difficult. This work forms essence of the Indo-French project whose investigators are *Dhurandhar* on the Indian side and B. Chauvineau and Vinet on the French side.

Cosmology and Structure Formation

Braneworld dynamics

Varun Sahni, Yuri Shtanov and H. Maeda have undertaken an analysis of higher dimensional 'braneworld' models. Braneworld models of the universe, in which the observable universe is a four-dimensional timelike hypersurface (brane) embedded in a higher-dimensional (bulk) spacetime, have attracted much recent attention. This is partly due to the fact that Superstring/M-theory seems to require the existence of extra dimensions and the braneworld approach may be one way of reconciling our (3+1)-dimensional universe with these higher-dimensional theories.

The current popularity of the braneworld construct is due to the fact that brane cosmology is usually accompanied by new features, and is therefore, in principle, falsifiable. The simplest Randall–Sundrum (RS) braneworld, for instance, gives rise to an evolutionary equation for the brane, which differs from standard general relativity at *early times*. This leads to several interesting consequences. For instance, the very early universe expands as $H \propto \rho$, instead of the more familar $H \propto \sqrt{\rho}$ in standard cosmology. The changed expansion rate causes a scalar field to experience greater damping, which, in turn, allows inflation to occur for a broader class of initial conditions and potentials.

An important class of braneworld models are those for which the gravitational action includes, in addition to the familiar Einstein term, a Gauss–Bonnet contribution. Gauss–Bonnet terms arise naturally in superstring theories, and *Sahni*, Shtanov and Maeda discuss in detail the cosmological dynamics of this class of theories. In doing so, they develop a new pictorial method of analysis, which provides qualitative insights into the evolution of the universe in this potentially important new model of gravity.

The Gauss-Bonnet action has the following form:

$$S = \int d^n x \sqrt{-g} \left[\frac{1}{2\kappa_n^2} (R - 2\Lambda + \alpha L_{GB}) \right], \quad (3)$$

where R is the n-dimensional Ricci scalar, Λ is the n-dimensional cosmological constant, and $\kappa_n := \sqrt{8\pi G_n}$, where G_n is the n-dimensional gravitational constant. The Gauss–Bonnet term L_{GB} is a combination of the Ricci scalar, the Ricci tensor $R_{\mu\nu}$ and the Riemann tensor $R^{\mu}{}_{\nu\rho\sigma}$:

$$L_{GB} := R^2 - 4R_{\mu\nu}R^{\mu\nu} + R_{\mu\nu\rho\sigma}R^{\mu\nu\rho\sigma} \,. \quad (4)$$

The constant α in (3) is the coupling constant of the Gauss–Bonnet term and for $\alpha \to 0$ this model reduces to the familiar Randall–Sundrum model. The action in Eq. (3) can be obtained in the low-energy limit of heterotic superstring theory, in which case α can be regarded as the inverse string tension and is positive definite. ($n \geq 5$ is assumed, since for $n \leq 4$, the Gauss–Bonnet term is a topological invariant and does not contribute to the field equations.)

Although, the system of equations resulting from Eq. (3) is complicated, it can nevertheless be analysed using a simple geometric method. For this purpose, *Sahni*, Shtanov and Maeda show that the (3+1)-dimensional equations of motion of several popular cosmological models can be depicted as simple curves in the $(H^2, (\rho+\sigma)^2)$ plane. Here, H is the Hubble parameter, ρ the density and σ the brane tension.

For instance, the spatially flat Friedmann–Robertson–Walker universe in GR has the form of a *quadratic curve*, while the Randall-Sundrum model describes a *straight line* in the $(H^2, (\rho+\sigma)^2)$ plane. The Gauss–Bonnet brane, on the other hand, describes a *cubic curve* in the $(H^2, (\rho+\sigma)^2)$ plane. This *pictorial depiction of dynamics* permits us to discover the salient features of cosmic evolution very simply. Applying this approach to the Gauss–Bonnet brane *Sahni*, Shtanov and Maeda discover the following interesting properties:

- For a finite region in parameter space, the Gauss–Bonnet brane *accelerates* at late times. Acceleration can be *phantom-like* ($w < -1$), but does not lead to the eventual destruction of the universe in a *big-rip* future singularity. Instead, at very late times, the expansion of the universe approaches de Sitter space and becomes exponential (i.e., $w \to -1$).
- The expansion of the universe may commence from or terminate in a 'sudden' quiescent singularity, at which, the Hubble parameter and the density of matter remain finite, but $\dot{H}$ diverges.
- The universe can evade the initial big-bang singularity and *bounce*. (This possibility is realized if the fifth dimension is timelike.)

An example of brane evolution is shown in figure 2.

Braneworld perturbations

Braneworld models have many interesting properties: they can modify the inverse-square law on small scales, and on the very large scales, give rise to an accelerating universe. The issue of Braneworld cosmology has been extensively studied by *Sahni* and Shtanov in a series of papers. Recently, they have extended this discussion to include the effects of perturbations. They derive an exact system of equations governing the growth of perturbations of pressureless matter and dark radiation, and also discuss boundary conditions of various type.

Braneworld theories with large extra dimensions, while having a number of very attractive properties, also have a common difficulty: on the one hand, the dynamics of the higher-dimensional bulk space needs to be taken into account in order to understand brane dynamics; on the other hand, all observables are restricted to the four-dimensional brane. In field-theoretic language, the situation can be described in terms of an *infinite (quasi)-continuum* of Kaluza–Klein gravitational modes existing on the brane from the brane viewpoint. This property makes braneworld theory complicated, solutions on the brane non-unique, and evolution non-local. For instance, while the

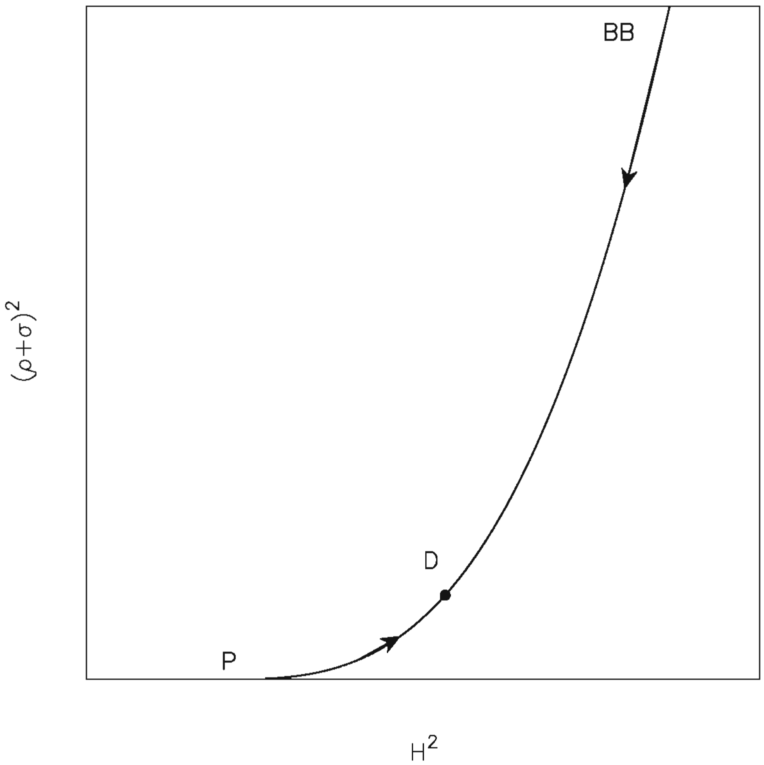

Figure 2: *Geometrical depiction of braneworld dynamics.* The point P corresponds to $H^2 = -A$. During the course of expansion, the motion along the curve is initially downwards from the initial Big Bang (BB) singularity towards P. However, for P to be reachable in a finite time interval, the brane tension σ must be negative, only then is $(\rho+\sigma)^2 = 0$ permitted. The point P marks a turning point for the evolution along the curve: after this point, the energy density of the universe keeps decreasing, while the quantity $(\rho+\sigma)^2$ is increasing. In this case, the Hubble parameter passes through an inflection point at P. In other words, $\dot{H} > 0$ for some length of time during the upward motion along the curve *away from* P. Thus, the universe *accelerates at late times*. Note that $\dot{H} > 0$ is usually associated with a *phantom* equation of state $w < -1$ in dark-energy models. We, therefore, conclude that our Gauss–Bonnet brane can display phantom-like features and super-accelerate at late times, before approaching $w \to -1$ in the distant future. Note that the big-rip future singularity (at which $H \to \infty$) is absent in this case, which is one of the appealing features of this scenario.

solution with a spherically symmetric source is relatively simple and straightforward in general relativity, a similar problem in braneworld theory does not appear to have a unique solution.

Fortunately, in situations possessing a high degree of symmetry, the above properties of braneworld theory do not affect its cosmological solutions (at least, in the simplest case of one extra dimension). Thus, homogeneous and isotropic cosmology on the brane is almost uniquely specified since, it involves only one additional integration constant, which is associated with the mass of a black hole in the five-dimensional bulk space. This makes braneworld theory an interesting alternative for modelling dark-energy and dark-matter effects on cosmological scales.

However, in order to turn a braneworld model into a *complete* theory of gravity viable in all physical circumstances, it is necessary to address the issue of boundary conditions. Usually, one tries to formulate reasonable conditions in the bulk by demanding that the bulk metric be non-singular or by employing other (regulatory) branes. However, neither of these conditions have been implemented in braneworld theory in full generality; moreover, they leave open the problem of non-locality of the gravitational laws on the brane (since the brane is left open to influences from the bulk).

Sahni and Shtanov adopted a different approach to the issue of boundary conditions in the brane–bulk system. From a broader perspective, boundary conditions can be regarded as any conditions restricting the space of solutions. Their approach is to specify such conditions directly on the brane, which represents the observable world, in order to arrive at a local and closed system of equations on the brane. The behaviour of the metric in the bulk is of no further concern in this approach, since this metric is for all practical purposes unobservable. Since the nonlocality of the braneworld equations is known to be connected with the dynamical properties of the bulk Weyl tensor projected onto the brane, it is natural to consider the possibility of imposing certain restrictions on this tensor. Perhaps, the simplest condition is to set its (appropriately defined) anisotropic stress to zero. This is fully compatible with all the equations of the theory and results in a brane universe described by a modified theory of gravity and having an additional invisible component, dark radiation, which is endowed with nontrivial dynamics.

One of the main results of a detailed analysis of perturbations carried out by *Sahni* and Shtanov is that extra-dimensional effects can significantly boost the growth of perturbations in matter. An important implication of this result is that perturbations in the baryonic component might overcome the 'growth problem', which plagues them in standard general relativity, and grow to acceptable values without requiring the presence of (deep potential wells in) dark matter.

Perturbations during inflation

The present decade appears to have ushered in a golden age for precise cosmological observations. A consensus seems to be emerging that the late time behaviour of this model is 'close to' LCDM with an approximately scale invariant primordial spectrum for density perturbations such as those predicted by the simplest inflationary models. However, it is well known that, although primordial fluctuations spectra expected from inflation are likely to be approximately flat, or scale-invariant ($n_s(k) \equiv d\ln P(k)/d\ln k \simeq 1$), a slightly red spectrum ($n_s \lesssim 1$) appears to be a generic prediction of the simplest viable one-parameter family of inflationary models. For all these models, $|n_s(k) - 1| \ll 1$, and the running of the slope $\tilde{\alpha}(k) \equiv dn_s(k)/d\ln k$ is expected to be small: $|\tilde{\alpha}(k)| \sim |n_s(k) - 1|^2 \ll 1$. Existing CMB and other observational data are just approaching the level of accuracy, necessary to detect deviations from exact scale invariance and to distinguish between different inflationary models. In this context, it is interesting that WMAP data appear to suggest a rather large value of the running $|\tilde{\alpha}(k)| \sim |n_s(k) - 1|$, and the existence of local spikes like the 'Archeops feature' at $l \sim 40$, which may indicate that inflation is an altogether more complex phenomenon. Therefore, though it is still a matter of some debate, whether these features really exist in the primordial perturbation spectrum and are not foreground effects or statistical flukes, it is important to consider models, which can give rise to a running of the spectral index. In particular, the large value of the running, if confirmed, would be expected to be a local feature around the present Hubble scale, since its persistence until the very end of inflation is incompatible with the requirement that the inflationary epoch be of sufficient duration (*i.e.*, the number of e-folds $N \sim 50$).

Minu Joy, *Varun Sahni* and A.A. Starobinsky have analysed these issues and developed an inflationary scenario, in which the inflaton potential experiences a sudden small change in its second derivative (the effective mass of the inflaton). In other words, $[V] = [V'] = 0, [V''] \neq 0$ and $|[V'']| \ll H^2$, where $V(\varphi)$ is the inflaton potential and $[A] \equiv A(\varphi_0 + 0) - A(\varphi_0 - 0)$. A sudden small change in the slope of the potential (a kink) leads to a step in its second derivative $V''(\varphi)$. (see Figure 3). This, mildest of all discontinuities, can be caused by a fast second order phase transition during inflation. An exact treatment demonstrates that the resulting density perturbation has a quasi-flat power spectrum with a break in its slope (a step in n_s). The step in the spectral index is modulated by characteristic oscillations and results in large running of the spectral index localized over a few e-folds of scales. A field-theoretic model giving rise to such behaviour of the inflationary potential is based on a fast phase transition experienced by a second scalar field weakly coupled to the inflation. Such a transition is similar to that which terminates inflation in the hybrid inflationary scenario. *Joy*, *Sahni* and Starobinsky conclude that the observed running of the spectral index in the WMAP data may be caused by a fast second order phase transition which occurred during inflation.

Cosmic origins: Microorganisms in the stratosphere

The ISRO-sponsored experiment led by *J.V. Narlikar* and collaborators has yielded positive result in terms of bacteria found at heights of 41 km above mean sea level. The characteristics of these microorganisms have been analysed and a technical write-up based on it has been sent to a journal on microbiology for publication. Scientists from ISRO prepared the payload, which was flown under the direction of scientists of TIFR balloon facility, and the results were analysed by biologists at CCMB and NCCS.

Cosmic Microwave Background Radiation

The measurements of Cosmic Microwave Background (CMB) anisotropy have played a key role in the rapid progress of cosmology. More recently, the detection and mapping of CMB polarization has added a new window to this success story. Results from ongoing and upcoming experiments promise to keep the CMB anisotropy and polarization at the centre stage of cosmology.

Tarun Souradeep and his collaborators have been involved in a successful research program covering a broad spectrum of issues related to the CMB anisotropy and polarization. The Wilkinson Microwave Anisotropy Probe (WMAP) had three data releases, and most recently five year data in March 2008. In the past couple of years, *Souradeep* and collaborators have applied different aspects of research to the WMAP data. The Planck Surveyor mission of ESA, arguably, the most ambitious of CMB experiments yet, is scheduled for launch in late 2008. Hence, current research at IUCAA has also focused on preparing for the high quality data expected from Planck.

CMB anisotropy and foregrounds

As reported in previous annual reports, *Souradeep*, Rajib Saha and Pankaj Jain of IIT Kanpur, have developed a novel method of estimating the angular power spectrum from multi-frequency data that evades the modeling uncertainties involved in template based methods that use extraneous foreground maps measured by different instruments at very disparate frequency bands. The method has provided an independent estimation of the angular power spectrum from different WMAP data re-

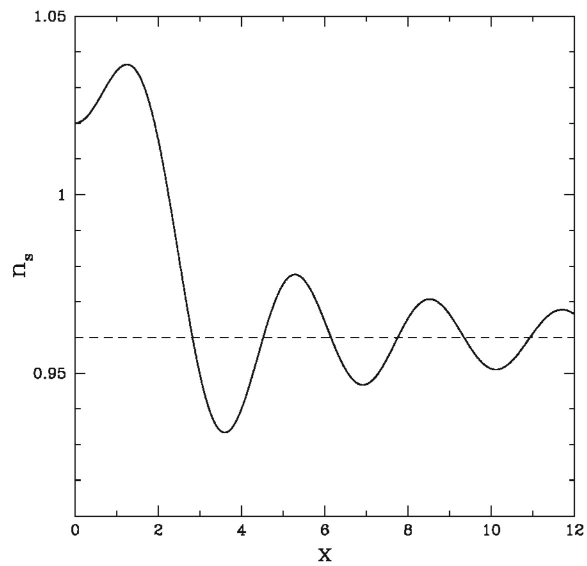

Figure 3: The primordial spectral index n_s is shown as a function of $x = k/k_0$ for the inflationary model analyzed by *Joy*, *Sahni* and Starobinsky in which the potential has a sudden change in its second derivative. Such a discontinuity in V'' leads to step in n_s at $x \sim 1$.

leases. In collaboration with Simon Prunet (IAP), the group has done an in-depth study of the method to identify and correct for subtle biases in the estimated power spectrum.

Tuhin Ghosh and *Souradeep* have carried out a feasibility study of the application of this method to the upcoming Planck Surveyor mission. Results on simulated data show that the method takes full advantage of the wider frequency coverage, higher number of independent detector assemblies per frequency, and higher sensitivity of Planck Surveyor in successfully removing foreground contamination and noise bias from the angular power spectra of CMB anisotropy and polarization. Further, the work also shows great promise for the CMB polarization measurements. This is particularly significant since very little is known about the polarized foregrounds at CMB frequencies to allow for reliable modeling based approaches to foreground removal.

In the past year, *Ghosh*, Saha, Jain and *Souradeep* have also produced the first, completely model independent estimate of the foreground contamination to the CMB maps from the diffuse galactic emission. In figure 4, the left column of panels show combined foreground maps at the Q band (top) and the W band (bottom) obtained by the model independent analysis. The right column shows the difference in these foreground maps and the Maximum Entropy Method (MEM) reconstruction by the WMAP team. While the foreground maps are broadly consistent with the estimates of WMAP, there are interesting differences that are under closer study.

Systematic effects in CMB measurements

In this era of high precision CMB measurements, subtle systematic effects limit the ability to extract cosmological information with precision and reliability. The non-circularity of the experimental beam has become progressively important as CMB experiments strive to attain higher angular resolution and sensitivity. As reported in earlier annual reports, the group at IUCAA (S. Mitra, A. Sengupta and *S. Ray*) have worked extensively on this problem. *Siddharth Malu* has initiated work to ex-

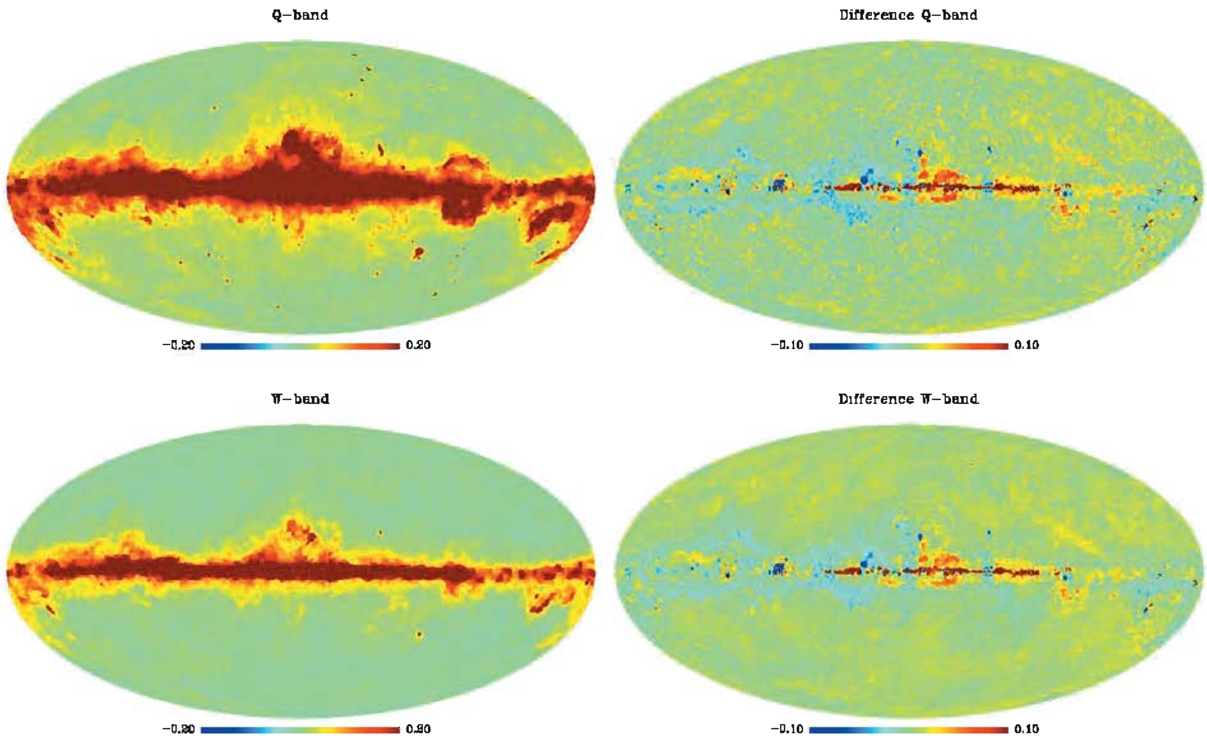

Figure 4: *Left:* Model independent foreground emission maps at Q (41 GHz.) & W (94 GHz.) band obtained from the WMAP data (*Ghosh*, Saha, Jain and *Souradeep*). *Right:* The difference of these maps with the corresponding Maximum Entropy Method (MEM) foreground maps recovered by the WMAP team.

tend the formalism developed earlier by *Souradeep* and Ratra to study beam systematics in CMB interferometer experiments.

A CEFIPRA funded Indo-French collaborative research program with Francois Bouchet and Simon Prunet on the systematic effects in the Planck CMB measurements has been underway over the past year and a half. *Aich* has worked on the effect on non-uniform/incomplete sky coverage on estimation of angular power spectrum of CMB anisotropy and polarization. Soumen Basak (IAP) and *Moumita Aich* are also working on different aspects of the effect of weak lensing on CMB anisotropy and polarization measurements.

Early universe from CMB

The form of the spectrum of primordial perturbations that seeded the large scale structure in the universe is essentially an unknown input that is implicitly folded into the present understanding of the universe and estimates of the cosmological parameters from observations of the perturbed universe. 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. The robust features in the published primordial spectrum derived from WMAP first year and three year data and a wavelet based analysis of their significance have also been reported earlier.

Shafieloo and *Souradeep* have now extended their research programme towards carrying out a revised cosmological parameter estimation 'optimized' over the unknown form of the primordial power spectrum. The approach is to assign to a given point in the space of cosmological parameter the likelihood obtained after deconvolving and deriving the primordial power that 'maximizes' the likelihood to the data. The wavelet based fully automated implementation of the algorithm allows exploration of the cosmological parameter space. The first results of this radical approach to cosmological parameter estimation over limited dimensions and at coarse resolution have been obtained in the past year. Figure 5 plots the likelihood over 3-dimensional region of the cosmological parameter space. The likelihood surface has a well defined landscape demonstrating that the current data retains the ability to differentiate between different sets of cosmological parameters even allowing for full freedom in the form of the initial power spectrum. These results motivate a high resolution and higher dimensional exploration of the cosmological parameter space. Work is in progress to address the computational challenges posed by this task.

Search for inflationary gravity waves in the CMB

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

Malu and *Souradeep* are actively exploring the possibility of constructing a polarization pathfinder, to detect polarized signal from the galaxy at 30GHz to be run at a dry, high altitude location in India, such as, Leh. This effort will characterize polarized foreground emission from the galaxy and will be an important contribution to the global experimental efforts that target the detection of B-mode of CMB polarization. The programme of activity initiated involves instrument simulation of proposed designs of CMB polarization experiments. The 'pathfinder' experiment is expected to open avenues for the Indian community to get involved in challenging B-mode experiments from the ground, or, possibly space.

Interpretation of CMBR

J. V. Narlikar (in collaboration with J.C. Pecker and N.C. Wickramasinghe) is examining the possibility of explaining the cosmic microwave background as a purely local effect generated by ther-

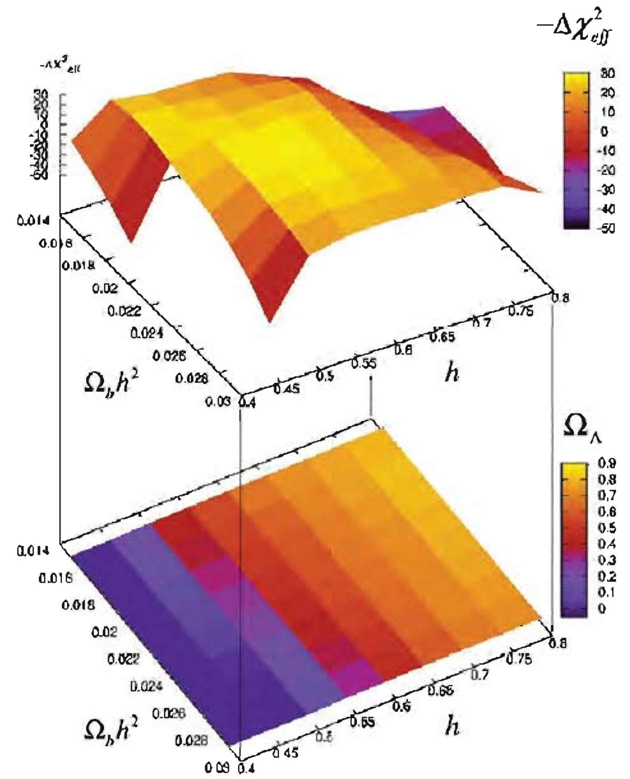

Figure 5: Cosmological parameter estimation 'optimized' over the form of the primordial spectrum has a well defined likelihood landscape The data retains the ability to discriminate despite the freedom in choosing the primordial power spectrum. The $-\Delta\chi^2_{eff}$ (relative to the best fit power law model) is plotted as a function of Hubble parameter and $\Omega_b h^2$. The lower panel color codes the corresponding value of the Ω_Λ.

malization of starlight in and around our galaxy or from the local supercluster. While the spectrum and energetics do not present a severe problem, there could be possible conflict with the solar motion relative to the background. This issue is being analysed.

Observational Cosmology and Extragalactic Astronomy

Galaxy mergers and morphologies

Ajit Kembhavi and *Abhishek Rawat*, in collaboration with Francois Hammer and Hector Flores of l'Observatoire de Paris have been working on determining the evolution in the merger rate of galaxies with redshift out to $z \sim 1.2$. This work involved counting pairs of galaxies within a projected distance of less than 20 Kpc of each other. They then estimate the fraction of galaxies that exist in pair in a given redshift bin. This pair fraction 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 CDFS (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 $\propto (1+z)^{3.43\pm0.49}$ for optically selected pairs, and $\propto (1+z)^{2.18\pm0.18}$ for pairs selected in the near-IR. Their result is unlikely to be affected by luminosity evolution, which is relatively modest when using rest-frame J band selection. The apparently more rapid evolution that they find in the visible band is likely caused by biases relating to incompleteness and spatial resolution affecting the ground based near IR photometry, underestimating pair counts at higher redshifts in the near-IR. The major merger rate was found to be ~ 5.6 times higher at $z \sim 1.2$ than at the current epoch. Overall $41\% \times (0.5\ Gyr/\tau)$ of all galaxies with $M_J \leq -19.5$ have undergone a major merger in the last $\sim 8\ Gyr$, where τ is the merger time scale.

Rawat, in collaboration with Yogesh Wadadekar at NCRA and Duilia De Mello at Goddard Space Flight Center (GSFC) USA has been working on comparing the rest-frame UV vs optical morphologies of intermediate redshift galaxies and it's implications to high-z results. They worked on comparing the rest-frame UV morphologies of a sample of 162 intermediate redshift ($z_{\text{median}} = 1.02$) galaxies with their rest-frame optical morphologies. They selected the sample from the deepest near-UV image obtained with the Hubble Space Telescope (HST) using the WFPC2 (F300W) as part of the parallel observations of the Hubble Ultra Deep Field campaign overlapping with the HST/ACS GOODS dataset. They performed single component Sérsic fits in both WFPC2/F300W (rest-frame UV) and ACS/F850LP (rest-frame optical) bands and deduced that the Sérsic index n is estimated to be smaller in the rest-frame UV compared to the rest-frame optical, leading to an overestimation of the number of merger candidates by $\sim 40\% - 100\%$ compared to the rest-frame optical depending upon the cutoff in n employed for identifying the merger candidates. They also find evidence that the axis ratio b/a is underestimated, i.e., ellipticity $(1 - b/a)$ is overestimated in rest-frame UV compared to the rest-frame optical. Moreover, they find that in the rest-frame UV, the number of high ellipticity ($e \geq 0.8$) objects are higher by a factor of ~ 2.8 compared to the rest-frame optical. This might explain the reported results in the literature that high redshift Lyman-Break Galaxies (LBGs) tend to show a significant skew towards higher ellipticities, since most high redshift LBG work is done using rest-frame UV datasets. This indicates that the reported dominance of elongated morphologies among high-z LBGs might just be a bias related to the use of rest-frame UV datasets. Finally, they suggest that ultra-deep images with the infra-red channel of WFC3 will be required to constrain the underlying galaxian light of LBGs at $z \sim 3.0!$ and will allow similar analysis of the rest frame optical morphologies of galaxies at high-z.

Super massive black holes in nearby galaxies

The existence of massive black holes (BHs) at the center of nearby inactive galaxies as well as in the nuclei of active galaxies and quasars is well established. Observations based on high resolution HST data and reverberation mapping are now available, which allow measurement of the masses of BHs using different techniques has shown that the measured BH mass (M_{BH}) is tightly with correlated physical properties of host galaxy such as bulge luminosity (M_B), bulge mass (M_{bulge}) and the velocity dispersion (σ). It is believed that these massive BHs play an important role in the formation and evolution of galaxies, and the growth of BHs and bulges must be linked to the same physical processes which results in BH masses that are related to the properties of host galaxies. *Sudhanshu Barway* and *Kembhavi* obtain a new fundamental plane for supermassive black holes at the centres of elliptical galaxies, involving measured central black hole mass and photometric parameters (mean bulge surface brightness ($\langle\mu_{\rm b}(< r_{\rm e})\rangle$) and effective radius ($r_{\rm e}$) of bulge) which define the light distribution. The galaxies are tightly distributed around this mass fundamental plane, with improvement in the rms residual over those obtained from the M_{BH}-σ and M_{BH}-M_B relations. The mass FP provides a convenient way for estimating BH mass from photometric data alone and implies a strong multidimensional link between the central massive black hole formation and global photometric properties of elliptical galaxies and provides an improved estimate of black hole mass from galaxy data.

The formation and evolution of lenticular (S0) Galaxies

Lenticular (S0) galaxies form a morphological transition class between ellipticals and early-type spirals in the Hubble (1936) classification system. When comparing properties, it is found that the bulges of lenticulars are very similar to elliptical galaxies, while their disks have similarities to the disks of early type spiral galaxies, except that they lack conspicuous spiral arms. Our understanding of the formation and evolution of lenticular galaxies, in terms of the individual physical processes involved, is still unclear, inspite of extensive efforts both by observational and theoretical means.

A detailed study of the morphology of lenticular galaxies in near-infrared band, with possible separation of bulge and disk components is carried out by *Sudhanshu Barway* and *Kembhavi* in collaboration with Wadadekar, C.D. Ravikumar, and Y. D. Mayya. They find that lenticular galaxies show markedly different correlations between their bulge effective radius (r_e) and disk scale length (r_d) as a function of their total luminosity (M_T). For faint lenticular galaxies ($M_T > -24.5$), r_e and r_d are positively correlated, in line with predictions of secular formation processes that likely formed the pseudo bulges of late-type disk galaxies. Such a formation scenario is also consistent with the predictions of numerical simulations of lenticular galaxy formation. Bright lenticular galaxies with $M_T < -24.5$, on the other hand, do not exhibit this correlation, indicating a different formation mechanism. These trends seem to hold irrespective of galaxy environment, although more luminous lenticulars are largely missing from our cluster sample. The relative fraction of lenticular galaxies is, of course, very different in clusters and in the field. Further investigations reveals other correlations such as Kormendy relation and also shows luminosity dependence.

Observational studies of galaxy evolution aim to understand how the physical properties of galaxies evolve with time. Understanding the morphological evolution of galaxies is an important part of such an analysis; quantitative measurements of structural parameters of the galaxy subcomponents (bulge, disk, point source, etc.) enable such studies.

Structural parameters of galaxies can be measured in two different ways. Non-parametric methods provide useful measures to describe the galaxy and its structure. There are several Non-parametric ways to describe galaxies which have been proposed in recent years. These methods do not assume any analytical model to describe the galaxy light profile. The main inadequacy of these methods is their low credibility when computed using shalow images as most of the quanties are reasonably sensitive to the signal-to-noise ratio.

Parametric methods, on the other hand, assume different analytical models for the light distribution of different components of galaxies. For example, the bulge is usually modeled as a Sersic function and the disk as an exponential. Parametric methods enable direct comparison between galaxy properties spanning a wide range of Hubble types and redshifts.

It is very important to develop user friendly automated software to extract the morphological parameters of large galaxy samples . Vinu Vikram of Mahatma Gandhi Unievrsity, Kottayam, working with *Kembhavi* and Wadadekar (NCRA), has developed such a software called PyMorph, which uses SExtractor and GALFIT together in such a way that the former provides initial values, which are needed by the latter to find the structural parameters of galaxies. Other than this PyMorph also measures non-parametric quantities, such as concentration index, asymmetry, clumpiness, Gini coefficient and second order moment of light distribution. The details of PyMorph are described in Vinu et al. 2008.

The goal of developing this software is to extract the structural parameters of galaxies, which can be used to constrain the formation mechanism of galactic bulges. The bulges of galaxies can differ because of their formation mechanism. We can constrain formation mechanism in bulges by studying the light distribution of light. Formation of bulges by accretion process predicts de Vaucoulers profile for the galaxies. On the other hand, exponential nature of late-type galaxy bulges and the correlations between bulge and disk scale lengths were interpreted as the evidence for regulated bulge formation by redistribution of disk material to the galaxy centre by a bar like perturbation.

Vinu, *Kembhavi* and Wadadekar have constructed a sample of nearly 1000 galaxies from 22 clusters at different redshifts. We have archival Hubble Space Telescope data on all these galaxies. The cluster redshifts range from 0.2 to 0.9. It is expected that the structural parameters of these galaxies can address the question of formation mechanism and evolution of galaxies in cluster environments.

Vigorous star formation in massive disk galaxies at z=1.5

In Daddi et al. (2007), *S. Ravindranath* and collaborators presented the first detection of molecular gas cooling CO emission lines from ordinary massive galaxies at $z = 1.5$. Two sources were observed with the IRAM Plateau de Bure Interferometer, selected to lie in the mass–star formation rate correlation at their redshift, thus, being representative of massive high-z galaxies. Both sources were detected with high confidence, yielding $L_{CO} = 2 \times 10^{10}$ K km s^{-1} pc^2. For one of the sources, we find evidence of velocity shear, implying CO sizes of $\sim$ 10 kpc. With an infrared luminosity of $L_{FIR} = 10^{12} L_\odot$, these disklike galaxies are borderline ULIRGs but with star formation efficiency similar to that of local spirals, and an order of magnitude lower than that in sub-millimetre galaxies. This suggests a CO to total gas conversion factor similar to local spirals, gas consumption timescales approaching 1 Gyr or longer, and molecular gas masses reaching 10^{11} $M_\odot$, comparable to or larger than the estimated stellar masses. These results support a major role of *in situ* gas consumption over cosmological timescales and with relatively low star formation efficiency, analogous to that of local spiral disks, for the formation of present-day most massive galaxies and their central black holes. Given the high space density of similar galaxies, 10^{-4} Mpc^{-3} , this implies a wide-spread presence of gas-rich galaxies in the early universe, many of which might be within reach of detailed investigations of current and planned facilities.

Multiwavelength study of massive galaxies at $z \sim 2$

Ravindranath and collaborators are involved in a detailed study of different properties of massive galaxies at high redshift. Approximately 20 – 30% of galaxies with $K_{Vega} < 22$ detected with Spitzer

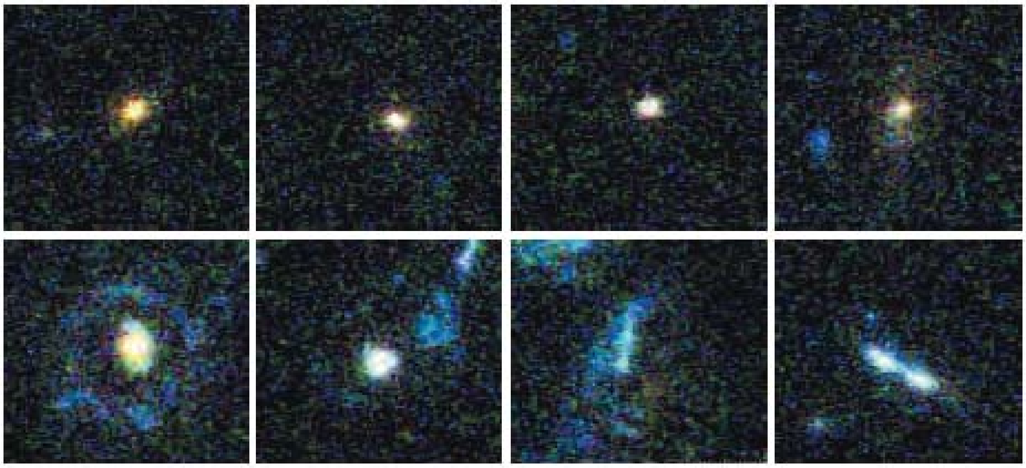

Figure 6: The HST ACS V, i, z color−composite images of the BzK galaxies at $z \sim 2$ from the GOODS ACS Treasury Programme. *Upper Panel:* These are galaxies with SEDs of a passively evolving stellar population, and have morphology typical of spheroidal galaxies in the local universe. However, they are about three times more compact, and have stellar mass densities about 10 times that of local ellipticals of similar mass. *Lower Panel:* The star-forming BzKs have bluer colours, lower stellar masses, and their morphology is more fragmented or distorted and resemble the irregular galaxies seen locally

.

MIPS at 24 μm show excess mid-IR emission relative to that expected based on the rates of star formation measured from other multiwavelength data. These galaxies also display some near-IR excess in Spitzer IRAC data, with an SED peaking longward of 1.6 μm in the rest frame, indicating the presence of warm dust emission usually absent in star-forming galaxies. Stacking Chandra data for the mid-IR excess galaxies yields a significant hard X-ray detection at rest-frame energies > 6.2 keV. The stacked X-ray spectrum rises steeply at >10 keV, suggesting that these sources host Compton-thick AGNs with column densities $N_{HI} \geq 10^{24}$ cm^{-2}, and an average, unobscured X-ray luminosity $L_{(2-8KeV)} \sim (1-4) \times 10^{43}$ erg s^{-1}. Their sky density (3200 deg^{-2}) and space density ($\sim 2.6 \times 10^{-4}$ Mpc^{3}) are twice those of X-ray-detected AGNs at $z = 2$, and much larger than those of previously known Compton-thick sources at similar redshifts. The mid-IR excess galaxies are part of the long sought after population of distant heavily obscured AGNs predicted by synthesis models of the X-ray background. The fraction of mid-IR excess objects increases with galaxy mass, reaching ∼ 50 - 60% for $M \sim 10^{11} M_{\odot}$, an effect likely connected with downsizing in galaxy formation. The ratio of the inferred black hole growth rate from these Compton-thick sources to the global star formation rate at $z = 2$ is similar to the mass ratio of black holes to stars in local spheroids, implying concurrent growth of both within the precursors of present–day massive galaxies.

TFIT: A photometry package using prior information for mixed-resolution data sets:

Ravindranath and collaborators describe the TFIT software package to measure galaxy photometry using prior information from high-resolution observations. The basic methodology is similar in principle but different in detail from previous procedures for crowded field photometry. They use the spatial positions and morphologies of objects in an image with higher angular resolution to construct object templates, which are then fitted to a lower resolution image, solving for the object fluxes as free parameters. Using extensive experiments on both simulated and real data, they showed that this template-fitting method measures accurate object photometry to the limiting sensitivity of the image. In this limit, their method derives robust flux upper limits for objects fainter than the limiting image surface brightness. They also describe the challenges encountered in applying this technique to real data, and methods to cope with some of them.

Morphological diversities among the BzK-selected galaxies at $z \sim 2$:

Ravindranath and collaborators have used the BzK-selection to identify a composite population of passive, and star-forming galaxies at redshifts $1.4 \leq z \leq 2.5$ from the Great Observatories Origins Deep Survey (GOODS). Using an unprecedented large sample of galaxies in this redshift range, they characterized the morphological diversity through the analysis of the surface-brightness profile shapes for 171 galaxies with passive SEDs, and 1068 star-forming galaxies. They find that the $z \sim 2$ galaxies show a wide range of morphologies, from spheroidals to disk-like. (see Figure 6). Interestingly, the galaxies with passively-evolving SEDs predominantly have steep profiles as seen for the classical bulges at low redshifts, although they are very compact with $r_e < 3$ kpc. Given that these galaxies already have the masses close to present-day ellipticals, and already harbour an old stellar population at $z = 2$, it is difficult to understand how they would have grown to their present sizes, without significant mass accumulation. The evolution via "dry mergers" seems to be a plausible mechanism, provided an increase in size of a factor of a few is achieved in a single merger. The star-forming galaxies, on the other hand, exhibit mostly disk-like and merger morphologies, and have sizes comparable to their low$-z$ counterparts. Many earlier studies based on various selection methods with a bias toward star-forming galaxies have essentially claimed that the $z = 2$ population is predominantly disks or irregulars. Our results emphasize the need for an unbiased selection in order to reveal the morphological diversities, and range of galaxy properties at high redshifts.

Probing the nature of a 300 kpc scale radio-halo in a distant galaxy cluster MRC 0116+111: a non-thermal laboratory

Apart from unknown dark-matter, the diffuse intracluster medium (ICM) has two other main baryonic constituents: the commonly observed Bremsstrahlung emitting hot ($T \sim 10^{7-8}$ K), tenuous ($n_0 \sim 10^{-(3-4)}$ cm^{-3}) thermal gas, and a difficult to observe population of extremely high energy relativistic particles (AKA 'cosmic rays': $e^{\pm}, P^{+}, \pi^{\pm/0}, \nu, \gamma$-rays, etc.) of largely unknown origin. In addition, a small fraction of galaxy clusters exhibit large-scale diffuse radio sources, which have no optical counterparts and no obvious connection to the galaxies in clusters, and are therefore believed to be synchrotron emission from electron/positrons of $\sim$ *GeV* energies in $\sim \mu$G magnetic fields, associated with the ICM. Diffuse radio emission from galaxy clusters is very rare phenomenon. These radio sources, which usually possess large sizes ($0.1 - 1$ Mpc) and steep spectra ($\alpha \sim 1 - 3$), are called radio halos if they permeate the cluster centres and radio relics, if they are located in cluster peripheral regions. Observations found that radio halos exist only in the clusters that show X-ray sub-structures. Since a galaxy cluster having X-ray sub-structures indicates that it is under ongoing merging, it is likely that the origin of radio halos is closely related to the merging process of galaxy clusters.

Other than these clues, the exact process, which generates radio-halos is still unknown. The properties of large-scale radio halos and relics are poorly known, also because of the present observational limits. Due to synchrotron and inverse Compton losses, the typical lifetime of the relativistic electrons in the ICM is relatively short ($\sim 10^8$ yr), making it difficult for the electrons to diffuse over a Mpc-scale region within their radiative lifetime. The expected diffusion velocity of the electron population is indeed of the order of the Alfven speed, ~ 100 km/s. Because radio-halo sources extend throughout the cluster volume, their electrons cannot be injected or reaccelerated in some localized points of the cluster, such as an active galaxy or a shock, but they need global in situ reacceleration mechanism.

J. Bagchi and collaborators have studied a 300 kpc scale radio halo discovered serendipitously at the centre of a relatively poor cluster/group of galaxies MRC 0116+111 (at redshift z=0.13). They obtained multifrequency GMRT radio data at 240, 610 and 1300 MHz, as well as imaged the host cluster/group of galaxies with the newly commissioned 2 m optical telescope at the IUCAA Girawali Observatory. The radio and optical images of this radio-halo are shown in Figure 7. The GMRT map shows many of the characteristics of a 'classical' radio-halo, e.g., diffuse radio emission of quite low surface brightness ($\lesssim 1$ mJy/beam), location near the cluster centre but permeating across a vast $\sim$ Mpc-scale region, no definite identification with any galaxy which might belong to the cluster, and a peculiar radio structure of uncertain origin (lacking radio jets or lobes). Our detection of a new radio-halo source is very significant as radio-halos are very rare and complex phenomenon, having only 16 Mpc-scale examples known so far. Smaller scale (~ 100 kpc) mini radio-halos near giant cD galaxies are even more rarer with only a few examples known so far. Significantly, the mini radio halos are only observed at the centers of cooling-flows, where a giant cD galaxy is usually found, which indicates a significant feed-back/interaction between the central radio source and the cooling/heating processes inside the ICM.

Thus, it is clear that detailed observations of radio galaxies and radio-halos at the focus of cooling flows are very powerful probes of the physics of radio galaxy/ICM feedback process. Spectacular examples of this feedback are the radio lobe inflated 'cavities' with diameter ranging from 1-100 kpc which have been found in the hot gas surrounding nearly 20 galaxies, groups and clusters. In a few cases, the energy involved is $\sim 10^{60-62}$ erg, which is the most powerful radio outbursts known. The radio lobes fill the cavities, which suggests that expanding jets have filled and displaced the ICM gas, leading to cavities and possibly sending shock/sound waves in the surrounding medium, which provides a source of extra energy, which might heat up the ICM significantly. X-ray observations are essential probes for such processes in MRC 0016+111. A proposal was submitted with the *Chandra* X-ray observatory with an aim to detect the non-thermal (inverse-Compton on the CMBR) and thermal Bremsstrahlung emission from the intracluster gas associated with the galaxy group harbouring the MRC 0016+111 mini radio halo. The proposal involves *Bagchi*, in collaboration with SRON (Utrecht, Netherlands), Stanford University, IAP Paris and the Max Planck Institute, Germany.

Active Galactic Nuclei, Quasars and IGM

Warm absorbers in AGN

Absorption due to highly ionized oxygen and elements of similar atomic number (e.g., O VII, VIII, Ne X) is commonly found in the soft X-ray spectra of active galactic nuclei (AGNs), and are caused by partially ionized optically thin gas along the line of sight to the centre of the AGN. The typical temperature, ionization parameter and column density of these systems are $T \sim 10^5$ K, $\xi = L/nR^2 \sim 100$ erg cm s^{-1} and $N_{\rm H} \sim 10^{22\pm1}$ cm^{-2}, 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. *Susmita Chakravorty* and *Ajit Kembhavi* with collaborators Martin Elvis (CFA, Harvard University, USA) and Gary Ferland (Kentucky University, USA) are studying the thermal properties of the warm absorber.

The effect of various factors on the warm absorber can be studied conveniently using the stability curve of temperature (T) against the ratio of ionization parameter to T. Gas lying off the stability curve will cool or heat until reaching the curve. The temperature range, $5 < \log T < 7$, in the

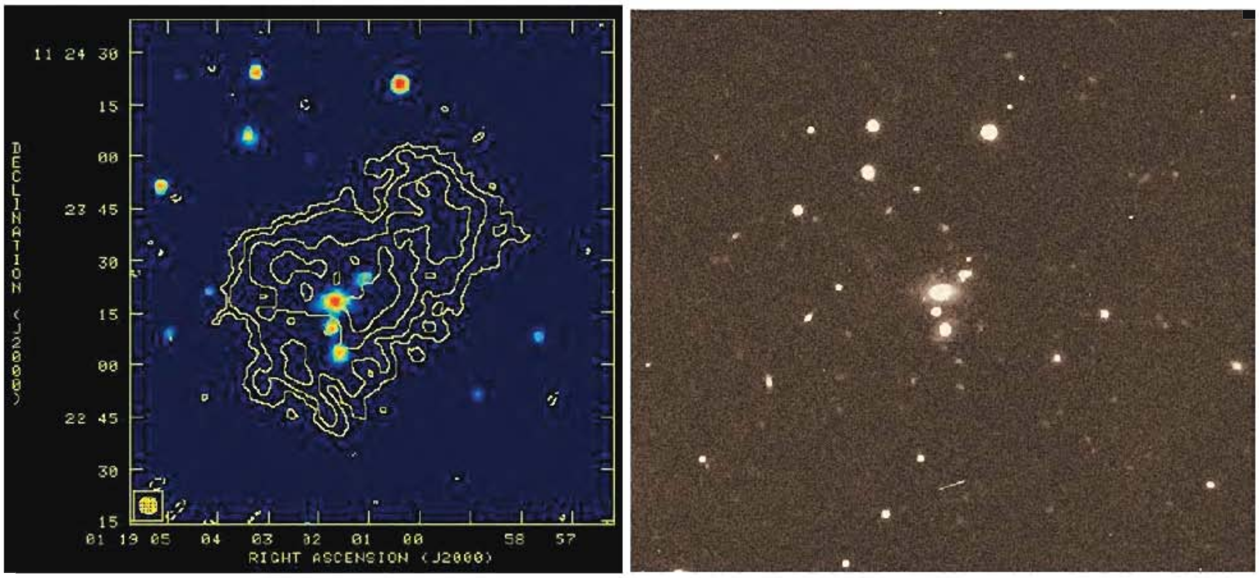

Figure 7: The extended, diffuse radio-halo type source, discovered using GMRT and the 2 meter IUCAA Girawali Observatory optical telescope in the central region of the galaxy group MRC 0116+11 (z = 0.13). The radio emission from the diffuse halo is shown with contours (**left**), superposed on the optical image of the 3 central galaxies. This 300 kpc scale radio structure was mapped by the GMRT telescope at 1.3 GHz frequency (at 5 arcsec FWHM resolution). The optical V-filter image of the group taken with the IUCAA telescope is shown on the (**right**). Neither a compact radio core (AGN) nor radio jets or lobes is detected, which shows that MRC 0116+11 is a true radio-halo source and not an active radio galaxy.

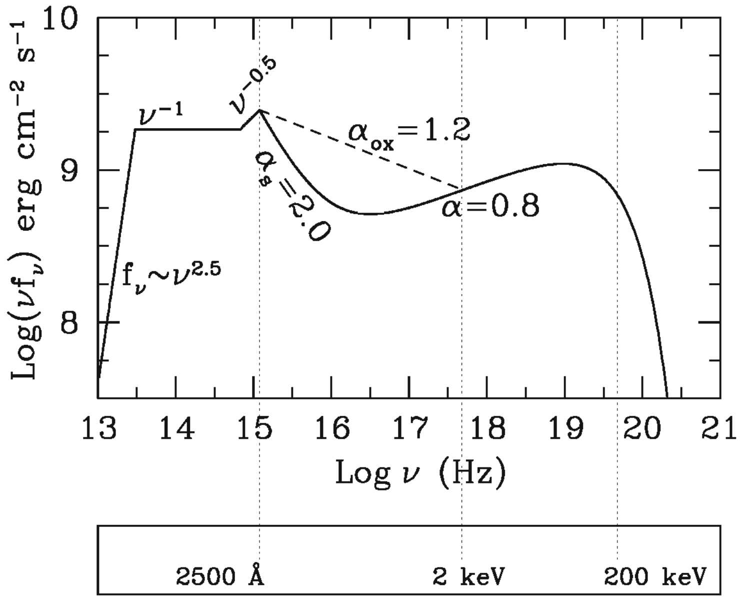

Figure 8: Form of the ionizing continuum irradiating the warm absorber

stability curve corresponds to the warm absorber. If the curve has kinks, that produce multiple stable values at fixed ξ/T, then the warm absorber can have multiple thermal states in mutual equilibrium. Such an investigation is interesting, because the recent high resolution X-ray spectroscopic data suggest absorbing systems at higher temperatures $\sim 10^6$ K, in addition to the presence of the $\sim 10^5$ K component. A systematic investigation is carried out by them to note the changes in the nature of the stability curves and hence, the warm absorber as a function of various physical parameters, viz. the ionizing continuum irradiating the gas and the chemical composition of the absorber.

Figure 8 shows the spectral energy distribution (SED) of the continuum ionizing the warm absorber. At energies greater than $2500A$, the SED is constructed by adding two powerlaws $f_\nu \sim \nu^{-\alpha}$ and $f_\nu \sim \nu^{-\alpha_s}$ with appropriate relative normalisation to attain $\alpha_{ox} = 1.2$, where α_{ox} gives the slope of the join between $2500A$ and 2 keV. The ionizing continuum is exponentially cut-off at 200 keV and at energies lower than $2500A$, it is cut-off using successive components having functional forms $f_\nu \sim \nu^{-0.5}, \nu^{-1.0}$ and $\nu^{2.5}$. Changing the values of α and α_{ox}, the shape of the ionizing continuum is varied and the effects on a solar metallicity warm absorber is shown in the top panels of Figure 9. The left panel shows the changes in the nature of the stability curve with the variation of α and the right panel shows that with the variation in α_{ox}. The warm absorber phases are highlighted with thicker lines.

The nature of the interaction between gas and radiation in the temperature range, $5 < \log T < 7$, relevant for warm absorbers is significantly influenced by the atomic physics of the heavier elements. Optical and ultraviolet emission and absorption line studies suggest that central regions of AGN have solar or higher metallicities. The effect of super-solar abundance of the absorbing gas, is shown in the middle left panel of Figure 9. Although, gas in AGN have super-solar metallicity, however, radiation from AGN also illuminate low density gas on large scales, which has low sub-solar abundances, especially at high redshift. It is, there-

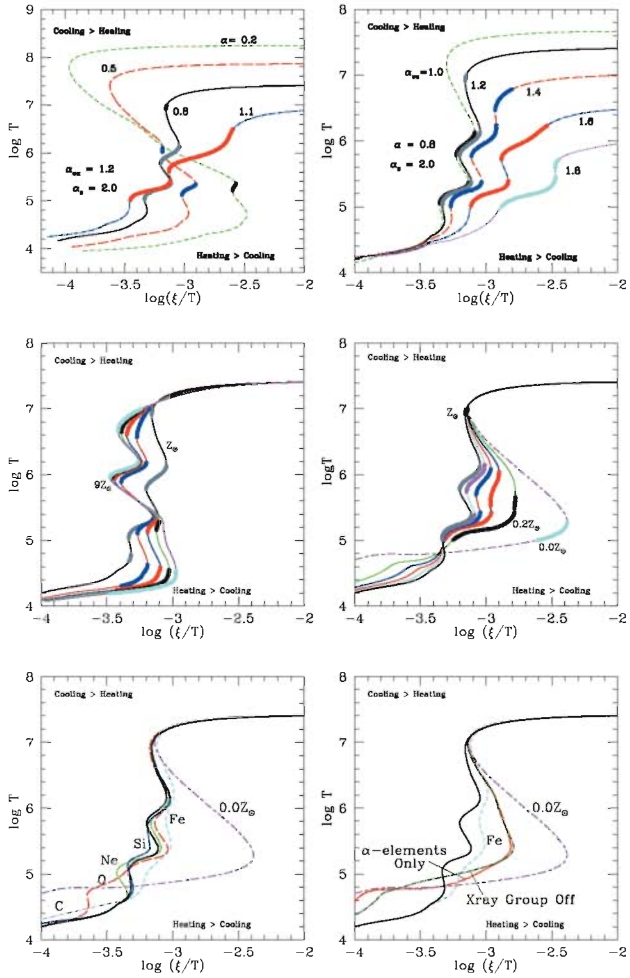

Figure 9: Stability curves as a function of ionizing continuum irradiating the warm absorber and chemical composition of the absorbing gas.

fore, interesting to examine the effects of sub-solar abundance, as shown in the middle right panel. Interaction between gas and radiation is sensitive to the ionization potentials of various ions of elements like C, O, Fe and Ne indicating that the warm absorber states are likely to be affected not only by the overall abundance of the absorber, but also by specific elements and groups of elements. The effect of removing individual elements, which have significant effect are shown in the bottom left panel, whereas, the bottom right panel demonstrates the influence of two specific groups of elements, viz. if X-ray group (C, O, Fe and Ne,) is absent in the chemical composition and if the only metals present are the α-elements (Ne, Mg, Si, S, Ar, Ca, Ti). For all the stability curve analysis done for the various abundances of the absorber, we have used the continuum shown in Figure 8. The trends observed from this extensive systematic study are summarised below:

If the X-ray spectral index, α, of the ionizing continuum intervening gas of solar metallicity is flat with $\alpha \sim 0.2$, then the AGN cannot have a warm absorber.

A multiphase nature of the warm absorber is seen only for $\alpha \sim 0.8$. It is an interesting coincidence that most of the observed quasars also have soft X-ray slopes similar to $\alpha \sim 0.8$.

If the ionization continuum becomes even steeper, then, instead of discrete phases, the absorbing gas exhibits a continuous distribution of ξ/T and T.

The chemical composition of the absorbing medium plays a critical role in determining its multiphase nature.

The higher the metallicity of the medium, the greater is the probability of a multiphase parameter space.

Investigating the role of the individual elements, it is found that iron, which is formed from type Ia supernovae no earlier than 1 Gyr, plays the most important role as a heating agent at higher temperatures ($\geq 10^5$ K), while oxygen is a significant cooling agent for $T \leq 10^5$ K.

The X-ray group (C, Ne, O, Fe), understandably, has significant influences, because the constituent elements are the ones which have important atomic transitions in the energy range relevant for warm absorbers ($0.3 - 1.5$ keV).

If the absorber is over abundant in iron, oxygen or in the X-ray group of elements, then the absorbing medium is likely to be multiphase.

A very interesting result seems to suggest itself from the study of influence of α-elements (Ne, Mg, Si, S, Ar, Ca, Ti), which are the first metals formed in the universe along with oxygen through the supernovae of type II. The thermal properties of the warm absorber change drastically from the time when the absorbing gas is essentially constituted of only α-elements as metals to the time when the absorber is enriched enough to have the whole X-ray group included in its chemical composition.

It is also observed that zero metal abundance gas does not produce warm absorbers in AGN.

When super-solar metallicities are concerned, the stability curve shows a 10^4 K stable state in pressure equilibrium with the warm absorber stable phases. This might imply some connection between the warm absorbers and the clouds in the broad emission line regions. In this work, broken power-laws have been used to define the ionizing continuum for the absorbing gas. However, the soft excess in ultraviolet is often modeled using blackbody components, which peak at $T \sim 150$ eV. Moreover the continuum spectra of AGN also has the disk blackbody component at $20\,\text{eV} \lesssim T \lesssim 30\,\text{eV}$. Detailed investigations addressing these issues are planned to be taken up in near future.

Molecular hydrogen and physical conditions in the high-z DLAs

R. Srianand (with Patrick Petitjean, Cedric Ledoux and Pasquier Noterdaeme) has been involved in large survey of molecular hydrogen in high-z DLAs. They have completed an extensive survey of molecular hydrogen in high-redshift ($1.8 < z_{\rm abs} \leq 4.2$) damped Lyman-$\alpha$ systems (DLAs) capitalising on observations performed with the ESO Very Large Telescope (VLT) Ultraviolet and Visual Echelle Spectrograph (UVES).

They gathered a total sample of 77

DLAs/strong sub-DLAs, with log $N(\text{H I}) \geq 20$ and $z_{\text{abs}} > 1.8$, for which the wavelength range where corresponding H_2 Lyman and/or Werner-band absorption lines are expected to be redshifted is covered by UVES observations of the quasars. This sample of HI, H_2 and metal line measurements, performed in an homogeneous manner, is more than twice as large as our previous sample (Ledoux et al. 2003) and considers every system searched for H_2 so far including all non-detections.

H_2 is detected in thirteen of the systems with molecular fractions as low as $f \simeq 5\times10^{-7}$ up to $f \simeq 0.1$, with $f = 2N(H_2)/(2N(H_2) + N(\text{HI}))$. Upper limits are measured for the remaining 64 systems with detection limits of typically log $N(H_2) \sim 14.3$, corresponding to log $f < -5$. We find that about 35% of the DLAs with metallicities relative to solar $[\text{X/H}] \geq -1.3$ (i.e., $1/20^{\text{th}}$ solar), with X = Zn, S or Si, have molecular fractions log $f > -4.5$, while H_2 is detected – regardless of the molecular fraction – in $\sim$ 50% of them. On the contrary, only about 4% of the $[\text{X/H}] < -1.3$ DLAs have log $f > -4.5$. They showed that the presence of H_2 did not strongly depend on the total neutral hydrogen column density, although the probability of finding log $f > -4.5$ was higher for log $N(\text{HI}) \geq 20.8$ than below this limit (19% and 7% respectively). The overall H_2 detection rate in log $N(\text{HI}) \geq 20$ DLAs is found to be about 16% (10% considering only log $f > -4.5$ detections) after correction for a slight bias towards large N(HI).There is a strong preference for H_2-bearing DLAs to have significant depletion factors, $[\text{X/Fe}] > 0.4$. In addition, all H_2-bearing DLAs have column densities of iron into dust larger than log $N(\text{Fe})_{\text{dust}} \sim 14.7$, and about 40% of the DLAs above this limit have detected H_2 lines with log $f > -4.5$. This demonstrates the importance of dust in governing the detectability of H_2 in DLAs. In this expanded dataset, unlike small number statistics previously seemed to suggest, there is no evolution with redshift of the fraction of H_2-bearing DLAs nor of the molecular fraction in systems with detected H_2 over the range $1.8 < z_{\text{abs}} < 4.3$.

The QSO spectra obtained in their H_2 have been used for studying various other issues related to DLAs. A brief summary is given below:

High ionization outflow probed by O IV and C IV are common in DLAs, as typically seen in Lyman break galaxies. They show that on an average, hot and warm phase traced by these species contains 40% and 20% of the baryonic mass in the DLAs and could contribute significantly to the metal budget of the universe. Most of the absorption could be associated with winds from DLAs. A typical SFR of few $M_\odot$ per year is needed to power the outflow.

In the case of HE 0027−1836, they found the kinetic energy derived from the Doppler parameters is linearly related to the energy of the rotational levels. This can be understood as a presence of C-Shocks in the molecular gas (Noterdaeme et al. 2007, A&A, 474, 393).

They studied the [O/N] in a sub-sample of DLAs, and found that the distribution of the [N/O] abundance ratio, measured from components that are detected in both species, is somehow double peaked: five systems have $[\text{N/O}] > -1$ and nine systems have $[\text{N/O}] < -1.15$. In the diagram [N/O] versus [O/H], a loose plateau is possibly present at $[\text{N/O}] \sim -0.9$, which is below the so-called primary plateau as seen in local metal-poor dwarf galaxies ([N/O] in the range −0.57 to −0.74). No system is seen above this primary plateau, whereas, the majority of the systems lie well below with a large scatter. All this suggests a picture, in which DLAs undergo successive star-bursts. During such an episode, the [N/O] ratio decreases sharply because of the rapid release of oxygen by massive stars, whereas in between two bursts, nitrogen is released by low and intermediate-mass stars with a delay and the [N/O] ratio increases[Petitjean, Ledoux and *Srianand*, 2008, A&A, 480, 349].

First detection of CO in a high-redshift damped Lyman-α system

Srianand and his collaborators (Pasquier Noterdaeme, Patrick Petitjean and Cedirc Ledoux) noticed a strong preference for H_2-bearing DLAs to be associated with C I absorption and to have high metallicities and large depletion factors. Using these criteria they selected H_2-bearing DLA

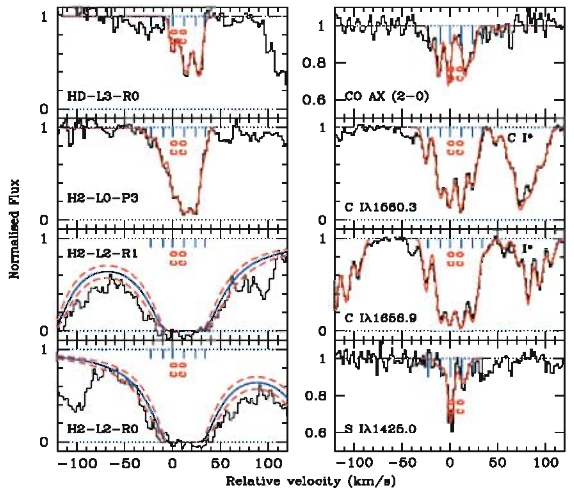

Figure 10: A sample of molecular and heavy element absorption lines associated with the damped Lyman-α system toward SDSS J143912.04+111740.5. The normalized flux is given on a velocity scale with the origin at $z_{\rm abs} = 2.41837$. Smooth curves in each panel show our Voigt profile fits to the data. The dashed profiles shown for J $\leq$ 1 H_2 lines are the 1σ ranges. Ticks in each panel indicate the locations of the 6 components that are used to fit the J = 3 H_2 absorption lines. The symbol "CO" marks the locations of two components detected in S I and CO.

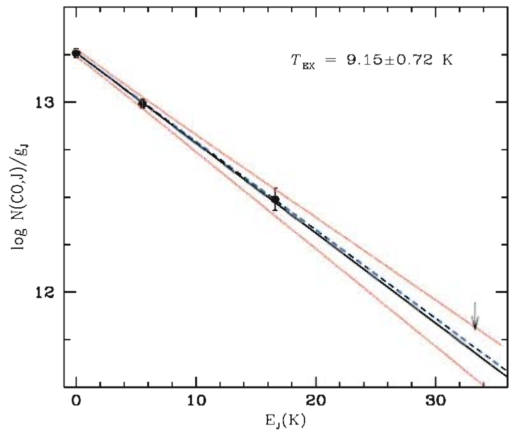

Figure 11: The CO excitation diagram. A straight line with slope $1/(T_{\rm ex} \ln 10)$ indicates thermalization of the levels. The diagram is given for the main CO component at $z_{\rm abs} = 2.41837$. The three lines give the mean and 1σ range obtained from T_{01}, T_{02} and T_{12}. The diagram is compatible with thermalization by a black-body radiation of temperature 9.15±0.72 K when $T_{\rm CMBR} = 9.315 \pm 0.007$ K (long dashed line) is expected at $z_{\rm abs} = 2.4185$ from the hot Big-Bang theory.

candidates from the Sloan Digital Sky Survey. They identified a most promising candidate at $z_{\rm abs} = 2.4185$ towards SDSS J143912.04+111740.5 and were allocated 8 hours of Director Discretionary Time on the Ultraviolet and Visual Echelle Spectrograph (UVES) at the VLT of the European Southern Observatory (ESO), during March 21−25, 2007, to search for CO in addition to H_2. This observation has resulted in the detection of CO UV absorption lines that were elusive for more than 25 years. They also detect H_2 and HD absorption lines (Figure 10).

They measure $N(\mathrm{CO})/N(\mathrm{H_2}) = 3\times10^{-6}$. This is similar or slightly higher to what is measured along, respectively, galactic sightlines with similar molecular fraction and along galactic sightlines with similar $N(\mathrm{H_2})$ (see figures 4 and 5 of Burgh et al. 2007). This is in any case much less than the CO/H_2 ratio of about 10^{-4} derived for dense molecular clouds. This strongly suggests that the physical conditions in the gas are similar to that in the diffuse galactic ISM.

The excitation temperatures derived from the population ratios of the different rotational levels are $T_{01} = 9.11 \pm 1.23$ K, $T_{12} = 9.19 \pm 1.21$ K and $T_{02} = 9.16 \pm 0.77$ K for the main component, where the errors come from the fitting uncertainties. Additional rms deviations come from uncertainties in the continuum placement and from the allowed range for the Doppler parameter of the second component. They estimate these to be ~ 0.21, ~ 0.37 and ~ 0.18 K respectively around the three excitation temperatures. The populations of the three rotational levels are, thus, consistent with a single excitation temperature, $T_{\rm ex} = 9.15 \pm 0.72$ K (see Figure 11) suggesting that a single mechanism controls the level populations.

They ran the statistical equilibrium radiative transfer code RADEX, available on line (van der Tak et al. 2007), and found that for the kinetic temperature, $T = 105$ K, derived from H_2, the collisional contributions to T_{01} and T_{12} are $\leq 5\%$ and $\leq 2\%$ for $n_{H_2} \leq 25$ cm^{-3}. The corresponding values are $\leq 3\%$ and $\leq 1\%$ for $n_{H_2} \leq 12$ cm^{-3}. Thus, the collisional excitation of CO by H_2 is negligible. Collisions with H contribute little to the CO excitation compared to collisions with H_2 in astrophysical conditions. This means that the CO excitation is dominated by CMBR and we conclude that $T_{ex} = T_{CMBR} = 9.15 \pm 0.72$K.

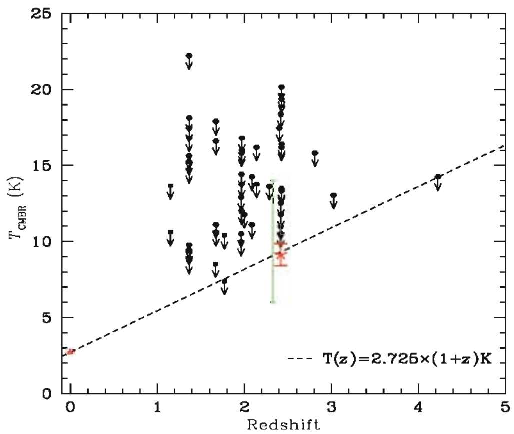

Figure 12: Measurements of T (CMBR) at various z. The star with error-bars is for the measurement based on CO presented here. Our earlier measurement using fine-structure lines of neutral carbon, $6.0 < T_{CMBR} < 14.0$ K, at z = 2.33771 is indicated by the long vertical bar (*Srianand* et al. 2000). Upper limits are measurements using C I from the literature (squares) and our UVES sample (hexagons). The dashed line is the prediction from the hot big bang theory, $T_{CMBR}(z) = T_{CMBR}\ (z = 0) \times (1 + z)$. T_{CMBR} measurement at $z = 0$ is based on the COBE determination (Mather et al. 1999).

The CMBR is an important source of excitation of species with transitions in the submillimetre range. This is the case of atomic species, whose ground state splits into several fine-structure levels and of molecules that can be excited in their rotational levels. If the relative level populations are thermalized by the CMBR, then the excitation temperature gives the temperature of the blackbody radiation. It has been proposed for long to measure the relative populations of such atomic levels in quasar absorption lines to derive T_{CMBR} at high redshift. Most of the measurements of C I fine-structure excitation led to upper limits on T_{CMBR}, however, as the excitation by collisions dominates. Only one lower limit was obtained in a particularly favourable case leading to $7 < T_{CMBR} < 13.5$ K at $z_{abs} = 2.337$. The CN molecule has proven to be a remarkable thermometer of the CMBR in our galaxy, as its rotational excitation is dominated by the CMBR. It has been used for precise measurement of T_{CMBR} in different directions. CO in diffuse gas provides an interesting possibility for mesurements at high redshift as the rotational energies between different rotational levels are close to T_{CMBR} at $z \geq 1$.

In Figure 12 they combine their precise measurement of T_{CMBR} together with 51 new upper limits obtained using C I and C I* absorption lines detected towards QSOs in their UVES sample and 5 measurements from the literature. Upper limits are obtained assuming CMBR as the only source for excitation. Their precise measurements using CO and the new upper limits using C I are consistent with the adiabatic evolution of T_{CMBR} expected in the standard big-bang model (dotted line in Figure 12).

Constrained semi-analytical models of galactic outflows

The rapid growth of observations of the high redshift universe has raised several intriguing questions regarding the physics of galaxy formation and the physical state of the intergalactic medium (IGM). Some of the important issues are: how and when the dark ages ended with the reionization of the IGM, the origin of the metals, and temperature of the low density IGM traced by Lyman-α forest at $z \simeq 2.5$. *S. Samui, K. Subramanian,* and *Srianand* have examined in some detail the issue of IGM metal enrichment.

The metals detected in the IGM can only have been synthesized by stars in galaxies, and galactic outflows are the primary means by which they can be transported from galaxies into the IGM. The mechanical energy that drives such outflows may arise either from an active galactic nuclei (AGN) in the galaxy or from the supernovae (SNe) explosions associated with the star formation activities in the galaxy. They have focused on the effects of the star formation activity and the resulting SNe in high redshift protogalaxies. The star formation activity is itself constrained by fitting the observed high-z UV luminosity functions, that we did in an earlier work.

Thus, they examine semi-analytic models of galactic outflows that are constrained by available observations on high redshift star formation and reionization. Galactic outflows are modeled in a manner akin to models of stellar wind blown bubbles. They find that large scale outflows can generically escape from low mass halos ($M < 10^9\ M_\odot$) for a wide range of model parameters while this is not the case in high mass halos ($M > 10^{11}\ M_\odot$). The flow generically accelerates within the halo virial radius, then starts to decelerate, and traverses well into the inter galactic medium (IGM), before freezing to the Hubble flow. The acceleration phase can result in shell fragmentation due to the Rayleigh-Taylor instability, although the final outflow radius is not significantly altered. The gas phase metallicity of the outflow and within the galaxy are computed assuming uniform instantaneous mixing. Ionization states of different metal species are calculated and used to examine the detectability of metal lines from the outflows.

The global influence of galactic outflows is also investigated using porosity weighted averages and probability density functions of various physical quantities. Models with only atomic cooled halos significantly fill the IGM at $z \sim 3$ with metals (with $-2.5 > [Z/Z_\odot] > -3.7$), the actual extent depending on the efficiency of winds, the initial mass function (IMF) and the fractional mass that goes through star formation. The reionization history has a significant effect on the volume filling factor, due to radiative feedback. In these models, a large fraction of outflows at $z \sim 3$ are supersonic, hot ($T \geq 10^5$K) and have low density, making metal lines difficult to detect. They may also result in significant perturbations in the IGM gas on scales probed by the Lyman-α forest. On the contrary, models including molecular cooled halos with a normal mode of star formation can potentially volume fill the universe at $z \geq 8$ without drastic dynamic effects on the IGM, thereby setting up a possible metallicity floor ($-4.0 \leq [Z/Z_\odot] \leq -3.6$). The order unity fluctuations at $z \sim 8$ that becomes the mildly non-linear fluctuations traced by Lyman-α forest at $z < 4$ will then have this metallicity. Interestingly, molecular cooled halos with a "top-heavy" mode of star formation are not very successful in establishing the metallicity floor, because of the additional radiative feedback, that they induce.

Radio galaxies: Magnetic fields and spectral ages

Astronomers still do not know whether radio lobes contain electron-protron plasma or electron-positron plasma; if it is electron-protron plasma, then whether protrons are energetically dominant or not. So depending upon how one can take care of the contribution of the protrons into the total kinetic energy of the particles, there are two different formalisms for estimating equi-partition magnetic fields in the synchrotron emitting regions. One is classical formalism and the other is called the revised formalism. *Chiranjib Konar* and his collaborators have found that when the magnetic field values are low, which is the case for giant radio sources (GRSs), the estimated magnetic field from revised formalism is higher than that from the classical formalism by only a factor of 3 and not by an order of magnitude. This variation does not statistically affect the estimates of synchrotron ages very much for GRSs.

The sizes of radio sources range from less than a few tens of pc for giga-Hertz peaked spectrum (GPS) sources to a few Mpc for GRSs. GRSs are defined to be those with a projected linear size greater than equal to 1 Mpc. The limit of 1 Mpc is merely for convenience, as there is a continuity in the sizes of radio sources. It is widely believed that the double-lobed radio sources evolve from the most compact GPS sources (a few tens of pc) to the compact steep spectrum (CSS, less than 10 kpc) sources and then to the normal-sized (a few hundred kpc) radio source before evolving to form the GRSs. The radio power-linear size or P-D diagram for the 3CR and giant sources shows a deficit of sources with radio luminosity greater than about 2×10^{27} W Hz^{-1} at 1.4 GHz and sizes over a Mpc. Such a trend, where the luminosity decreases as the source ages is broadly consistent with the models of evolution of radio sources. GRSs are usually found in regions of low galaxy density at least in the nearby universe. It has been suggested in the literature that a low density intergalactic medium (IGM) and/or a more powerful central engine may help the formation of these giant structures. However, recent studies have not found any significant evidence for the GRSs to have more prominent radio cores compared with smaller radio sources of similar luminosity. The large sizes are perhaps a combination of large ages and a low density external environment through which the jets propagate. In an investigation, *Konar* and his collaborators have conducted multifrequency observations with the Giant Metrewave Radio Telescope (GMRT) and the Very Large Array (VLA) of a sample of selected GRSs to estimate their spectral ages. The maximum spectral ages estimated for the detected radio emission in the lobes of their sources range from 6 to 46 Myr with a median value of 23 Myr, using the classical equi-partition magnetic fields. Using the magnetic field estimates from the revised formalism, the spectral ages range from 5 to 58 Myr with a median value of 24 Myr. These ages are significantly older than smaller sources. This work provides a strong evidence that the GRSs are of such large sizes mainly because of their older ages. Strong central engines may also be the reason of their such large sizes but do not seem to be the only reason. The spectral age gradually increases with distance from the hotspot regions, confirming that acceleration of the particles mainly occurs in the hotspots.

Episodic activity in radio galaxies

One of the important issues concerning galaxies is the duration of their AGN phase and whether such periods of activity are episodic. In the currently widely accepted paradigm, activity is believed to be intimately related to the 'feeding' of a supermassive black hole, whose mass ranges from $\sim10^6$ to 10^{10} solar mass. Such an active phase may be recurrent with an average total timescale of the active phases being $\sim10^8$ to 10^9 yr. One of the more striking examples of episodic jet activity is when a new pair of radio lobes is seen closer to the nucleus before the 'old' and more distant pair of radio lobes have faded. Such sources have been christened as DDRGs by Schoenmakers et al. In such sources, the newly-formed jets propagate outwards through the cocoon formed by the earlier cycle of activity rather than the general intergalactic or intracluster medium, after traversing through the interstellar medium of the host galaxy. Approximately, a dozen or so of such DDRGs, are known in the literature. It is important to identify more DDRGs not only for understanding episodic jet activity and examining their time scales, but also for studying the propagation of jets in different media. *Konar* and his collaborators are searching for new such objects and studying a few candidates, which are actually showing the signs of episodic activity. There has been three cases so far in the literature, where it has been found that the injection spectral indices of the lobes for two different episodes of activity are similar. They are presently investigating observationally whether such a phenomenon is universal.

Magentic Fields in Astrophysics

Kinematic alpha effect in isotropic turbulence simulations

The generation and maintenance of large-scale magnetic fields in stars and galaxies is often studied within the framework of the mean-field dynamo (MFD). A particularly important driver of MFDs is the α-effect. For isotropic turbulence and weak magnetic fields, i.e., in the kinematic regime, the α-effect can be expressed purely in terms of the kinetic helicity. Research in recent years has mostly been concerned with clarifying the effects of nonlinearity, but there are serious uncertainties even in the linear (kinematic) regime. In particular, whether or not α can then be expressed in terms of the kinetic helicity, depends on the applicability of the first order smoothing approximation (FOSA) or other closures used to calculate α. Such approaches become questionable when the magnetic Reynolds number, R_m, is large, i.e., when the magnetic diffusion time is long compared with the turnover time, which, in turn, is comparable with the correlation time of the turbulence. Furthermore, high R_m random flows typically lead to a fluctuation dynamo, which leads to rapidly growing small-scale magnetic fields independent of the mean field. This also breaks the assumption made by FOSA that fluctuating fields are much smaller than the mean field.

The existence of α-effect and turbulent diffusion has been worrying dynamo researchers over several decades. Recently, based on specific imposed (kinematic) flow patterns, it has been suggested that there is no simple relation between α and helicity of the flow. It is, therefore, important to examine this issue in some detail. In order to clarify the R_m dependence in the kinematic regime, *K. Subramanian* and collaborators (*S. Sur*, A. Brandenburg) have performed numerical turbulence experiments, where they adopt an externally imposed body force to drive the flow. This is a common technique applied in simulations and helps to develop homogeneous and isotropic turbulence, which is easier to handle analytically.

Using such numerical simulations at moderate magnetic Reynolds numbers up to 220, they have shown that in the kinematic regime, isotropic helical turbulence leads to an alpha effect and a turbulent diffusivity, whose values are independent of the magnetic Reynolds number, R_m, provided, R_m exceeds unity. These turbulent coefficients are also consistent with expectations from the first order smoothing approximation. This result comes almost as a surprise, given that in recent years, mean field theory has been seriously challenged based on numerical simulations. For small values of R_m, α and turbulent diffusivity are proportional to R_m. Over finite time intervals, meaningful values of α and turbulent diffusivity can be obtained even when there is small-scale dynamo action that produces strong magnetic fluctuations. This suggests that the fields generated by the small-scale dynamo do not make a correlated contribution to the mean electromotive force.

Primordial magnetic fields and formation of molecular hydrogen

It is believed that the first luminous objects in the universe appeared at $z \sim 15-30$ when substantial amount of molecular hydrogen formed in objects of mass in the range of 10^{6-7} $M_{\odot}$. Molecular hydrogen formation is catalyzed by the residual free electrons, which were left behind after recombination. Any process, which increases this electron fraction can have a significant impact on molecule formation. If magnetic fields were produced in the early universe, they dissipate energy into the intergalactic medium due to ambipolar diffusion or by generating decaying turbulence. In an earlier paper by S. Sethi and *Subramanian*, they had computed the the effects of such dissipation on the thermal and ionization history of the universe.

Subramanian (along with Biman Nath and S. Sethi) has now examined how the resulting increased ionization fraction in the intergalactic medium and collapsing halos, can affect the formation of molecular hydrogen and shows that, for magnetic field strengths in the range $2 \times 10^{-10}\,\mathrm{G} \leq B_0 \leq \times 10^{-9}\,\mathrm{G}$, the molecular hydrogen fraction in IGM and collapsing halo can increase by a factor 5 to 1000 over the case with no magnetic fields. They also discuss the implication of the increased molecular hydrogen fraction on the radiative transfer of UV photons and the formation of first structures in the universe. The net impact of the primordial magnetic fields depends also on the role played by the magnetic fields in inducing the formation of first structures.

High Energy Astrophysics

Gamma Ray Bursts

The Gamma Ray Burst (GRB) of March 29, 2003 has been one of the brightest in recent times at all wavelength bands. *Dipankar Bhattacharya* and his collaborators detected its radio afterglow with the Giant Metrewave Radio Telescope (GMRT) soon after the burst, and have since then continued to monitor the evolution of its flux at two radio frequencies: 1280 MHz and 610 MHz. This follow up continued through 2007-08. The afterglow, although dimming gradually, still remains above the detection limit. The span of this study, covering its evolution over more than five years, is the longest for any GRB till date. During this year, this group has combined the observations from GMRT with those from the Westerbork Synthesis Radio Telescope and performed theoretical modelling of the multiwavelength light curves. The group demonstrates that the expansion of the fireball shows a clear transition from ultra-relativistic to sub-relativistic regime. They also derive the total energy content of the fireball to be about 3×10^{51} erg, similar to the energy in a supernova explosion.

The ejection of matter from a GRB is thought to be strongly collimated to start with. The observer needs to be located close to the axis of the jet for radiation to be visible. If counter-jet, which is going away exists, then the radiation from it would not normally be visible during the ultra-relativistic phase of expansion, but is expected to make its appearance once the motion becomes sub-relativistic. From the absence of prominent bumps in the observed light curve, *Bhattacharya* and his collaborators constrain the degree of emission anisotropy at a time corresponding to the peak of the forward jet emission.

A large international team, including *Bhattacharya* studied the afterglow of the Gamma Ray Burst of October 22, 2005 at multiple wavelength bands, including radio, millimetre waves, near-infrared, optical and X-rays. Optical and near-infrared observations did not detect the afterglow, despite strong emission seen in X-rays and a strong flare at millimetre waves. The team concludes that this event falls in the category of "Dark GRBs", in which the optical afterglow is absent due to the extinction caused by dense molecular gas around the burst site.

Ultra luminous x-ray sources

Ultraluminous 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 harbour intermediary size black holes ($10^2 - 10^4 M_\odot$). Following up on their previous spectral studies of sources found in thirty galaxies, A. Senorita, *R. Misra*, K. Shanthi and Y. P. Singh have undertaken a systematic temporal study of these sources. They have identified an interesting source in NGC 6946, which has a soft spectrum, high luminosity ($L \sim 3 \times 10^{39}$ ergs/sec), which shows strong variability factor of ~ 1.3 in a timescale of ~ 5000 secs. Their detailed time dependent spectral analysis reveals that as the source luminosity decreases, the temperature of the black body emitting plasma decreases and consistent with standard accretion disk models, as the inner disk radius remains constant. This consistency allows the estimation of black hole mass from the measured radius, which turns out to be definitely greater than 100 solar masses and more probably of the order of 400 solar masses. This has strengthened the evidence that ULX harbour massive black holes.

The rapid variability of black hole systems like Cygnus X-1 is believed to be produced in the inner regions of an accretion disk, where strong gravity effects are important. However, the epicyclic frequency corresponding to such radii is significantly larger than the frequencies observed.*Misra* and A. Zdziarski have developed a model of an accretion disc, in which the variability induced at a given radius is governed by a damped harmonic oscillator at the corresponding epicyclic frequency. That variability induces both linear and non-linear responses in the locally emitted radiation. The total observed variability of a source is the sum of these contributions over the disc radius weighted by the energy dissipation rate at each radius. It is shown that this simple model, which effectively has only three parameters including the normalization, can explain the range of the power spectra observed from Cyg X-1 in the soft state. Although, a degeneracy between the black hole mass and the strength of the damping does not allow a unique determination of the mass, they can still constrain it to $\sim$ (16 – 20) solar masses.

Supernova

Bhattacharya and his collaborators have reported the multi-wavelength study of a Type-II Plateau supernova event SN2004et in X-ray, optical and radio bands. Using these observations, this group estimates the pre-supernova mass loss rate from the progenitor of this event ($\sim 2 \times 10^{-6}\ M_{\odot}\ \mathrm{yr}^{-1}$), the total energy of the explosion ($\sim 1 \times 10^{51}$ erg) and the amount of radioactive Nickel synthesized in the explosion ($\sim 0.06\ M_{\odot}$), all pointing to the mass of the progenitor being about $20 M_{\odot}$.

Magnetars

Bhattacharya and Vikram Soni have put forward a new model for strongly magnetized neutron stars, called "Magnetars", the radiation from which appears to be partly powered at the expense of stored magnetic energy. In this new model, if the neutron star is very massive, then a phase transition at the core creates spontaneously magnetized material. The resulting magnetic field, initially shielded by currents outside the core, slowly makes its appearance at the surface over $10^4 - 10^5$ yr, as the shielding currents decay due to ambipolar diffusion. The energy dissipated in the ambipolar diffusion process would power the observed emission and accompanied by this, the surface magnetic field would rise. Contrary to other existing models, this new model predicts that magnetars with stronger magnetic fields should be older than those with weaker fields, and thereby, provides an explanation for the puzzling observation that weaker field magnetars are associated with supernova remnants, while the stronger field ones are not.

Discovery of the largest radio jet with highly unusual polarization structure, ejected from a supermassive black hole

Relativistic jets, which contain highly collimated streams of plasma traveling close to the speed of light, are commonly found in diverse astrophysical environments. They are believed to be associated with extreme relativistic phenomena such as radio galaxies and quasars, microquasars, pulsars, supernovae and gamma ray bursts. Bipolar jets in a radio galaxy or quasar are launched from the central region of an active galaxy, probably from a rotating magnetized accretion disk around a massive spinning black-hole, the "central-engine". While astrophysical jets have begun to reveal their mysteries, many of their basic properties, such as their ejection, collimation, stability and composition, remain to be understood. Fundamental questions raised by astrophysical jets include the roles of magnetic fields in their survival against internal instabilities out to distances approaching hundreds of kiloparsec (kpc) from the galactic nucleus and in the formation of the radio "hotspot" and lobe due to the jet's termination. Using radio data from GMRT and optical spectroscopic data from the recently commissioned IUCAA 2 m telescope at Girawali, an international team led by *J. Bagchi* has discovered a very interesting radio galaxy CGCG 049-033, which harbours a (single-lobed) giant radio jet of 440 kpc size. *The exceptional size of this jet makes it the longest astrophysical jet yet detected, while its high degree of collimation and strong polarization point towards hitherto unexplored MHD plasma processes at work.* This giant radio jet emanates from a super-massive blackhole of mass $\mathrm{M}_{BH} = (2 \pm 1) \times 10^9\ \mathrm{M}_{\odot}$, which places it in the league of most massive nuclear black-holes known, such as the one detected in the nearby radio galaxy M87 (Virgo A). Significantly, this is one of the most important science results from GMRT and the first collaborative work using data from IUCAA 2 m optical telescope and the GMRT.

• Radio maps with GMRT (1.3 GHz) and the Max Planck Institute 100 m radio dish at Effelesberg,

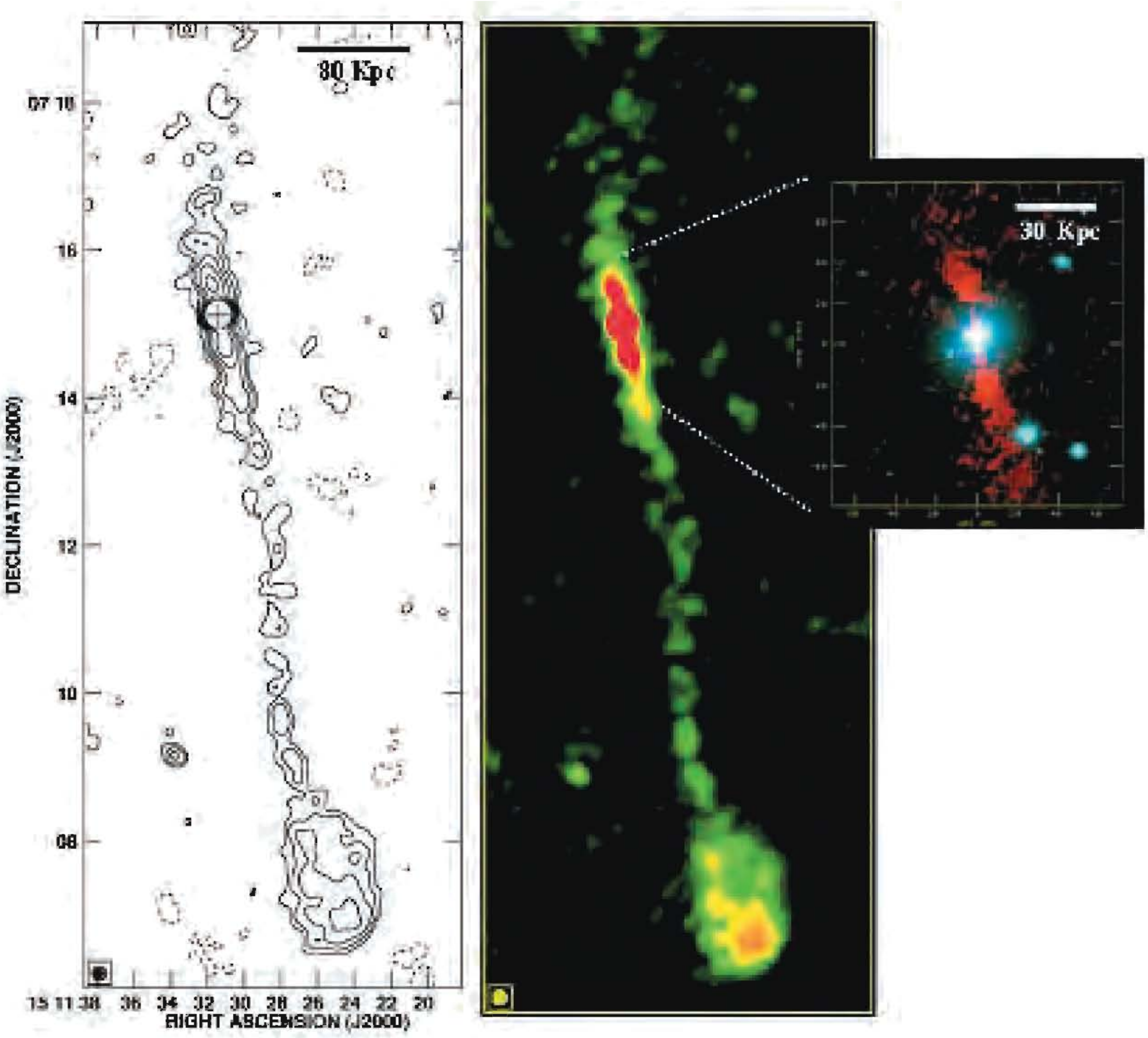

Figure 13: GMRT 1.28 GHz radio observations of the giant radio-jet source CGCG 049-033. **(Left)** the synchrotron emission intensity contours: - 0.18, 0.18, 0.36, 0.72, 1.44, 3 and 6 mJy/beam; r.m.s. noise: $\sim 60\ \mu$Jy/beam, and the pseudo-colour image (Center), both with a $11''$ beam. The details of the inner $\sim 2'$ region **(Small inset on right)** are visible in the $3''$ resolution GMRT image (shown in red), overlaid on the optical r-band image from the *Sloan Digital Sky Survey* (shown in blue). The radio images show a spectacular radio structure having a bright radio core, a main jet extending $\sim$ 440 kpc upto the lobe/hotspot, a counter-jet, but no detectable counter lobe or a hotspot, which is a very peculiar situation.

Germany (8.4 GHz) were obtained. These show (see Figure 13) a spectacular radio structure having a bright radio core, a main jet extending ~ 440 kpc upto the lobe/hotspot, a short counter-jet, but no detectable counter lobe or a hotspot, which is a very peculiar situation. Also, this is the largest of all astrophysical jets detected so far.

• Optical spectroscopic data obtained with IUCAA Faint Object Spectrograph and Camera (IFOSC) on the 2 m telescope of the IUCAA Girawali Observatory (see Figure 14) suggest an ultra-massive black hole of mass $M_{BH} = (2 \pm 1) \times 10^9\ M_{\odot}$, which implies that CGCG 049-033 is one of the most massive central engines known.

• Polarization mapping with Effelsberg 100 m radio telescope finds strongly polarized synchrotron radiation from the radio jets. An extraordinarily high degree of linear polarization (p between 20 and 50%, mean value of 30%) is found all along the jets, despite a large beam averaging (see Figure 14). After correcting for the rather small Faraday Rotation effect at this high frequency, the data imply extremely well ordered magnetic fields, predominantly transverse to the jets. This is in contrast to the longitudinal field pattern typically found in Fanaroff-Riley II jets (FR II, which have hot-spots at the end of lobes) and may be linked to the several other unusual properties exhibited by this source.

• We have tried to understand the formation of an extremely compact radio lobe at the end of the main jet and the peculiar non-detection of a counter radio-lobe, invoking two theoretical scenarios for the lobe's compactness. The first one invokes a delayed lobe formation coupled with light-travel-time effects and thereby, seeks to simultaneously also explain the lobe's apparent one-sidedness. The second scenario explains the lobe's compactness in terms of a jet having a dominant toroidal/helical magnetic field. Although, bolstered by the polarization measurements, this scenario leaves unanswered the question of the counter-lobe's non-detection.

• An alternative possibility for the compact lobe formation involves a dynamically important (toroidal) magnetic field associated with the jet itself. One scenario for the ejection of toroidal magnetic field on the innermost scale is the so called, "sweeping magnetic twist model". Basically, the bending of the poloidal magnetic lines threading the accretion disk by its rotation develops a toroidal structure. The build-up of the magnetic tension in the disk is released along the poloidal lines as large-amplitude torsional Alfvén wave (sweeping magnetic twist) and the associated Poynting flux (in which, the energy and angular momentum from the disk are carried predominantly by the electromagnetic field). The final magnetic configuration has a poloidal geometry with a helical/toroidal annulus propagating outward at the local Alfvén speed.

• Therefore, observation of a highly organized transverse (toroidal) magnetic field for the present jet on the largest physical scale detected until now, being orthogonal to the usual pattern exhibited by FR II jets, underscores its importance as a rare case in which, a dynamically important magnetic field may persist upto a few hundred kiloparsecs. Plausibly, the light-travel time and some peculiar external (or internal) magnetic configuration are two rare effects simultaneously at work in this source, leading to its extraordinary nature.

• A central issue about this giant radio jet concerns its stability, particularly over the first 350 kpc length, where no "protective cocoon" of synchrotron plasma is evidently available for containing the growth of a mixing layer which usually transforms the jet into a turbulent flow, often leading to its deceleration and dissipation. Problems arising from a mixing layer, would be much less daunting if the source were located inside a fossil radio lobe (relic) containing little thermal plasma which would inhibit strong mixing and turbulence within jet and the radio lobe.

• Being strongly polarized (with a transverse magnetic vector), as well as laterally extended on 10 arcsec scale, this giant radio jet provides a unique laboratory to search for helically wound magnetic field on mega-parsec scale, through observation of transverse gradients of Faraday Rotation Measure.

More radio observations will be obtained for mapping the polarization structure of the jet,

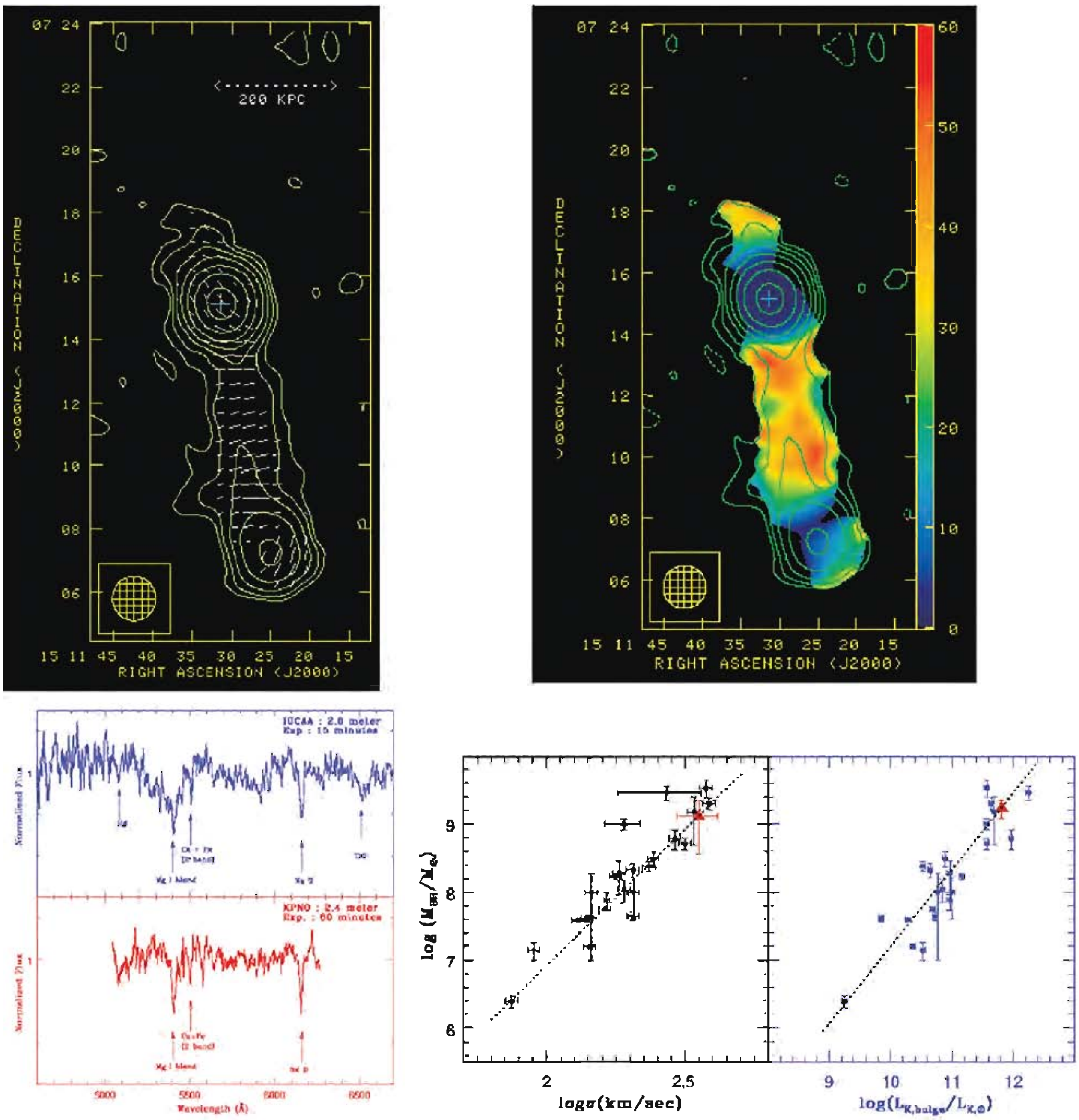

Figure 14: Effelsberg 8.35 GHz observations of CGCG 049-033 with 83.6″ beam showing **(Upper left)** the total intensity map [contours: - 0.75, 0.75, 1.5, 3, 6, 12, 24 and 48 mJy/beam] along with rotation-measure corrected magnetic field vectors (lines), having lengths proportional to the local intensity of linearly polarized flux. The percentage degree of linear polarization is shown with pseudo-colours in the **(Upper right)** panel. The '+' marks the radio core at the nucleus of the elliptical galaxy CGCG 049-033. **(Lower left)** The optical spectra of CGCG 049-033 taken with IFOSC on the 2 m telescope of IUCAA Girawali Observatory and with the 2.4 m Hiltner/KPNO telescope. **(Lower right)** The nuclear black hole mass is estimated from two independent methods, using the velocity dispersion σ of Na D spectral line (left), and from the K-band bulge luminosity $L_{K,bulge}$ (right). The red triangles show the calculated black hole mass M_{BH} of CGCG 049-033 plotted on the very tight M_{BH}-σ and M_{BH}-$L_{K,bulge}$ correlation plots of several other known super massive black holes. The dotted lines are the best fitting linear regression lines. Thus, CGCG 049-033 harbours one of the most massive nuclear black holes known.

counter-jet and the radio lobe. These observations will reveal what role a toroidal/helical magnetic field might play in stabilizing this remarkably long radio jet. We will also search for the 'missing' northern radio lobe. Plans are also afoot for an X-ray imaging study with *Chandra* of the inner $\sim$100 kpc scale jet and counter-jet region close to the radio core and of the central AGN.

Stars and Interstellar Medium

Physical conditions in the galactic ISM

The spatial distribution of the cosmic-ray flux is important in understanding the Interstellar Medium (ISM) of the galaxy. This distribution can be analyzed by studying different molecular species along different sight lines, whose abundances are sensitive to the cosmic-ray ionization rate. Recently, several groups have reported an enhanced cosmic-ray ionization rate in diffuse clouds compared to the standard value, ζ (average) = 2.5×10^{-17} s^{-1}, measured toward dense molecular clouds. In an earlier work, we reported an enhancement in the cosmic ray rate of 20 towards HD185418. McCall et al. have reported enhancements of 48 towards ζ Persei based on the observed abundance of H_3^+, while Le Petit et al. found a cosmic ray enhancement of 10 to be consistent with their models for this same sight line. *R. Srianand* and his collaborators (Gargi Shaw, Gary Ferland, Abel, N. P., van Hoof, P. A. M.; Stancil, P) have revisited zeta Persei and perform a detailed calculation using a self-consistent treatment of the hydrogen chemistry, grain physics, energy and ionization balance, and excitation physics. They showed that the value of ζ deduced from the H_3^+ column density in the diffuse region of the sight line depends strongly on the properties of the grains because they remove free electrons and change the hydrogen chemistry. The observations are largely consistent with a cosmic ray enhancement of 40, with several diagnostics indicating higher values. This underscores the importance of a full treatment of grain physics in studies of interstellar chemistry.

Dust in the interstellar medium

In a recent work, *Ranjan Gupta* and collaborators have shown that the observed interstellar extinction and polarization can be modeled by using porous and composite dust grains consisting silicate and graphite material. Figures 15 and 16 and demonstrate the fitting of this model to the observed extinction and polarization.

Further, their model also provides a better constraint on the cosmic abundance, i.e., it reduces the 'carbon crisis' problem as is shown in the Table 3.

Near-IR spectral library

Arvind C.Ranade, *Ranjan Gupta*, H.P. Singh and N.M. Ashok have recently completed and released the NIR spectral library with more than 100 stars observed from the GIRT Mt. Abu NIR spectrometer. The complete library in J, H & K is now available online.

Instrumentation

FIFUI - Fibre-based Integral Field Unit for IFOSC

An optical fibre based Integral Field Unit (IFU) is being developed at the Instrumentation Laboratory. This unit will be used as one of the modes of IUCAA Faint Object Spectrometer and Camera (IFOSC) and would offer the facility to do area spectroscopy of extended astronomical objects. The 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 $\times$ 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 IFU consists of 3 optical sections: The Fore-Optics, the Lenslets and Fibre Unit and the Output Optics. The optical design strategy of these three sections and their expected performances have been described in the last annual report. After consulting with the optics manufacturers, several iterations of the optical design

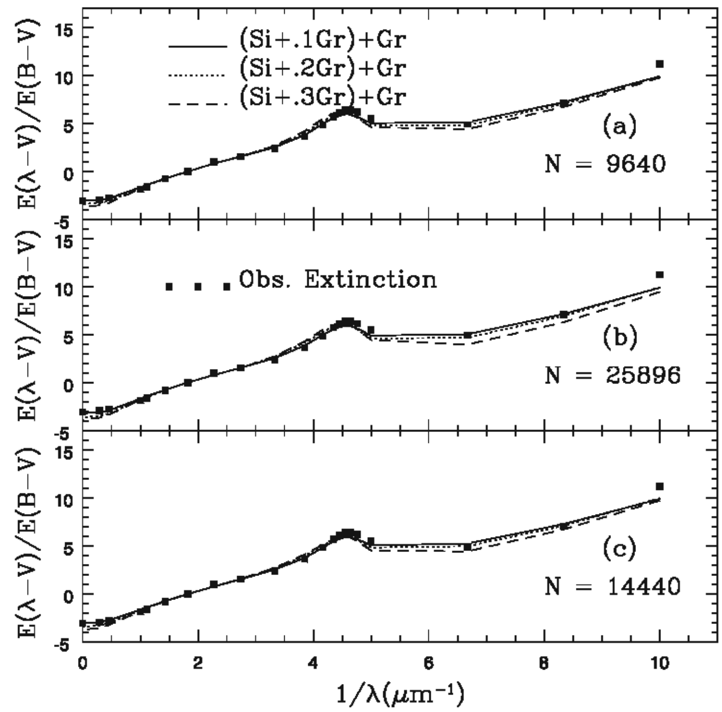

Figure 15: Fitting of observed interstellar extinction data to the composite grain model extinction.

Table 3: Abundance Ratios & carbon crisis

Abundance Ratio (ppm)	ISM	Other Models	Our Model
C/H	110	254	160
Si/H	17	32	25

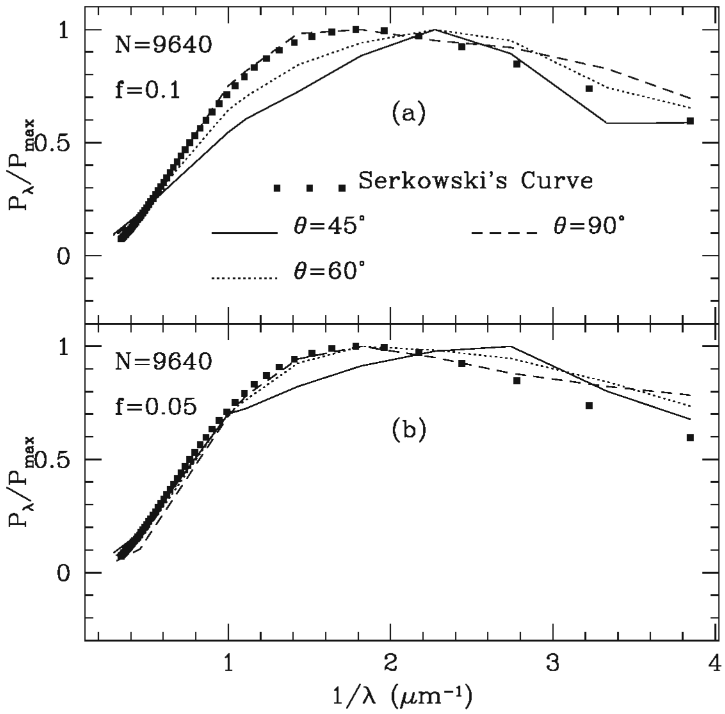

Figure 16: Fitting of composite grain model interstellar polarization to the Serkowski Law.

have been done and orders for the procurements of the various optical component have been placed. Here the Opto-Mechanical Layout and Integration Strategy of the IFU is described:

The Opto-Mechanical Design of the IFU consists of various sections:

(a) *Front Unit:* This section would be mounted on one of the side ports of the telescope and is to provide different magnification to the input telescope image for different sampling options. It contains three achromatic doublet lenses of the fore optics section. A combination of one achromatic doublet with the singlet lens is used to provide one sampling mode. In order to get desired sampling of the image, the achromatic doublets would be mounted on one-dimensional translational stage, which is movable using a stepper motor, therefore, any one of the three sampling scales can be achieved by bringing the corresponding achromatic doublet in to the path of the light beam. Their distances are to be changed by varying lengths of the lens mounts (mounted on the translation stage) and by varying the telescope focus. A folding mirror is also attached to the optical design, considering the space available out side the side port is not enough for the linear design. Further provision for calibration lamps is also made to this unit, for the calibration of observed spectra. The light from these lamps would be fed to the fore-optics section of the IFU using another folding mirror and by blocking the light from the Telescope.

(b) *Fibre Head Mount Unit:* It is the part that would carry the singlet lens of the fore-optics section, optical fibres, which are to be fixed in quartz ferrules, and the lenslet array, which is to be formed on a glass window. This part has a rectangular cavity (40 mm $\times$ 24 mm) in it. The fibres (core diameter: 70 microns, cladding diameter : 98 microns and buffer diameter: 125 microns) would be first glued inside the cylindrical quartz ferrules (ID: 0.200 mm and OD : 1.85 mm, length: 60 mm) and then these ferrules (with optical fibres in the central 100 ferrules) would form a closed packed stack into the cavity. The polishing of the fibres would be done along with this unit. A glass window (made up of a very low dispersion glass) would be placed over the polished fibres array and the lenslet array would be formed on it, while pressing the glass window by a mechanical unit. After making the singlet lens of the fore-optics, it would be mounted into this mechanical unit. This Fibre Head Mount Unit would be attached to the Front Unit.

(c) *Fibre Slit Unit:* The fibres would be taken out of the Fibre Head Mount Unit and fed to Fibre Slit Unit. This unit has similar structure as the Head Mount Unit. It consists of the cavity of size 28 mm $\times$ 6 mm. Here also, the fibre would be glued to quartz ferrules (ID: 200 micron, OD : 350 micron), and later the ferrules consisting of the fibres would be stacked in to the cavity. Here the fibre would be aligned in two vertical layers with 50 fibres in each layer, creating the two fibre slits. The fibre pitch would be set to 400 microns. This Fibre Slit Unit would be attached to the IFOSC through the output optics.

Apart from lenses, the output optics also contains a folding mirror. The lens and mirror mounts for the output optics are being designed. Further, a fibre polishing apparatus has also been designed in order to polish the optical fibres.

This instrumentation work forms part of the Ph.D thesis work of *M. Srivastava* who is working under the guidance of *A.N.Ramaprakash.*

UltraViolet Imaging Telescope (UVIT)

UltraViolet Imaging Telescope (UVIT) is one of the 5 instruments to go on the first Indian astronomy satellite ASTROSAT, which is expected to be launched in the near future. UVIT consists of two telescopes, each of aperture 380 mm. The two telescopes make images in a field of 0.5 degree with a resolution of 1.5", simultaneously in three channels: 1300 - 1800 A, 1800 - 3000 A, and 3200 - 5300 A. In addition to UVIT, 4 X-ray telescopes are used on ASTROSAT to provide simultaneous wide band coverage in the observations.

UVIT is being developed through collaboration between several Indian institutions: IIA, ISRO, IUCAA, PRL, and TIFR, and Canadian Space Agency. At present the various subsystems are under developments at different centres. In the following, some of the important work done at IUCAA during the last year is described.

In order to minimise the scattered light from out of field bright sources, like, e.g., moon, a black surface coating is required on the baffles. To maintain the ultraviolet transmission of optics, it is required that any black coating does not outgas - even mono-molecular layers can absorb ultraviolet. Thus, a fully inorganic coating was developed, for Invar36 and aluminium alloy Al 6061, at ISAC, ISRO and its suitability and ruggedness to ultrasonic cleaning was verified in the Instrumentation Laboratory by *Abhay Kohok, Swapnil Prabhudesai, and Shyam Tandon*: The coatings have an averaged reflectivity of 3% .

An overall spatial resolution of 1.5" is challenging and it can only be achieved by optimising the photon counting detectors (Intensified CMOS imagers) and characterising these carefully. One of the effects to be characterised is distortion, which occurs in the fibre-taper used to couple the intensifier to the CMOS imager. To understand these distortions, a typical fibre-taper was studied, using a grid of lines, by *Prabhudesai* and *Tandon*. It was found that the taper has a significantly smaller magnification near its axis, and that this effect is not circularly symmetric. This effect has to be characterised for the UVIT detectors.

Though the optics and detectors of UVIT are designed to give a spatial resolution of 1.5", tracking of ASTROSAT is only designed to keep the drift to $<$ 0.2", i.e., in an exposure of 100 s the altitude could drift by $>>$ 1.5". Thus, in order to get sharp images, frames are recorded at rate $> 1/s$, and these are combined by "shift and add" process on ground. In order to implement "shift and add", it is required to know the full time series of the drift. To check if the images from the visible channel (3200 - 5300 A) can be used to get this time series with the required accuracy they have done a simulatin. The simulation showed that even near the galactic poles, there were enough sources to give the time series with an error $<$ 0.1" rms.

In order to have a realistic evaluation of the various instrumental effects, *Mudit Srivastava* and *Tandon* are simulating observations of galaxies. The galaxies are taken from the data base of Galex mission, which gives ultraviolet images with a spatial resolution of 4 - 5"; these images are transformed to images as would be seen if the galaxy were placed three times farther. The effects on spatial resolution and photometric accuracy are being studied for different algorithms available in UVIT for recording of the individual photons. It is expected that through these simulations, the optimal choice of the algorithm could be made for any individual observation, and a procedure would be found to correct for photometric non-linearities.

Mirror coating plant for IUCAA Telescope

A primary mirror coating plant for 2 m telescope at IUCAA Girawali Observatory has been successfully installed recently, which was fabricated by Hind High Vacuum, Pvt. Ltd., Bangalore. The coating plant has been able to render an aluminium coating thickness of about 1000 Ang $+/-$ 150 Ang, and reflectivity in visible region of about 88%, uniformly over all regions of the active primary mirror area which are close to its demanded specifications.

Further, in September 2007, the primary mirror was brought down and re-coated, and placed back into its mirror cell for regular observations. An improvement of about 1 magnitude was noticed in the overall sensitivity of the telescope after this primary recoat.

Goniometer fabricated for Assam University

Figure 17 shows the picture of a goniometer, which was fabricated from a workshop at Pune for Assam University, Silchar, under an ISRO-RESPOND project by Ranjan Gupta in collaboration with Asoke K. Sen. This instrument will be used to study the light scattering properties of asteroid and regolith samples, and model them using various light scattering codes.

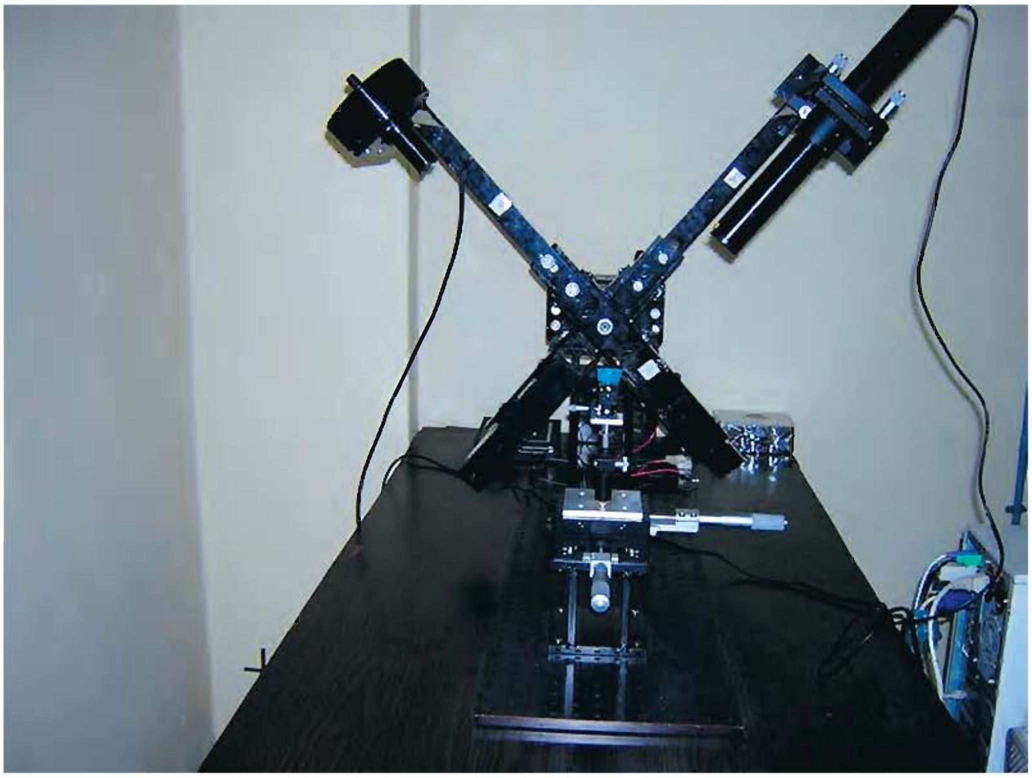

Figure 17: Goniometer fabricated for Assam University, Silchar, for the study of light scattering properties of regolith materials.

(II) RESEARCH BY VISITING ASSOCIATES

Archaeoastronomy

Iqbal, Naseer

Naseer Iqbal and collaborators have worked on the problem, *"A Probable Meteor Impact in Kashmir Valley (India)."* It has been proposed that Dal Lake in Srinagar, Kashmir has been formed by meteor impact that has taken place in prehistoric times. They have undertaken some preliminary investigations, which include the pH value of water present in the Dal Lake, presence of shock metamorphic effects, presence of Breccias, presence of certain elements necessary for the confirmation of a meteor crater, and knowing the exact shape of the Lake. These results are in good agreement with the results obtained earliar for the meteor crators like Arizona crater in USA and Lonar crater in Maharashtra, India. In future, the authors are planning to undergo certain investigations for the confirmation of some other scientific ideas like presence of Breccias and Meskelnite rocks inside the lake, etc. In this work they invited the attention of international community of scientists towards its existence.

They have also worked on the problem, *"Some Earliest Astronomical Observatories in Kashmir (India)"*. They identify some ancient observatories in the north-west belt of Kashmir (India) and predict that Bomai Sopore, which seems to be stone observatory, as the oldest one in this region belonging to upper Paleolithic period. They have found many other carvings in the northern India, which include the places like Bomai Sopore in Baramulla, Burzuhama in Srinagar, Chillas and Drass in Ladakh area, and these carvings have a good astronomical interpretation leading to the study of meteor impact, supernova, change of seasons in a year and others in prehistoric times.

Classical and Quantum Cosmology

Banerjee, Narayan

Narayan Banerjee is working on the dark energy problem, the agent that gives rise to the present accelerated expansion of the universe. Presently, he is working on the possibility of using a modification of Brans-Dicke theory, so that the acceleration is achieved with a high positive value of the Brans-Dicke parameter ω. It matches the local astronomical observations and through this one can avoid the botheration of a negative kinetic energy. He is also working on the gravitational collapse scenario with a scalar field, which may help in understanding the clustering of the dark energy vis-à-vis the dark matter.

Chandra, Deepak

Deepak Chandra has continued his study of the dark energy problem in cosmology, specially the coincidence problem. He is exploring current observations which indicate that our universe is accelerating and it seems to be a rather late phenomenon. He is interested in the resolution of this problem, and is looking at the different dark energy models (scalar fields, phantom fields, Chaplagyn gases, etc.) and their equations of state. Cosmological constant seems to satisfy the current observations quite well, but its origin is still not clear. The scalar field (tracker) models can remove the fine-tuning problem that bogs the cosmological constant .

He is also studying the modified gravity models, which modify the geometry and do not need dark energy to explain the acceleration of the universe.

Debnath, U.

U. Debnath and collaborators have studied a model of the universe filled with modified Chaplygin gas and another fluid (with barotropic equation of state) and its role in accelerating phase of the universe. He has assumed that the mixture of these two fluid models is valid from (i) the radiation era to Λ CDM for $-1 \leq \gamma \leq 1$, and (ii) the radiation era to quintessence model for $\gamma < -1$. For these two fluid models, the statefinder parameters describe different phase of the evolution of the universe.

He has proposed a model of variable modified Chaplygin gas and shown its role in accelerating phase of the universe. The equation of state of this model is valid from the radiation era to quintessence model. The statefinder parameters characterize different phase of evolution of the universe. Recently developed generalized cosmic Chaplygin gas (GCCG) is studied as an unified model of dark matter and dark energy. To explain the recent accelerating phase, the universe is assumed to have a mixture of radiation and GCCG. The mixture is considered for without or with interaction. Solutions are obtained for various choices of the parameters and trajectories in the plane of the statefinder parameters. For particular choice of interaction parameter, He has shown the role of statefinder parameters in various cases for the evolution of the universe.

Also U. Debnath has considered the universe to be filled with modified Chaplygin gas, and the cosmological constant to be time-dependent with or without the gravitational constant G to be time-dependent. He has considered various phenomenological models for Λ, viz. $\Lambda \propto \rho, \Lambda \propto \frac{\dot{a}^2}{a^2}$, and $\Lambda \propto \frac{\ddot{a}}{a}$. Using these models, it is possible to show the accelerated expansion of the universe at the present epoch. He has studied a model of interaction between the scalar field and an inhomogeneous ideal fluid. He has shown that besides being a dark energy model to explain the cosmic acceleration, this model shows a decaying nature of the scalar field potential and the interaction parameter.

Jotania, Kanti

A. Pradhan, Kanti Jotania and Archana Singh have investigated a cylindrically symmetric inhomogeneous magnetized string cosmological model with cosmological term varying with time. To get the deterministic solution, it has been assumed that the expansion term θ in the model is proportional to the eigen value σ_1^1 of the shear tensor σ_j^i .

Anirudh Pradhan, Vandana Rai and Kanti Jotania have obtained a cylindrically symmetric inhomogeneous cosmological model for bulk viscous fluid distribution with electromagnetic field. The source of the magnetic field is due to an electric current produced along the z-axis. F_{12} is the non-vanishing component of electromagnetic field tensor. To get the deterministic solution, it has been assumed that the expansion θ in the model is proportional to the shear σ. In the above two models, the values of cosmological constant are found to be small and positive at late time, which are consistent with the results from recent supernovae **Ia** observations. Physical and geometric aspects of the models are also investigated in presence and absence of magnetic field.

Paul, B.C.

B.C. Paul, P. Debnath and A. Beesham have explored a flat FRW universe in higher derivative theories, with a variable gravitational and cosmological constants. They have obtained new cosmological solutions, which are interesting. The solutions admit a late accelerating universe. It is found that in the R^2 -theory with the matter dominated regime, the gravitational constant decreases initially, which at a later epoch attains a constant value in the presence of a negative cosmological constant. Thus, G may be large in the early universe but at the present epoch it becomes a constant. It is noted that realistic cosmological solutions are permitted if (i) $\Lambda > 0$ with $a < 0$, and (ii) $\Lambda < 0$ with $a > 0$. A power law inflation is permitted during matter dominated era if one allows G to increase at a later stage. However, when $\Lambda \to 0$ and Newton's constant does not vary, the solution reduces to the usual matter dominated decelerating universe.

B.C. Paul, P. Thakur and A. Saha have explored a holographic dark energy model of the universe considering a modified generalized Chaplygin gas (GCG). The modified GCG behaves as an ordinary barotropic fluid in the early epoch when the universe was tiny but behaves subsequently as a Λ CDM model as the universe evolves. They have determined the corresponding holographic dark energy field and its potential. The stability of the holographic dark energy in this case is also studied.

Pradhan, A.

One of the outstanding problems in cosmology today is developing a more precise understanding of structure formation in the universe, that is, the origin of galaxies and other large scale structures. Existing theories for structure formation of the universe fall into two categories, based either upon the amplification of quantum fluctuations in a scalar field during inflation, or upon symmetry breaking phase transition in the early universe, which leads to the formation of *topological defects,* such as domain walls, cosmic strings, monopoles, textures and other 'hybrid' creatures. Cosmic strings play an important role in the study of the early universe. Within the ambit of general relativity, A. Pradhan, together with Raj Bali, A. K. Yadav and Anju Rai have studied inhomogeneous domain walls and string cosmological models. They had two main reasons to study these types of models. First, as a test of consistency, for some particular field theories based on string models and other models that use strings as basic elements. Second, they pointed out that the universe can be represented by collection of extended objects (galaxies). So a "string dust" cosmology gives a model to investigate this fact.

Several modifications of Einstein's general relativity have been proposed and extensively studied so far by many cosmologists to unify gravitation and many other effects in the universe. Barber (1982) has produced two continuous self creation theories by modifying the Brans-Decke theory and general relativity. The modified theories create the universe out of self-contained gravitational and matter fields. Brans-Decke theory (1961) develops Mach's principle in a relativistic framework by assuming interaction of inertial masses of fundamental particles with some cosmic scalar field coupled with the large scale distribution of matter in motion. However, Barber has included continuous creation of matter in these theories. Branse (1987) has pointed out that Barber's first theory is in disagreement with experiment as well as inconsistent, in general, since the equivalence principle is violated. Barber's second theory is a modification of general relativity to a variable G-theory. The second is an adaptation of general relativity to include continuous creation and is within the observational ambit. In view of the consistency of Barber's second theory of gravitation, A. Pradhan, G. P. Singh and Shilpi Agarwal have obtained locally rotationally symmetric Bianchi type I universe with a variable deceleration parameter in Barber's second theory and investigated some physical consequences of these models.

Magnetic fields are a widespread and significant components of the universe. Cylindrically symmetric spacetime plays an important role in the study of the universe on a scale in which anisotropy and inhomogeneity are not ignored. Inhomogeneous cylindrically symmetric universe has significant contribution in understanding some essential features of the universe, such as the formation of galaxies during the early stages of their evolution. Also the discovery of the expansion of the universe, which is accelerating has promoted the search for new types of matter that can behave like a cosmological term by combing positive energy density and negative pressure. A. Pradhan in collaboration with Kanti Jotania and others has studied a wide class of magnetized string cosmological models in cylindrically symmetric inhomogeneous universe with time dependent cosmological term. In order to obtain a singularity free universe, they have introduced a modified version of quintessence-like dark energy, which at the same time is able to explain the accelerated expansion.

Ray, Saibal

Saibal Ray is continuing the investigations on dynamical models of the cosmological term Λ, in connection to the dark energy theory.

Along with U. Mukhopadhyay and S. B. Dutta Choudhury, he has considered a time-dependent phenomenological model of Λ, viz., $\dot{\Lambda} \sim H^3$ to investigate the Λ CDM cosmology. Time-dependent form of the equation of state parameter ω is derived, and it has been possible to obtain the flip of sign of the deceleration parameter q. Present age of the universe, calculated for some specific values of the parameters agrees very well with the observational data.

In another problem, they have studied two variable Λ models, viz. $\Lambda \sim (\dot{a}/a)^2$ and $\Lambda \sim \rho$ under the assumption that the equation of state parameter ω is a function of time. The selected Λ models are found to be equivalent, both in four and five dimensions. The possibility of signature flip of the deceleration parameter is also shown.

Einstein field equations under spherically symmetric spacetimes have been considered by them in connection to dark energy investigation. A set of solutions are obtained for a kinematical Λ model, viz., $\Lambda \sim (\dot{a}/a)^2$ without assuming any *a priori* value for the curvature constant and the equation of state parameter ω. Some interesting results, such as the nature of cosmic density Ω and deceleration parameter q, have been obtained with the consideration of two-fluid structure, instead of usual uni-fluid cosmological model.

Choosing the three phenomenological models of the dynamical cosmological term Λ, viz., $\Lambda \sim (\dot{a}/a)^2$, $\Lambda \sim \ddot{a}/a$ and $\Lambda \sim \rho$, where a is the cosmic scale factor, it has been shown by the method of numerical analysis for the considered non-linear differential equations that the three models are equivalent for the flat universe $k = 0$ and for arbitrary non-linear equation of state. The evolution plots for dynamical cosmological term Λ vs. time t and also the cosmic scale factor a vs. t are drawn for $k = 0, +1$. A qualitative analysis has been made from the plots, which supports the idea of inflation and hence expanding universe.

Among the various phenomenological Λ models, a time-dependent model $\dot{\Lambda} \sim H^3$ is selected to investigate the Λ CDM cosmology in collaboration with U. Mukhopadhyay, P. P. Ghosh and M. Khlopov. Using this model, the expressions for the time-dependent equation of state parameter ω and other physical parameters are derived. It is shown that in H^3 model, accelerated expansion of the universe takes place at negative energy density, but with a positive pressure. It has also been possible to obtain the change of sign of the deceleration parameter q during cosmic evolution.

Seshadri, T.R.

T.R. Seshadri, along with S. Unnikrishnan and H. K. Jassal has shown that on length scales much smaller than hubble radius, perturbations in dark energy is negligible in comparison to the perturbations in dark matter. However, on scales comparable to the hubble radius ($\lambda_p > 1000$Mpc), the perturbation in dark energy, in general, cannot be neglected. As compared to the ΛCDM model, large scale matter perturbation is suppressed in generic dark energy models.

T.R. Seshadri, along with J. S. Bagla and Jaswant Yadav has derived the expected fractal dimension for a homogeneous distribution of a finite number of points. They have shown that for sufficiently large data sets, the expected fractal dimension approaches D in absence of clustering. It is also important to take the weak, but non-zero amplitude of clustering at very large scales into account. They have also computed the expected fractal dimension for a finite point set that is weakly clustered. Clustering introduces departures in the fractal dimensions from D, and in most situations the departures are small if the amplitude of clustering is small. Features in the two point correlation function, like those introduced by Baryon Acoustic Oscillations can lead to non-trivial variations in the fractal dimensions.

Singh, G.P.

Several modifications of Einstein's general relativity have been proposed and extensively studied by many researchers to unify gravity and other fields. Though, present day observations strongly favour homogeneous, isotropic accelerating expansion of the universe, in its early stages, it might not have so smooth behaviour. A number of scientific arguments available in the literature support the idea of existence of anisotropic stage of the early universe, which phased out during its evolution and approached to present day isotropic one. In order to study the evolutionary behaviour of the early universe, G. P. Singh, A. Pradhan and coworkers have studied anisotropic cosmological models in modified theories of gravitation. They have obtained a new class of higher dimensional cosmological model with variable gravitational and cosmological terms. Further, they have studied a singularity free LRS Bianchi type I cosmological model. The results of their investigations are consistent within observational limits. G. P. Singh and A. Pradhan are continuing the investigations on cosmological models in alternative theories of gravitation.

Usmani, Anisul Ain and Ray Saibal

Anisul Ain Usmani and Saibal Ray along with their Collaborators have proposed a time dependent equation of state parameter of the form $\omega(t) = \omega_0 + \omega_1(t\dot{H}/H)$. This, when employed in phenomenological Λ model of the form, $\dot{\Lambda} \sim H^3$ explains both linearly and inflationary universes with a single set of equations, provided inflation leads to a scaling in the equation of state parameter. He has determined one of its two parameters and has delineated the other. It has been possible to show a connection between dark energy and Higgs-Boson. He is also exploring the utility of our proposition in case of an oscillatory universe.

Compact Objects, X-ray Binaries and Globular Clusters

Chattopadhyay, Asis Kumar and Tanuka Chattopadhyay

Asis Kumar Chattopadhyay, jointly with Tanuka Chattopadhyay, Ranjeev Misra, and Malay Naskar has done new work on classification of gamma ray bursts (GRB). New statistical methods developed in recent years are very useful to uncover underlying features of different data sets. Two different multivariate clustering techniques, the K-means partitioning method and the Dirichlet process of mixture modeling, have been applied to the BATSE GRB catalog, to obtain the optimum number of coherent groups. In the standard paradigm, GRBs are classified into only two groups, the long and short bursts. However, for both of the clustering techniques, the optimal number of classes were found to be three, a result that is consistent with previous statistical analysis. In this classification, the long bursts are further divided into two groups that are primarily differentiated by their total fluence and duration, and hence are called low- and high fluence GRBs. Analysis of GRBs with known redshifts and spectral parameters suggests that low-fluence GRBs have nearly constant isotropic energy output of 1052 ergs, while for the high-fluence ones, the energy output ranges from 1052 to 1054 ergs. It is speculated that the three kinds of GRBs reflect three different origins: mergers of neutron star systems, mergers between white dwarfs and neutron stars, and collapse of massive stars.

Asis Kumar Chattopadhyay has also taken part in other two works jointly with Tanuka Chattopadhyay, on objective classification of the globular clusters and proper understanding of horizontal branch morphology. Besides the above works, there were contributions by them in the solutions of statistical problems in the areas other than astronomy and astrophysics.

Tanuka Chattopadhyay, jointly with Asis Kumar Chattopadhyay has carried out work related to objective classification of the globular clusters in our galaxy, M31, and LMC using a new method of cluster analysis and the set of parameters for this method was selected through an objective process, Principal Component Analysis (PCA). Robustness of the classification was established using bootstrap samples. In every case, they exhibit multi-population structure, instead of bimodality as is found in many spirals and giant elliptical galaxies. The kinematics of MW and M31 GCs are examined in support of these sub-populations in the cluster system. It is found that for MW and M31 GCs, a disc, inner halo, and outer halo populations of GCs are more likely to exist than only the disc and halo populations of GCs in MW as concluded by Zinn (1985, ApJ, 293, 424). This supports the existence of three populations more firmly explained by Zinn (1993, Globular Cluster-Galaxy Connection, 38) and Mackey and Gilmore (2004, MNRAS, 355, 504), whereas only two populations are found for LMC GCs. The new multivariate analysis increases the importance of the inclusion of many parameters while at the same time it eliminates less significant parameters, and helps to enunciate a unique theory of galaxy formation.

Usmani, Anisul Ain

The knowledge of baryon-baryon interactions (hyperon-hyperon and hyperon-nucleon) is required for a many-body calculation of the equation of state of a hyperon star. The useful information may be obtained from a realistic study of light nuclei and hypernuclei. A. A. Usmani, Z. Hasan and F. C. Khanna, have recently performed realistic calculations on light single and double hypernuclei and have pin pointed the strengths of various interactions. Based on these effective two- three-body interactions, they have developed a variational many-body technique to perform realistic calculations of infinite-body systems, like a neutron star or a hyperon star. Using the relativistic mean field approach, They are studying the early evolution and the cooling scenario of the star.

Cosmology and Structure Formation

Jain, Deepak

Dark energy is the invisible fuel that seems to drive the current acceleration of the universe. At present, the nature of dark energy is not very well understood. Deepak Jain has studied the observational constraints on the dark energy equation of state (ω) from lookback time measurements of high redshift galaxies. He has shown that these age measurements are compatible with values of ω close to -1, although there is still space for quintessence ($\omega > -1$) and phantom ($\omega < -1$) behaviour. Jain has studied the cosmological constraints on the two purely phenomenological models of oscillating dark energy. In these oscillating models, the equation of state of dark energy varies periodically. He has examined the observational constraints on the oscillatory models from the latest observational data including the Gold sample of SNe Ia, CMBR and BAO.

Galaxies and Quassars

Khare, Pushpa

Pushpa Khare, along with her collaborators, has observed several $z_{abs} < 1.5$ Damped Lyman Alpha systems (DLAs) and sub-DLAs in the spectra of QSOs, with the VLT and the Magellan telescope with the aim of determining the metal abundances in these systems. Five systems were found to have near/super solar abundance of Zn, the least depleted metal.

Also, they have studied the average properties of associated absorption systems in the spectra of SDSS DR3 QSOs. These systems show higher onization and higher extinction as compared to the intervening systems. The radio-loud QSOs were shown to have larger number of associated systems as compared to the radio-quiet QSOs, by a factor of 1.7. The associated absorbers in radio-loud QSOs cause three times more reddening as compared to the associated absorbers in radio-quiet QSOs. The excess reddening appears to originate in the absorption systems and indicates intrinsic nature of these absorbers.

Ravikumar, C.D.

C.D. Ravikumar has been involved in studies on formation and evolution of galaxies. His collaboration with the scientists from Paris Observatory and IUCAA has resulted in observation and analysis of about 700 galaxies in the Chandra Deep Field - South in an attempt to obtain robust kinematics of distant galaxies. The spectroscopic observations with sensisitive GIRAFFE and FORS spectrographs reveal strong evolution in galaxy kinematics, with velocity fields of a large fraction of galaxies showing that they are not dynamically relaxed. He has also conducted studies on the properties of lenticular galaxies with Ajit Kembhavi and Sudhanshu Barway of IUCAA, Yogesh Wadadekar (NCRA) and Divakar Mayya of Instituto Nacional de Astrofisica, Mexico, and they support a clear division in the formation scenario for lenticulars, with secular evolution for fainter S0s, and a more merging dominant formation for brighter lenticulars.

Ray, Saibal

Saibal Ray in collaboration with F. Rahaman, M. Kalam, A. De. Benedictis, A. A. Usmani has considered flat rotational curves of the galaxies under the framework of brane-world models, where the $4d$ effective Einstein equation has extra terms, which arise from the embedding of the 3-brane in the $5d$ bulk. It has been shown that these long range bulk gravitational degrees of freedom can act as a mechanism to yield the observed galactic rotation curves without the need for dark matter. The present model has the advantage that the observed rotation curves result solely from well-established non-local effects of gravitation, such as dark radiation and dark pressure under a direct use of the condition of flat rotation curves and does not invoke any exotic matter field.

General Relativity

Ghosh, Sushant G.

S. G. Ghosh, in collaboration with A. K. Dawood, has proved a theorem that characterizes a large family of non-static solutions to Einstein equations in N-dimensional spacetime, representing in general, spherically symmetric Type II fluid. It is shown that the best known Vaidya-based (radiating) black hole solutions to Einstein equations, in both four dimensions (4D) and higher dimensions (HD), are particular cases from this family. The spherically symmetric static black hole solutions for Type I fluid can also be retrieved.

S. G. Ghosh and V. S. Morozova have considered a modification of the above work, so that large families of exact non-spherically symmetric radiating anti-de Sitter black hole solutions are possible in 4D.

S. G. Ghosh with D. W Deshkar have studied a Vaidya-based model of a radiating black-hole in a 5-dimensional Einstein gravity with Gauss-Bonnet contribution of quadratic curvature terms. The structure and locations of the apparent and event horizons of the radiating black hole are determined. They also examined the analogous results for Bonnor-Vaidya model, i.e., for charged null fluid.

They have also studied the junction conditions for non-spherical collapsing radiating star, consisting of a shearing fluid undergoing radial heat flow with outgoing radiation. It was shown that, at the boundary, the pressure is proportional to the magnitude of the heat flow vector.

Ibohal, Ngangbam

Ngangbam Ibohal has proposed a class of non-stationary de Sitter, rotating and non-rotating, solutions of Einstein's equations with a cosmological term of variable function. The energy momentum tensor of the non-stationary rotating de Sitter metric satisfies the equations of motion. It is found that the spacetime of the non-stationary de Sitter model is algebraically special in the Petrov classification of gravitational field with a null vector, which is geodesic, shear free, expanding as well as non-zero twist. However, that of the non-rotating model is conformally flat with non-empty space. It is also shown that the surface gravity of non-stationary spacetime is also constant.

Ngangbam Ibohal and Kapil have obtained an exact solution of Einstein's field equations by choosing suitable Wang-Wu function. This solution describes as a non-stationary rotating Kerr-Newman-Vaidya (KNV) black hole. This solution can also be considered as Kerr-Newman black hole embedded into the rotating Vaidya solution. The metric of KNV can be expressed in terms of Kerr-Schild ansatz on Vaidya background. This can also be written in another Kerr-Schild ansatz of rotating Vaidya black hole on Kerr-Newman background. These two Kerr-Schild ansatzs show that the possibility of embedded-ness must be from very beginning of early universe and it may be hard to speak which embedded first, either Kerr-Newman or Vaidya. However, it will remain embedding forever. It is also found that the energy momentum tensor of the KNV black hole metric satisfies the equation of motion. The surface gravity, entropy, temperature and angular velocity at the horizons are also determined. The laws of black holes are also satisfied. It is also found that the electrical radiation will continue to form instantaneous charged black holes, thereby, creating negative mass naked singularities describing the possible lifestyle of the radiating embedded black hole during their continuous radiation process. This negative mass naked singularity can also be expressed in Kerr-Schild anstaz as naked mass background as well as Vaidya background.

Ibohal, Ishwarchandra and Yugindro Singh have proposed a class of possible models of dark matter. These are solutions of Einstein's field equations, describing conformally flat spacetimes in case of non-rotation. The energy momentum tensor of these models satisfies the equations of motion. It is also found that these dark matter spacetimes can be embedded into different black hole background like Schwarzschild, Reissner-Nordstrom and Vaidya-Bonner, and showing the existence of the dark matter amidst black holes. Hawking radiation of charged black holes on the dark matter back ground is also studied. It is found that the spacetime of the rotating dark matter is algebraically special in the Petrov classification of gravitational field with a null vector, which is geodesic, shear free, expanding as well as non-zero twist.

Tikekar, Ramesh and Kanti Jotania

Ramesh Tikekar and Kanti Jotania have studied a core-envelope model for spherical super dense distribution of matter with the feature - core consisting of anisotropic fluid engulfed by an envelope containing fluid with isotropic pressure on the background spacetime of the whole configuration characterized by two parameter parabolic geometry. The physical plausibility of the model was examined both analytically as well as numerically to explore its suitability for describing spacetime of the super dense stars containing strange matter such as Her-X1, SAX. Further the study indicated that the approach described was applicable to massive object 2S 0921-30, which has mass about 2.9 solar mass.

Nandi, Kamal Kanti

Kamal Kanti Nandi has been engaged in research in Einstein's gravity theory with special emphasis on wormhole physics. During this year, in a collaborative work, he has proposed an effective method of testing Einstein's gravitation theory at the second post Newtonian level. It was argued that the current plans about such a test using light signals would not yield desired results. His collaborative work on the scalar field gravity suggested a method to distinguish between Jordan and Einstein frames. Currently, he is engaged in studying rotating wormholes.

Gravitational Theory and Gravitational Waves (Collapse)

Chakraborty, S.

Quasi-spherical gravitational collapse in higher dimension has been studied by Subenoy Chakraborty and co-workers. S. Chakraborty, in collaboration with Sanjukta Chakraborty and Ujjal Debnath has investigated gravitational collapse in higher dimensional quasi-spherical Szekeres spacetime for matter with anisotropic pressure, and has shown that it is possible to have Cosmic Censorship Conjecture (CCC) for six and higher dimensions. Radial null geodesics have been studied for global visibility of central shell focusing singularity and the strength of the naked singularity has been examined in Tipler sense. Also, S. Chakraborty and his collaborators have presented the identical behaviour of collapse dynamics with non-vanishing radial pressure having different equations of state in different dimensions. Moreover, S. Chakraborty, in collaboration with Anusua Baveja and Tanwi Bandyopadhyay has studied the dynamical symmetry in quasi-spherical gravitational collapse with a general choice of initial area radius. The work deals with the role of anisotropy and inhomogeneity of spacetime in characterizing the end state of collapse.

S. Chakraborty, in collaboration with Tanwi Bandyopadhyay has investigated collapse dynamics of an inhomogeneous quasi-spherical star in the background of dark matter and dark energy. They have taken dark matter in the form of dust and anisotropic fluid is chosen as dark energy. They have studied the role of dark energy in the formation of apparent horizon and have examined how dark energy modifies the collapsing process.

Debnath, U.

U. Debnath has studied gravitational collapse in higher dimensional quasi-spherical Szekeres spacetime for matter with anisotropic pressure. Both local and global visibility of central curvature singularity has been studied and it is found that with proper choice of initial data it is possible to show the validity of CCC for six and higher dimensions. Gravitational collapse in $(n+2)$ dimensional quasi-spherical spacetime is studied for a fluid with non vanishing radial pressure. An exact analytic solution is obtained for the equation of state $P_r = (\gamma - 1)\rho$. The singularity is studied locally by comparing the time of formation of apparent horizon and the central shell focusing singularity, while the global nature of the final fate of collapse is characterized by the existence of radial null geodesic. It is revealed that the end state of collapse for D dimension with equation of state $p = -\rho$, for $(D-1)$ dimensional dust and $(D-2)$ dimension with equation of state $p = \rho$ are identical.

The visibility of the shell-focusing singularity in Szekeres spacetime which represents quasi-spherical dust collapse has been studied on numerous occasions in the context of the CCC. The various results derived have assumed that there exist radial null geodesics in the spacetime. One has been shown that such geodesics do not exist in general, and so previous results on the visibility of the singularity are not generally valid. More precisely, the existence of a radial geodesic in Szekeres spacetime implies that the spacetime is axially symmetric, with the geodesic emanating in the polar direction (i.e., along the axis of symmetry). If there is a second non-parallel radial null geodesic, then the spacetime is spherically symmetric, and so is a Lemaitre-Tolman-Bondi (LTB) spacetime. For the case of the polar geodesic in an axially symmetric Szekeres spacetime, one gives conditions on the free functions (i.e., initial data) of the spacetime, which lead to visibility of the singularity along this direction. The complications involved in addressing the question of visibility of the singularity, both for non-radial null geodesics in the axially symmetric case and in the general (non-axially symmetric) case, are looked into, and suggested a possible approach.

Kuriakose, V.C.

It is hoped that studies on black holes can throw more light in the attempt to develop a formulation for quantum theory of gravity. Direct observation of black holes are still elusive and indirect methods are used to detect them. In this attempt, studies on black scattering and quasi normal modes (QNMs) play important roles. R. Sini and V.C. Kuriakose have studied scattering of charged scalar field from Reissner- Nordstrom(RN) black hole using WKB approximation. In this calculation they have assumed that the scalar waves get reflected at the black hole event horizon, they have obtained expressions for Hawking temperature and absorption cross section. Calculations are extended to the cases of extremal RN and extremal SdS black holes, and in these cases also the absorption coefficients are calculated. QNM is one of the important and exciting themes in black hole physics. When a black hole gets perturbed, during certain interval of time, the perturbation is dominated by damped single frequency oscillations. The frequency and damping of these oscillations depend on the parameters of the black hole. R. Sini, Nijo and V.C. Kuriakose have studied QNMs of spherically symmetric black hole spacetimes with cosmic string in Dirac field and found that the decay is small when cosmic string is present.

No-hair theorem states the non-existence of any information other than mass, charge and angular momentum of black holes. There are conjectures for and against this theorem. There are reports for the existence and non-existence of scalar hair. Kuriakose and Kuriakose have obtained a non-trivial scalar black hole solution for a massive self interacting conformal scalar field in (3+1) dimensions. The metric proposes horizon and temperature and the metric contains traces of scalar filed signalling scalar hair.

The maximum mass of neutron stars plays an important role in determining the end point of the evolution of massive stars. Although, it is now more than sixty years since the first attempt made by Oppenheimer and Volkoff , no definite answer can be given. Their calculation was based on the equation of state, known as the Tolman-Oppenheimer-Volkoff (TOV) equation, which was based on general relativity theory. Vianayaraj and Kuriakose have made an attempt to modify TOV equation using Schwarzscild- de Sitter frame work and calculated the mass of neutron stars.

Patil, K.D.

A dyon is a hypothetical particle with both electric and magnetic charges. A dyon with zero electric charge is usually referred to as a magnetic monopole. The existence of magnetic monopoles is not yet confirmed, in spite of that many researchers have shown interest in it. Hence, considering the possibility of existence of magnetic monopoles, K.D. Patil, A.Chamorro and K.S.Virbhadra have obtained the generalization of Bonner-Vaidya solution known as radiating dyon solution.

They have also studied the gravitational collapse of radiating dyon solution and shown that the final outcome of the collapse (NS/BH) depends sensitively on the electric and magnetic charge parameters. They also have shown that the electric and magnetic components push the apparent horizon towards the retarded time-coordinate axis, which in turn reduces the radius of the apparent horizon in Vaidya spacetime. It has also been observed that the radius of the apparent horizon decreases with the increase in total charge.

Ray, Saibal

In a collaborative work Saibal Ray with F. Rahaman, M. Kalam and M. Sarker has performed a survey whether higher dimensional Schwarzschild spacetime is compatible with some of the solar system phenomena. As a test, they have examined five well known solar system effects, viz., (1) Perihelion shift, (2) Bending of light, (3) Gravitational redshift, (4) Gravitational time delay and (5) Motion of test particle in the framework of general relativity with higher dimensions. It is shown that the results related to all these physical phenomena are mostly incompatible with the higher dimensional version of general relativity except that of motion of test particle. They compared all these results with the available data in the literature.

Linear and Non-linear Dynamics

Ambika, G.

G. Ambika has studied numerically the bifurcation structure of two Henon maps coupled in the drive response mode. It is found that for a range of values of coupling coefficient C, as the control parameter of the driven map A_d is varied, the response map follows the same bifurcations. This is because, for large coupling strengths, the two systems are in complete synchronization (CS) and as C decreases or as Ad is varied, due to increasing parameter mismatch, they come out of CS, but continue in generalised synchronization (GS). This means that in GS even though the states are not identical, their functional relationship preserves the periodicity. For further lower values of C, additional bubble like structures occur in the bifurcation diagram, which is due to period doubling followed by period halving.

Ambika has analysed the evolutionary dynamics of virus-host interaction in the presence of immune response under drug therapy using a 10-d model. The effect of drug therapy due to repeated dosages is introduced through a periodic drug function as a perturbation in the system. It is found that starting from the pretreatment infective equilibrium, by increasing the dosage, the system can be taken through a series of limit cycles that eventually leads to non-infective equilibrium. The results are highly relevant in arriving at a structured policy of therapy. Moreover, since the system is high dimensional, using principal component analysis, the transitions can be captured in the relevant phase space. This is compared with the usual transitions in non-linear systems. Apart from the biological significance of the work, the characterization of transitions in high dimensional systems is an interesting result.

A detailed study of the twin phenomenon of stochastic and vibrational resonance is done in collaboration with K. P. Harikrishnan. Using a one dimensional discrete system as model, the significant results for bichromatic input signal are arrived at by treating the system in both the bistable mode and threshold mode. The study of vibrational resonance in the same system brings out the cross over behaviour from vibrational to stochastic that can be characterised using the response time of the system.

The work on characterization of attractors from time series analysis started in collaboration with Ranjeev Misra and K. P. Harikrishnan is extended to include multifractal characterisation also. It has been possible to arrive at a parametric characterisation of a chaotic attractor using a two scale Cantor set. The efficient use of correlation entropy for distinguishing coloured noise from chaos has also been demonstrated effectively.

Das, M. K.

M. K. Das, along with Pankaj Narang, M. Yuasa and L. M. Saha has studied the particle trajectories in restricted 3-body problem, including the effect of radiation, particularly in Sun - Jupiter. In this work, they have simulated orbits of a particle moving in gravitational field of the Sun-Jupiter system. The effect of solar radiation pressure, including Poynting-Robertson (PR) drag, on the evolution of particle orbits in phase space have been studied for different values of the parameter β_1 (the ratio of radiation to gravitational force) and initial conditions. Characteristics of various computed trajectories have been studied using wavelet transform (WT), Fourier transform (FT) and Poincare surface of section method. They have used wavelet analysis to identify transitions of a trajectory in time- frequency plane and further applied it to classify it as regular or chaotic in phase space. Unlike the fourier transform method (FT), it is observed that the wavelet transform (WT) also provides a basis to identify 'sticky' trajectories in the present dynamical system.

Further, along with Pankaj Narang, S. Mahajan and M. Yuasa he has studied the stability of location of various equilibrium points of a passive micron size particle in the field of radiating binary stellar system, within the framework of circular restricted three body problem. Influence of radial radiation pressure and PR drag on the equilibrium points and their stability in the binary stellar systems *RW-Monocerotis* and *Krüger-60* have been studied. It is shown that both collinear and off axis equilibrium points are linearly unstable for increasing value of β_1 in presence of PR drag for the binary systems. Further, they find that out of plane equilibrium points $(L_i, i = 6, 7)$ may exists for range of values of $\beta_1 > 1$ for these binary systems in the presence of PR drag . Their linear stability analysis shows that the motion near the equilibrium points $L_{6,7}$ of the binary systems is unstable both in the absence and presence of PR drag.

In continuation with the foregoing, 'out of plane' equilibrium points of a passive micron size particle in the field of radiating binary stellar systems $Krüger - 60$, $RW - Monocerotis$ have been studied within the framework of photo - gravitational circular restricted three body problem. It is observed that the 'out of plane' equilibrium points $(L_i, \quad i = 6, 7, 8, 9)$ may exist for range of β_1 values for these binary systems in the presence of PR drag. In the absence of PR drag, they find that the motion of a particle near the equilibrium points $L_{6,7}$ is stable in both the binary systems for a specific range of β_1 values. The PR drag is shown to cause instability of the various 'out of plane' equilibrium points in these binary systems.

Harikrishnan, K. P.

K.P. Harikrishnan, in collaboration with G. Ambika has made a detailed numerical study of the twin phenomenon of stochastic and vibrational resonance in a discrete model system in the presence of bichromatic input signal. The analysis brings out several interesting results, both for stochastic and vibrational resonance, including the existence of a cross over behaviour between the two. Also, in the case of stochastic resonance, the study reveals a fundamental difference between bistable and threshold mechanisms, with respect to amplification of multi signal input. K.P. Harikrishnan has also developed an algorithmic scheme to compute the multifractal spectrum of a chaotic attractor from the time series, in collaboration with R. Misra and G. Ambika. The scheme has been applied to time series from standard chaotic systems as well as that from real world systems.

Kuriakose, V. C.

When electromagnetic waves pass through a medium, the shape of the pulse gets spread in the medium. This can be due to either dispersion or diffraction or both. If ordinary light is used, the polarisability of the medium depends only on the strength of the electric component of the field, which is a linear effect. But, if one uses laser light, it is found that the polarizability depends on higher powers of electric component of the field, bringing in non-linear effect. This non-linearity also affects the quality of wave of propagation. Under suitable conditions the effect due to non-linearity could be balanced by the effect due to dispersion or diffraction, depending on the nature of medium. The resulting wave structure is known as optical soliton. If we consider the propagation of light through an optical fibre, optical-solitons are formed by balancing the effects of nonlinearity and dispersion. These types of solitons are called temporal solitons. If we consider a bulk medium like photorefractive crystal or polymer, it is the effect of diffraction, which balances with nonlinear effects, producing optical solitons known as spatial solitons. P.A. Subha, C.P. Jisha and V.C. Kuriakose have studied spatial solitons by taking into consideration the effects of diffraction managed and non-linearity managed situations. Jisha and Kuriakose also have studied the formation of spatial solitons in photorefractive polymers. The mathematical tool used to study these problems is variational analysis, supported by numerical calculations.

Josephson junction (JJ) has been identified as an ideal physical system to study chaos, and chaos in JJ has been studied extensively. The rf-biased JJs find practical importance in the construction of devices like parametric amplifiers, voltage standards, pulse generators, SQUID for detection of very weak magnetic fields, even devices for astronomical observations, etc. For these devices, it is essential to avoid all types of noise, chaos, etc. Chitra R. Nayak and V.C. Kuriakose have analyzed a parallel array of N-coupled JJs with parameters lying in the chaotic regime and studied synchronization of the system. They have found that suppression of chaos can be obtained in JJ systems in the presence of a phase difference between the applied fields, and this property may find applications in the working of devices constructed using JJs.

Singh H. P.

H.P. Singh and collaborators have analyzed the time series of solar wind velocity fluctuations measured by the Helios spacecraft in the inner heliosphere corresponding to solar cycle 21. To understand the local dynamics of fluctuations in the slow speed wind velocity, they have calculated the largest Lyapunov exponent and its variance for a total of 18 data sets measured at a distance of 0.32 AU from the sun during the years 1975 - 1982. The Lyapunov exponents obtained are positive for all data sets, but show large variance for some of the time series, suggesting inherent changes in the dynamics over the solar cycle. Furthermore, estimation of the correlation dimension for each of the 18 time series indicates presence of low-dimensional chaotic behaviour in the underlying dynamics.

Mathematical and Theoretical Physics

Mukku, C.

C. Mukku's work in the last year has focused on tenable ways to couple torsion to Yang-Mills fields while maintaining gauge invariance. This leads to gauge couplings to become scalar fields. In the past, this has been untenable from experimental constraints at the current epoch for the electromagnetic field at least. Recent researches on the "landscape" arising out of string theory provides for many scalar fields, which eventually determine the various low energy parameters including gauge couplings in the universe. Within this scenario, the very early universe provides a Riemann-Cartan geometry with non-zero torsion coupling to gauge fields. The torsion is just the derivative of gauge coupling (scalar) fields. As a result, in the evolution of the universe, when the scalar (moduli) fields determine the geometry of the universe to be Riemannian, torsion goes to zero, implying that the associated modulus (and hence the gauge coupling) has a constant value. An equivalent view is that the modulus fixes the gauge coupling at some constant value causing the torsion to vanish as a consequence. Various applications of the theory are now underway.

Rao, Nagalakshmi

It is well established in non-relativistic quantum mechanics that the harmonic oscillator is one of the most important quantal systems, as it is one of the very few that can be solved exactly. Surprisingly, in the relativistic situation, it is seen that if the oscillator potential is included as a Lorentz vector, the effective potential is unbounded from below at infinity and no true bound states occur. Nagalakshmi A. Rao and B.A. Kagali have suggested a novel method of introducing the harmonic oscillator potential into the Klein-Gordon equation, leading to genuine bound states. Relativistic quantal oscillators are significant, as special features are seen when the oscillator motion becomes relativistic. They have analysed the Dirac oscillator in two spatial dimensions extending the prescription of Moshinsky, and further extended the study to explore the salient features of the Klein-Gordon oscillator, considering an interaction that couples to the momentum.

The one dimensional Klein-Gordon equation in the presence of a vector potential may be rewritten in the Schrodinger form with an effective energy, E_{eff} and effective potential, V_{eff}. Introducing the harmonic oscillator potential that couples to the momentum, would transform the Klein Gordon equation to a solvable Kummer's differential equation, the eigen functions of which may be expressed in terms of regular confluent hypergeometric functions. Physically admissible solutions require finiteness and normalizability, and the necessary square integrability of ψ implies the vanishing of the wave function at infinity. Termination of the hypergeometric series to a polynomial ensures normalization, further leading to quantization of energy. The binding energies and also the relativistic correction may be computed numerically for different classical frequencies and strength parameters. It is trivial to note that in the non-relativistic limit, the binding energy of the Klein-Gordon oscillator is $e \approx (n + \frac{1}{2})\hbar\omega$, consistent with the wisdom of quantum mechanics. Interestingly, the prescription yields the relativistic energies having unequal spacing. While discreteness is a property of bound states, equispacedness is a characteristic feature of non-relativistic oscillator. At high energies, the oscillator becomes more sluggish and they have shown that the spacing between the levels change slowly compared to the non-relativistic oscillator. It would be interesting to extend the calculation to the 3D case, the results of which may be compared with those of the 3D isotropic Dirac oscillator.

Saha, Anirban

Anirban Saha has performed a thorough analysis of Galilean symmetries for the gravitational well problem on a non-commutative (NC) plane. A complete closure of the one-parameter centrally extended Galilean algebra is realised for the model. This implies that the field theoretic model that he has constructed earlier to describe NC gravitational quantum well is indeed independent of the coordinate choice. Hence, the energy spectrum predicted by the model is a physical one and not the artifact of special coordinate choice. It can, thus, rightly be associated with the experimental results to establish the upper-bound on time-space NC parameter.

Data Analysis, Machine Learning and Virtual Observatory

Chattopadhyay, Asis Kumar

Asis Kumar Chattopadhyay, jointly with Ajit Kembhavi, G.J. Babu, E.D. Feigelson and others, has developed the VO Stat part of Virtual Observatory, India. This part of VO can be used as statistical software for the analysis of large data sets. Besides astronomy and astrophysics, scientists from other disciplines also may use this free software for statistical analysis of their data sets. It includes, statistical tools like correlation and regression, different statistical tests, graphical presentation, multivariate analysis etc. The programmes are written in "R", which is, one statistical software freely available in the internet. The basic advantages of VO Stat are its user friendly environment, usefulness and wide coverage. Improvements are going on to make VO Stat, a good menu driven statistical package

Philip, Ninan Sajeeth

Use of computers has been best explored by the astronomy community in the history of science. The tools developed by astronomers to explore the deep universe has been used in medical imaging and diagnostics. Despite all its wide acceptance as pioneers in the field of computing, astronomy research tools are still not easily portable across machines. Even installing the most popular IRAF package sometimes takes up a reasonable amount of expertise and time. This could be the most challenging task especially when workshops and hands on sessions in astronomy are organised at remote places, where such expertise are not easily available. What one would love to see is a package that runs on all machines and if possible without installation.

Each machine has a different architecture. Even when the processors are same, they might have different peripheral units. Thus, all modern operating systems have an installation programmes that configures the OS to the local requirements at the time of installation. While this would be considered an advantage by commercial software builders, it was looked down as an unnecessary overhead by the opensource Linux community, who appreciated the freedom to share knowledge. The solution they came up gave way to the Live-CDs, that can boot from a removable media and hence is portable. Live-CDs have boot time scripts that checks and configures itself to the requirements of the system it is booted on, and hence devoid the need for any installation script. The additional cost for this is more memory usage, more computing resource consumption and longer execution times as CD-roms are usually much slower than hard drives.

Thumb drives (also known as pen drives or flash drives) introduced a technological alternative to the read only media of CD-roms. They offer rewritable media with access speeds that are faster by over a factor as compared to any other removable media. Naturally, they turned out to be a better alternative to Live-CDs. Today, many Live-CDs have pendrive versions as well.

One of the major challenges addressed by N. Sajeeth Philip during the year was to port popular astronomy packages such as IRAF, votools, aladin, specview, source extractor, etc. to a portable Linux distribution, so that they may also benefit the same flexibility and ease of usage found in live-CD distributions. The first task was to find an optimal distribution for the live OS. From about a dozen possible variants, it was found that a slackware based distribution known as Slax (available at slax.org) is the fastest and best suited live OS to port the astronomy software. He has created a module named ATMA, to extend the read only limitation of Live-CDs to a rewritable and configurable distribution. ATMA stands for Automated Trans-Migration Algorithm, that mimics the myth of trans-migration, the ability of the soul (software) to move from one body (hardware) to another, and exhibit the juster of the soul in the host bodies.

Slax-ATMA, the OS solution that includes the new algorithm, transports the virtual environment and configurations made on one machine to any other machines, to which the pendrive is ported to. The astronomy software package with all the said tools and the basic Linux OS that can directly boot up even a windows machine to browse the internet can be packed into a pendrive with about 600 MB free space. Given the fact that 1 GB pendrives typically costs only around Rs. 300/-, this could be the simplest alternatives to a pocket PC. A much more simpler approach, especially, for the distribution of astronomy software was to give off CD versions of Slax-ATMA for astronomy.

N. Sajeeth Philip is also working on a ISRO sponsored research project to develop machine learning tools in astronomy with Ajit Kembhavi as the co-investigator. This would essentially provide a high performance solution to some of the classification challenges relating to astronomical data. A cluster computer with 32 GB RAM, two terabytes of storage media driven by eight Core-2 Duo processors running at 3 GHz each and an FSB of 1333 MHz with gigabyte interconnect is being built at St. Thomas College, Kozhencherri, Kerala for this purpose. Apart from catering to the local research requirements, it would also form the test bench for larger distributed computing experiments in astronomy research in the locality. The many challenges it offers is expected to occupy the lion share of his research activity in the next 3 years

Singh, H. P.

In order to develop a pipeline for automated classification of stars to be observed by the Tel-Aviv University Ultra-Violet Experiment (TAUVEX) ultraviolet space telescope, H.P. Singh, Archana Bora, Ranjan Gupta and their collaborators have employed an artificial neural network (ANN) technique for classifying stars by using synthetic spectra in the ultraviolet (UV) region from 1250 to 3220 Å as the training set and International Ultraviolet Explorer (IUE) low-resolution spectra as the test set. Both the data sets were pre-processed to mimic the observations of the TAUVEX UV imager. They have successfully classified 229 stars from the IUE low-resolution catalogue to within three to four spectral sub-class using two different simulated training spectra, the TAUVEX spectra of 286 spectral types and UVBLUE (http://www.inaoep.mx/modelos/uvblue/uvblue.html) spectra of 277 spectral types. Further, they were able to obtain the colour excess [i.e., E(B - V) in magnitude units] or the interstellar reddening for those IUE spectra, which have known reddening to an accuracy of better than 0.1 mag. It was shown that even with the limitation of data from just photometric bands, ANNs not only classified the stars, but also provided satisfactory estimates for interstellar extinction. The ANN based classification scheme has been successfully tested on the simulated TAUVEX data pipeline. It is expected that the same technique can be employed for data validation in the UV from the virtual observatories. Finally, the interstellar extinction estimated by applying the ANNs on the TAUVEX data base would provide an extensive extinction map for our galaxy, which could in turn be modelled for the dust distribution in the galaxy.

Observational Astronomy

Pandey, S.K.

As part of an ongoing collaborative research programme with A. K. Kembhavi and other colleagues on "Multiwavelength photometric study of dusty early-type galaxies," S.K. Pandey has continued the process of obtaining good quality deep images in BVRI broad bands as well as in narrow H-alpha band. Deep CCD images of six early-type galaxies were obtained during March 31 - April 3, 2008 using the 2 m HCT. Likewise, the 2 m IUCAA telescope at IGO was used to obtain deep imaging in H-alpha band for nine early-type galaxies during March 12 - 13, 2008 and April 4 - 5, 2008. So far, they have good quality data of 36 early-type galaxies. Detailed analysis of dust properties is in progress. The work constitutes the doctoral work of Samridhi Kulkarni.

A research project entitled "Photometric and spectroscopic studies of galaxies in deep survey fields" was approved by ISRO, Bangalore under RESPOND programme, with S. K. Pandey as Principal Investigator (PI) and A. K. Kembhavi as Co-PI during March 2008. Total cost of the project is Rs 18.24 lakhs. The process of appointing research scholars in the project is in progress.

Particle Physics

Dutta, Sukanta

S. Dutta and A. Goyal have investigated the impact of unparticle physics on the annihilation of relic neutrinos with the neutrinos identified as primary source of ultra high energy (UHE) cosmic ray events, producing a cascade of photons and charged particles. They compute the contribution of the unparticle exchange to the cross-sections $\nu\bar{\nu} \rightarrow \gamma\gamma$ and $\nu\bar{\nu} \rightarrow f\bar{f}$ scattering. They have estimated the neutrino photon decoupling temperature from the reaction rate of $\nu\bar{\nu} \rightarrow \gamma\gamma$. They find that the inclusion of unparticles can, in fact, account for the flux of UHE cosmic rays and can also result in the lowering of neutrino - photon decoupling temperature below the QCD phase transition for unparticle physics parameters in a certain range. They calculate the mean free path of these high energy neutrinos annihilating themselves with the relic neutrinos to produce vector, axial -vector and tensor unparticles.

SN 1987A observations have been used to place constraints on the interactions between standard model particles and unparticles. S. Dutta and A. Goyal calculate the energy loss from the supernovae core through scalar, pseudo scalar, vector, pseudo vector unparticle emission from nuclear bremsstrahlung for degenerate nuclear matter interacting through one pion exchange. In order to examine the constraints on $d_{\mathcal{U}} = 1$, they considered the emission of scalar, pseudo scalar, vector, pseudo vector and tensor through the pair annihilation process $e^+e^- \rightarrow \mathcal{U}\gamma$. In addition, they have re-examined other pair annihilation processes. The most stringent bounds on the dimensionless coupling constants for $d_{\mathcal{U}} = 1$ and $\Lambda_{\mathcal{U}} = m_Z$ are obtained from nuclear bremsstrahlung process for the pseudo scalar and pseudo-vector couplings $|\lambda^{\mathcal{P}}_{0,1}| \leq 4 \times 10^{-11}$ and for tensor interaction, the best limit on dimensionless coupling is obtained from $e^+ e^- \rightarrow \mathcal{U}\gamma$ and we get $|\lambda^{\mathcal{T}}| \leq 6 \times 10^{-6}$.

In the framework of the effective field theory method, S. Dutta and coworkers have used the experimental data and the perturbative unitarity bounds to determine the values and uncertainty of all the 11 chiral coefficients (α_i, $i = 0, \cdots, 10$) of the standard electroweak chiral Lagrangian. Up to linear terms in α_i, they provide the one-loop renormalization group equations of all the chiral coefficients, which are calculated in the Feynman-'t Hooft gauge using the modified minimal subtraction scheme. With the improved renormalization group equations to sum over the logarithmic corrections, they analyzed the current experimental uncertainty of oblique correction parameters, $S(\Lambda)$ and $T(\Lambda)$. They found that, due to the large uncertainty in the triple gauge-boson coupling measurements, the parameter space of positive $S(\Lambda)$ for $\Lambda > 1$ TeV is still allowed by the current experimental data. $T(\Lambda)$ tends to increase with Λ even in the presence of the operators that contribute to the triple and quartic gauge-boson couplings.

Mukherjee, Pradip and Anirban Saha

Pradip Mukherjee, together with his collaborator Anisur Rahaman and his Ph. D. student Anirban Saha, has continued his work on the non-commutative Bosonised Schwinger model in a generalized gauge invariant regularization. The original commutative model with the indicated regularisation revealed the transition from confinement to deconfinement of the fermion. Though the introduction of spacetime non-commutativity gave rise to new features in the confinement scenario, the deconfining limit remained unaffected.

In collaboration with Rabin Banerjee and Saurav Samanta, he has also extended his earlier work on non-commutative general relativity for a more general Lie algebraic structure of spacetime. Detailed expressions for the Seiberg-Witten maps were worked out. It has been shown that in spite of the more general non-commutativity, non-trivial corrections to gravity still starts from the second order in the non-commutative parameter.

Though the effect of noncommutativity appears as second order, it is believed to be important in the context of black hole physics and cosmology. Pradip Mukherjee and Anirban Saha have worked out the second order corrections to the Reissner-Nordstrom solutions of the Einstein's equations. From the deformed metric, the horizons were derived and the curvature scalar was also computed. The introduction of non-commutativity led to the removal of the coordinate singularities.

They have also proposed a new Hamiltonian approach of abstracting the independent gauge degrees of freedom in second order metric gravity and related these with the diffeomorphism invariance of the theory.

Pandita, P.N.

Supersymmetry (SUSY) is, at present, the only known framework, in which the hierarchy between the weak scale (characterized by the mass of the Z-boson, M_Z) and the large grand unified scale (GUT scale) can be made technically natural. The minimal supersymmetric standard model (MSSM) is a concrete implementation of the idea of low energy supersymmetry. However, the MSSM suffers from various problems, including the μ problem. One of the most elegant ways to solve this problem is to extend the model by including a singlet Higgs chiral superfield, resulting in the non-minimal supersymmetric standard model (NMSSM).

P. N. Pandita, in collaboration with M. Chemtob, has carried out a detailed analysis of the scalar sector of the NMSSM with lepton number violation. The constraints imposed on the model by the stability of the electroweak symmetry breaking vacuum have been studied in detail. The model contains a trilinear lepton mumber violating term in the superpotential together with the associated soft supersymmetry breaking interactions, which can give rise to neutrino masses. The mass matrices for the various boson and fermion modes have been evaluated and the implications of the lepton number violating interactions for the mass spectra have been analysed. The conditions on the lepton number violating parameters set by the unbounded from below directions, and from the absence of the charge and colour breaking minima in this model have also been discussed.

The idea of supersymmetric grand unification is one of the most compelling theoretical ideas that goes beyond the standard model of electroweak and strong interactions. Grand unified theories (GUTs) can lead to non-universal gaugino masses at the unification scale. P. N. Pandita, in collaboration with Katri Huitu, Jari Laamanen and Sourov Roy, has studied the implications of such non-universal gaugino masses for the composition of the lightest neutralino in supersymmetric (SUSY) theories based on SU(5) gauge group. The implications of non-universal gaugino masses for the phenomenology of Higgs bosons in the context of Large Hadron Collider have been studied in detail.

Plasma Physics

Kumar, Nagendra

Nagendra Kumar, in collaboration with Vinod Kumar and Anil Kumar has studied the propagation and damping of low frequency ion acoustic waves in steady state, unmagnetised, self gravitating dusty plasma taking into account two important damping mechanisms, namely creation damping and Tromso damping (named after Tromso group). The creation damping is due to the continuous injection of fresh ions into the plasma to replace the ions, lost by the dust grains. The electron inertia is neglected because of the effects of self gravitation in the low frequency range. The dispersion relations are obtained in each case and have been solved numerically. It is found that imaginary part of wave number is independent of frequency in case of creation damping alone. But in the case of creation and Tromso damping together, an additional contribution to damping appears with the increase in frequency attributed to Tromso effects. The relative importance of both the damping mechanisms is also discussed. The results obtained might be useful in understanding the problems of dusty protostars and dusty dark molecular clouds.

Nagendra Kumar, along with Meenakshi Yadav has studied wave propagation and instabilities in molecular clouds without self-gravity under strong coupling approximation. The strong coupling approximation is valid when mass of the ion is negligible and momentum exchange time between the ions and neutrals is also negligible. The study of wave propagation without self-gravity is performed, because even at long wavelengths, the waves become almost undamped and propagate with almost the same speed as the waves in ideal MHD. It allows unambiguous identification of the waves as slow, Alfven and fast. The characteristics of the family of slow, Alfven and fast waves are discussed analytically and graphically in the broad range of directions to the magnetic field. It is observed that slow waves propagate without significant damping on short wavelengths, while the fast and Alfven waves damp rapidly. The study has important implications for gravitational collapse in the clumps that are found in molecular clouds to form stars.

Solar Physics

Jaaffrey, S.N.A.

S.N.A. Jaaffrey is engaged with modeling and data analysis for umbral dots and sunspots, finding the fine structure of their magnetic fields, Joule heating and intensity variability. Presently inversion of spectropolarimetric magnetic structures from onboard Hinode mission is in progress and SIR inversion code is being used to convert STOKES spectra. He has analyzed spectropolarimetric data of umbral dots and light bridge fragment that show dark lanes in G-band images. He has, for the first time introduced an azimuthal magnetic component, which resolved the Joule heating enhancement problem at the circumference of the umbral dots as well as variability in the diameter. Recently, he has also started research work on umbral flashes and penumbral running waves using G-band and Ca filter data taken by Hinode. The intensity variations show increased power at 5.5 MHz, and an attempt was made to find a relationship between the dark umbra and oscillation power.

He is also actively involved in the timing and spectral studies of the X- ray binary stars, X-ray transients Pulsars with and with out QPOs. He has analyzed data of a number of X-Ray binary (EXO 053109- 6609.2, XTE J1110.2-7317, 4U0115+634, etc.) of large megallanic clouds (SMC X-1, LMC X-4) taken by space telescopes RXTE. He has collaborative work with TIFR, PRL, RRI and IUCAA groups engaged in X- rays spectroscopy of pulsars.

Udayashankar, Paniveni

U. Paniveni has studied the fractal structure of the supergranular structures using the intensity data consisting of Ca II K filtergrams in the wavelength 396.36 nm of the Sun, obtained between 16 May 2001 and 26 August 2001 during the Solar maximum phase of the 23^{rd} solar cycle, at the Solar Observatory, Kodaikanal. The data was analysed using the visual inspection method by adopting to the velocity profile scans.

The area A and perimeter P of these cells are well correlated by a relation P $\propto A^{D/2}$, with the fractal dimension D determined to be about 1.3. Thus, the supergranular network is found to be isobaric in nature and in support of a turbulent convective model as proposed by Kolmogorov's theory of turbulence applicable to large scale solar convection.

Quantum Cosmology, Brane World and Quintessence

Chakraborty, S.

In braneworld scenario, S. Chakraborty, in collaboration with Tanwi Bandyopadhyay and Asit Banerjee, has obtained a model of an emergent universe. The 5D bulk energy is in the form of a cosmological constant, while the brane matter consists of a Chaplygin gas with the modified equation of state $p_b = A\rho_b - B/\rho_b$. They have shown that initially, the brane matter for the special choice $A = 1/3$, may have a negative or positive pressure, depending on the relative magnitudes of the parameter B and the bulk cosmological constant, while asymptotically in future, the braneworld approaches the ΛCDM model.

Usmani, Anisul Ain

F. Rahaman, M. Kalam, A. DeBenedictis, A. A. Usmani and Saibal Ray have peresented a model for the dark matter in galaxies using a 5D spacetime with a brane, in the Randall-Sundrum theory. The projection of Weyl's tensor into the 3D brane can be seen as an extra matter contribution on it. Using a spherically symmetric metric and a suitable ansatz for the global monopoles, they solve the field equations and obtain that the mass function grows up in a similar way as in real galaxies. The present model has the advantage that the observed rotation curves result solely from well-established non-local effects of gravitation, such as dark radiation and dark pressure under a direct use of the condition of flat rotation curves and does not invoke any exotic matter field.

Radio Astronomy

Jacob, Joe

Study of galaxy clusters unravels many enigmatic phenomena and the explanation of which sheds more light into the evolution history of the universe. Cluster radio halos are one among them, which gives insight into the physics and properties of galaxy clusters. The study of radio halos can probe the nature of dynamical activity in clusters and the connection between the thermal and non-thermal plasma and the evolution of magnetic fields in the intra-cluster medium. Radio mini halo is a new rare class of phenomena associated with ICM mostly observed around a central cD like galaxy, the formation of which still awaits a full fledged explanation. During the current year, Joe Jacob, in collaboration with J. Bagchi has participated in analyzing the GMRT data on a diffuse mini radio halo source MRC 0116+111 at a redshift of z = 0.13. The study is expected to reveal the radio jet dynamics of the source, which in turn will connect to the environment and evolution history of the source. Since the target of the investigation appears to be a rare example of a steep spectrum AGN-fed radio bubble, the results from the present study are expected to shed more light into the genesis of the rare phenomena of mini radio halos and its connection with the galaxy cluster dynamics.

He has also participated in the GMRT observations by J. Bagchi on cluster of galaxies Sersic 159-03 and Abell 3112, aimed at investigating the possibility of non-thermal origin of the soft X-ray excess emission from them. In the non-thermal model, soft x-ray excess is produced by relativistic electrons with Lorentz factors of $\sim$ 600 to $\sim$ 3500. The huge reservoir of relativistic electrons responsible for this is expected to be visible as a diffuse steep spectrum, extended radio halo. The study of this will provide more insight into the interaction of the central AGN with the ICM, which is expected to be the source of relativistic electrons producing the soft excess emissions in the cluster cores.

Jacob has participated in the efforts by J. Bagchi in building up the radio astronomy lab in IUCAA.

Stars and Interstellar Medium

Chandra, Suresh

Suresh Chandra and his research group is 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 c-C_7H_2, c-C_3H and c-C_3D molecules and found that some lines of them are found showing 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 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.

Chattopadhyay, Tanuka

Tanuka Chattopadhyay, jointly with Asis Kumar Chattopadhyay, G.J. Babu and Saptarshi has done another work on proper interpretation of horizontal branch (HB) morphology . Horizontal branch morphology is crucial to the understanding of the formation history of stellar populations. For the above study, multivariate statistical technique is used (Principal Component Analysis) for the selection of appropriate horizontal branch morphology parameter which, in the present case, is the logarithm of effective temperature extent of the HB (LogTeffHB). Then this parameter is expressed in terms of the most significant observed independent parameters of Galactic Globular Clusters (GGC) separately for coherent groups through a stepwise multiple regression technique. It is found that, metallicity ([Fe/H]), central surface brightness ($\mu_\mathbf{v}$) and core radius ($\mathbf{r}_c$) are the significant parameters to explain most of the variations in HB morphology ($multipleR^2 \sim 0.86$) for GGC belonging to the disc, while metallicity ([Fe/H]) and absolute magnitude (Mv) are for GGC belonging to the inner halo ($multipleR^2 \sim 0.52$). The robustness is tested by taking 1000 bootstrap samples. A cluster analysis is performed for the red giant branch (RGB) stars of the GGC belonging to these two groups. For disc GGC (Cluster 1), bimodal star formation is preferred, while multi episodic star formation is preferred for asymtotic giant branch (AGB) stars of GGC belonging to galactic inner halo (Cluster 2). It supports the AGB model in three episodes instead of two as suggested by Carretta et al for halo GGC, while AGB model is suggested to be revisited for disc GGC.

Rastogi, Shantanu

The mid IR features at 3.28, 6.2, 7.7, 8.6 and 11.2 μm are attributed to 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 is being studied by Shantanu Rastogi and his collaborators to relate the source to source variations in the features with type of PAHs surviving in different regions. PAHs and their cations with 10 to 96 carbon atoms have been studied using density functional method. Computations are done using the HPC facility at IUCAA. IR emission by these PAHs, after being excited by a UV photon, have been modeled assuming cascade down from a high vibrational state. Taking different PAH size groups, composite spectra have been compared with observations. Correlation with features and intensity ratios between modes obtained from the models are useful in putting constraints on PAH size and ionization states in the ISM. For a complete match with observations, the work is being extended for substituted PAHs, more complex hydrogenated and de-hydrogenated PAHs, etc.

Observation of 3.43 and 3.53 μm lines in Ae/Be Herbig stars and detection in certain carbonaceous meteorites suggests the presence of nanodiamonds in ISM. The scattering and extinction of nanodiamonds are studied using the discrete dipole approximation technique. 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 far UV rise is better represented. Incorporating PAHs and nanodiamonds in dust models is important.

Saikia, Eeshankur

Eeshankur Saikia has done research work in stellar structure and evolution, as well as non-linear dynamical theory. The High Performance Computational facility available at IUCAA has been used during the last visit. The new parallel machine Cetus was used for test runs of two parallel codes for hydrodynamical simulations, apart from calculations carried out at another clusters for some new models. Besides, calculations of non-linear time series analysis led to some new results that have been communicated for publication. Three popular articles in Assamese were also written (and now published in local magazines) utilizing the resources available there at IUCAA during the visits.

Sen, Asoke K.

Stars are formed as a result of the gravitational (Jeans) collapse of dense clumps in interstellar clouds. These clouds are partially ionized, because of nearby ionizing sources (new born stars). The gravitational instability in such molecular clouds, considering the non-Boltzmannian distribution for electrons and ions, have been investigated by Asoke Sen and his collaborator. Assuming the perturbation (fluctuation) response in radial direction as a mathematical analogue of X-direction in plane geometry approximation, the equations of motion for different species of the multi fluid plasma are linearized. Jeans swindle is used as a local approximation for the equilibrium, and the dispersion relation is derived by usual normal mode analysis. Then, an analytical solution to the dispersion equation with an explanation of the effects on star formation has been studied.

Singh, H.P.

H.P. Singh and collaborators have performed large eddy simulations of turbulent compressible convection in stellar-type convection zones by solving the Naviér-Stokes equations in three dimensions. They estimated the extent of penetration into the stable layer above a stellar-type convection zone by varying the rotation rate (Ω), the inclination of the rotation vector (θ) and the relative stability (S) of the upper stable layer The computational domain was a rectangular box in the f-plane configuration and was divided into two regions of unstable and stable stratification with the stable layer placed above the convectively unstable layer. Several models were computed and the penetration distance into the stable layer above the convection zone was estimated by determining the position where time averaged kinetic energy flux has the first zero in the upper stable layer. The vertical grid spacing in all the model was kept non-uniform, and was less in the upper region so that the flows are better resolved in the region of interest. It has been found that the penetration distance increased as the rotation rate was increased for the case when the rotation vector was aligned with the vertical axis. However, with the increase in the stability of the upper stable layer, the upward penetration distance decreases. Since they were not able to afford computations with finer resolution for all the models, they computed a number of models to see the effect of increased resolution on the upward penetration. In addition, they estimated the upper limit on the upward convective penetration from stellar convective cores.

Sun and the Solar System

Das, H. S.

H. S. Das has studied the light scattering properties of comet Levy 1990XX through simulations using Ballistic Particle-Cluster Aggregation (BPCA) or Ballistic Cluster-Cluster Aggregation (BCCA) aggregates of different compositions (e.g., silicates, carbonaceous materials, etc.) and the best fit theoretical polarization curve is generated using the superposition T-matrix code. The best fit refractive indices coming out from the present analysis show silicate behaviour when monomer radius is 0.12 micron and provide excellent results on the maximum and negative degrees of linear polarization at a single wavelength 0.485 micron for BCCA aggregates.

Ray, Saibal

Saibal Ray in collaboration with P. Chowdhury and P. C. Ray have investigated the occurrence rate of high energetic ($E > 10$ MeV) solar electron flares measured by IMP-8 spacecraft of NASA for solar cycle 21 (June 1976 to August 1986) first time by three different methods to detect periodicities accurately. Power spectrum analysis confirms a periodicity $\sim$ 155 days which is consistent with the earlier result of Chowdhury and Ray that "Rieger periodicity" was operated throughout the cycle 21, and it is independent on the energy of the electron fluxes.

Sahijpal, Sandeep

Sandeep Sahijpal has been working on the origin and the early evolution of our solar system. Based on the astronomical observations of the star forming regions, he has proposed a novel scenario for the origin of solar system in an OB association, where a massive star exploded as a supernova subsequent to Wolf-Rayet stage, and injected freshly synthesized nuclides into the early solar system.

S. Sahijpal has developed realistic, comprehensive numerical simulations of the planetary differentiation of planetesimals and asteroids in the early solar system. The planetary differentiation resulted in the formation of iron-core, silicate mantle and crust in some of the planetesimals and asteroids. He has also developed a comprehensive numerical simulation of the irradiation environment associated with the young active sun going through T Tauri phase.

Shrivastava, Pankaj K.

Pankaj K. Shrivastava has studied the various characteristic of high speed of solar wind streams and their effect on cosmic ray intensity variation. Solar wind is an ionized gas, which continuously emanates from the sun. When galactic cosmic rays enter in our solar system, this solar wind impedes galactic cosmic rays reducing their energy from reaching the earth. High speed solar wind stream is defined as rapidly increase in the solar wind speed over a short period reaching a maximum value $\geq$ 480 km/sec. persist a high value for at least five days after the increase. P.K. Shrivastava and his Ph.D. students have investigated that streams in association with sudden storm commencement (SSC) produce large forbush type transient decreases in cosmic ray intensity. They have studied the characteristics of coronal mass ejections (CMEs), interplanetary coronal mass ejections (ICMEs), magnetic clouds and interplanetary shocks waves and their role in short-term modulation of cosmic ray intensity. The fast CMEs coming from the sun into interplanetary space are solar/coronal features that contain high magnetic field having the capability to produce interplanetary disturbance. The complex family of CMEs, sometime with their leading shock waves has been called interplanetary coronal mass ejections (ICMEs) during their heliosperic propagation. One of the interplanetary phenomena, the magnetic cloud is a large interplanetary structure produced due to transient ejections in the ambient solar wind. It is found from the study that magnetic clouds in association with sudden storm commencement (SSCs) are effective in producing decreases in cosmic ray intensity. Also, they have studied the role of equatorial coronal holes in sporadic variation of cosmic ray intensity for the period of 1990 to 1995. Adopting the chree analysis of super epoch method, they have investigated that the coronal hole areas$>$ 10 to $<$ 20 are capable in producing short-term decreases in cosmic ray intensity variation. It is also suggested that the solar wind streams associated coronal hole areas are more effective in cosmic ray modulation as compared to without solar wind streams associated coronal holes areas.

(III) IUCAA-NCRA GRADUATE SCHOOL

Four IUCAA Research Scholars, Amrit Lal Ahuja (Guide: Ajit K. Kembhavi; Co-Guide: Yashwant Gupta (NCRA)), Hum Chand (Guide: R. Srianand), Atul Deep (Guide: A. N. Ramaprakash), Sanjit Mitra (Guide: Sanjeev Dhurandhar; Co-Guide: Tarun Souradeep) have defended their Ph.D.theses submitted to the University of Pune during the year of this Report. The abstracts of the same are given below:

A study of pulsar DM using the GMRT

Amrit Lal Ahuja

In this thesis work, he has described a novel experiment for the accurate estimation of pulsar dispersion measures (DMs) using the Giant Metrewave Radio Telescope (GMRT). This experiment was carried out for a sample of 12 pulsars, over a period of more than one year (2001 January to 2002 May) with observations about once every fortnight. At each epoch, the pulsar DMs were obtained from simultaneous dual-frequency observations, without requiring any absolute timing information. The DM estimates were obtained from both the single-pulse data streams and from the average profiles. The accuracy of the DM estimates at each epoch is 1 part in 10^4 or better, making the data set useful for many different kinds of studies.

The time-series of DMs shows significant variations on time-scales of weeks to months for most of the pulsars. An analysis of the mean DM values from these data shows significant deviations from catalogue values (as well as from other estimates in the literature) for some of the pulsars, with PSR B1642-03 showing the most notable differences. It appears that the constancy of pulsar DMs (at the level of 1 in 10^3 or better) cannot be taken for granted. For PSR B2217+47, there is evidence of a large scale DM gradient over a 1-year period, which is modelled as being due to a blob of enhanced electron density sampled by the line of sight. Some of the sample pulsars show a significant differences in DM results obtained from the average profile (AP) analysis method and the single-pulse (SP) method. These two methods (AP and SP) actually measure slightly different quantities, hence the difference in DM results from the two methods are not so surprising. Another interesting result is that some of the sample pulsars, including pulsars with fairly simple pulse profiles such as PSR B1642-03, show a variation of pulsar DM with frequency. This effect is investigated in detail in this work.

For frequency dependent DM variation, there can be various possible explanations. A possible candidate is the effect of pulse shape evolution on the DM estimation technique. In this work extensive simulations and more observations are carried out to investigate the effect of pulse profile evolution on pulsar DM estimates. It is found that this effect is possible only for asymmetric pulse shapes. PSRs B0329+54 and PSR B1642−03 have central core dominated emission, which does not show significant asymmetric profile evolution with frequency. Even so, it is found that the estimated DM shows significant variation with frequency for these pulsars. Results from new simultaneous multi-frequency observations of PSR B1133+16, carried out using the GMRT in phased array mode, are also reported here. This pulsar has an asymmetric pulse profile with a significant evolution with frequency. Here, it is shown that in such a case, amplitude of the observed DM variations can be attributed to profile evolution with frequency.

Probing the universe using absorption lines seen in the spectra of quasars

Hum Chand

In this thesis he has investigated the possible time variation of electromagnetic fine-structure constant, α, by using the absorption lines seen in the spectra of QSOs. Detecting or constraining the possible time and space variations of such fundamental physical constants is an important step toward complete understanding of the fundamental physics. With the advent of 10m class telescopes equipped with very high resolution spectrographs, such as UVES/VLT and HIRES/Keck, it becomes feasible to obtain spectra of high-z QSOs with high signal-to-noise ratio ($\approx 70-80$) and high spectral resolution ($R \approx 50\,000$). As a result, the absorption lines seen in the spectra of QSOs have became a very sensitive tool to study the time variation of α. In addition, the recently devised many-multiplet (MM) method has improved the sensitivity of $\Delta\alpha/\alpha$ measurements by an order of magnitude compared to the standard alkali-doublet (AD) method that was used in the past.

Therefore, the time has ripen to exploit the high quality absorption line spectra to detect or constrain the time and space variation of α, with very high accuracy. He has used a high signal-to-noise ratio ($\sim$ 70 per pixel) and high spectral resolution ($R \geq 50,000$) UVES/VLT data sample, to detect or constrain the possible variation of the fine-structure constant. In view of various possible systematic errors involved in MM method, he carried out detailed simulations to devise a proper selection criteria for choosing suitable absorption systems for the analysis. He found that (i) best constraints on $\Delta\alpha/\alpha$ are obtained using either the systems with single absorption component or from systems with well resolved multiple components, (ii) there is a non-negligible probability for deriving a statistically significant deviation from the actual $\Delta\alpha/\alpha$ value, when one considers highly blended systems, (iii) it is better to consider only the species with similar ionization potentials (such as Mg II, Fe II, Si II and Al II), so that they are most likely to originate from similar regions in the cloud, (iv) weak lines (detected with $< 5\sigma$ level) should be avoided as their profiles can be affected by the Poisson noise, which could result in a possible false-alarm detections of non-zero $\Delta\alpha/\alpha$ values. Application of these selection criteria on the total of 50 Mg II systems have resulted in best 23 Mg II systems for the measurement of $\Delta\alpha/\alpha$ over a redshift range $0.4 \leq z \leq 2.3$. The weighted mean of the individual measurements from the analysis, resulted in $\Delta\alpha/\alpha = (-0.06 \pm 0.06) \times 10^{-5}$, which forms the most strongest constraint on α variation from quasar absorption line sample till date. However, it should be noted that the results of MM method hinges on two assumptions: (i) ionization and chemical homogeneity of different species used, and (ii) isotopic abundances of Mg II close to the terrestrial value. He has minimised the effect of former by applying proper selection criteria and by avoiding DLAs from the analysis, where the ionization and chemical inhomogeneity could be significant. The other assumption of Mg II isotopic compositions close to the terrestrial value, also seems to be reasonable, based on the observed metal abundance in the quasar absorption systems. He has also extended the experiment to obtain constrain based on AD method. Although AD method is less sensitive as compared to the MM method, it avoids the implicit assumptions used in the MM method that chemical and ionization inhomogeneities are negligible. Also the effect of isotopic shifts is negligible in the case of Si IV doublets. He has applied AD method to 15 Si IV doublets selected from the UVES/VLT data sample. The weighted mean of the individual measurements, resulted in $\Delta\alpha/\alpha = (+0.15 \pm 0.43) \times 10^{-5}$ over a redshift range of $1.59 \leq z \leq 2.92$. This result also represents a factor of three improvement on $\Delta\alpha/\alpha$ measurements based on Si IV doublets compared to the published results in the literature. He has also made use of the high resolution (R $\approx$ 112000) HARPS/ESO data of HE 0515-1444 to chase the possible systematic errors. He used the HARPS spectrum of very high wavelength calibration accuracy (better than 1 mÅ), to constrain the variation of α and investigate any possible systematic inaccuracies of wavelength calibration in the UVES/VLT data. He found that the shift between the HARPS and UVES spectra has a mean around zero with a dispersion of $\sigma \simeq 1$ mÅ. This is found to be well within the wavelength calibration accuracy of UVES (i.e., $\sigma \simeq 4$ mÅ). The analysis shows that the uncertainties in the wavelength calibration of UVES induces an error of about $\Delta\alpha/\alpha \leq 10^{-6}$ in determining the variation of the fine-structure constant. Thus, the above results of non-evolving $\Delta\alpha/\alpha$ as well as other results reported in the literature based on UVES/VLT data set should not be heavily influenced by problems related to wavelength calibration uncertainties. The higher resolution spectrum of the $z_{\rm abs} = 1.1508$ damped Lyman-α system toward HE 0515−4414 reveals more components compared to the UVES spectrum. Using only Fe II lines of the $z_{\rm abs} = 1.1508$ system, he has obtained $\Delta\alpha/\alpha = (0.05 \pm 0.24) \times 10^{-5}$.

In summary, from the detailed study using UVES/VLT data sample, he has come to the conclusion that electromagnetic fine-structure constant (α), does not vary by more than about one part per million ($\langle\Delta\alpha/\alpha\rangle_w = (-0.06 \pm 0.06) \times 10^{-5}$) over a look back time of around 9.7 Gyr (i.e., median redshift of 1.55), and this result does not support the claims of its significant variation reported in literature, based on the HIRES/Keck data sample.

Near Infrared PICNIC Imager (NIPI)

Atul Deep

The telescope at IUCAA Girawali Observatory (IGO) has 2 m aperture f/3 primary of Astro-Sital, and a Ritchey-Chretien optics to get a focal ratio of 10 at the Cassegrain focal station. This station will have a direct port as well as four side ports. An imager-spectrograph

(IFOSC) for the optical band (3500Å- 8500Å), which will be the main work-horse instrument mounted at the direct port has already been installed on the telescope. This instrument was developed for IUCAA at Copenhagen University. In order to fully utilize the observational capabilities of IGO, it was decided to develop a near-infrared camera, which would be attached to one of the side ports of the telescope. This thesis is mainly concerned with the design and fabrication of Near Infrared PICNIC Imager (NIPI).

The NIPI works in the wavelength range of 1 - 2.5 μm. It has four broad-band filters, viz. J, H, K and K. NIPI has a de-magnification of 0.5, thereby, increasing the plate scale to 20"/mm and reducing the final focal ratio to 5. The field of view of the instrument is about 2.5 arc minutes radius. The camera has been equipped with a 256 x 256 HgCdTe IR PICNIC array from Rockwell International Corporation. PICNIC is an upgrade of the well known NICMOS3 array. The major improvement, with respect to NICMOS3 device, is the reduced readout noise. The Quantum Efficiency (QE) for the desired wavelength range is around 0.65.

The FWHM of a seeing limited image of a point object would be contained within 2 $\times$ 2 pixels in the detector plane. This matches the Nyquist limit for critical sampling. The instrument has a collimator-camera type optical design and uses two pairs of CaF_2-SiO_2 achromatic doublets. The material for lenses was chosen on the basis of their transmittance in near-infrared wavelength range, cost and availability. The linear layout of the design from telescope focus to detector is around 900 mm. The design has been folded using three mirrors. The image quality has been analyzed using spot diagrams and encircled energy. RMS spot size and the 80% encircled energy fall within one pixel for on-axis as well as full-field point objects. Finally, tolerance analysis was performed on the optical design to check that the specifications of lenses are well within manufacturing (and cost) limits. The optical design was optimized and toleranced using ZEMAX software.

In order to save manufacturing time and money, a standard size dewar with some modifications was purchased directly from Infrared Labs, Arizona. This dewar has a 7 litre capacity liquid nitrogen tank for cooling the optics and detector. An extension box, which houses the lenses, mirrors, filter wheel and detector is connected to this dewar. The extension and all the sub-assemblies inside it have been designed in-house and manufactured locally. The light from the telescope focus enters the instrument through a CaF_2 window and traverses the entire optical train consisting of lenses, mirrors and a filter, and finally reaches the detector. The entire optical assembly, other than the filters, is placed in vertical mounts attached to a base plate. A fiber glass isolator provides thermal isolation to base plate from the extension box. To reduce radiation losses all the opto-mechanical components have been enclosed in a radiation shield. A second actively cooled radiation shield encloses the detector assembly. The stresses developed in the lenses due to differential contraction of glass and mount material are well within the rule-of-thumb tolerance for compression of glass.

The filter wheel is the only moving part of the instrument. It has a steel shaft attached to its central portion. This shaft passes through a wall of the extension box where a worm gear has been mounted on its outer portion. The worm gear is rotated with the help of a stepper motor, which in turn rotates the shaft and filter wheel combination. This design makes sure that all the gearings and bearings are outside the evacuated, cooled enclosure so that there is no problem of low temperature,and vacuum grade lubricant. The joint, where the shaft passes through the extension box is sealed using two O-rings. This acts as a vacuum feedthrough for the filter wheel. The cold finger, which would be in direct contact with the PICNIC array is coupled to liquid nitrogen can using thick copper braids.

The PICNIC array is fabricated using PACE-I process. The input circuit is source follower per detector (SFD) and the full-well capacity of a pixel is around $2 \times 10^5\ e^-$. Read-noise of less than 20 electrons and dark current of less than 1 electron can be attained with this detector. The 256 $\times$ 256 PICNIC array is structured into four independent quadrants having four outputs. Six clocks and two bias voltages are required for the working of PICNIC array. These bias voltages and clock signals are generated by NIPI controller, which is the main component of the data acquisition system for the instrument. The NIPI controller consists of six cards - Master card, Waveform Generator card, Analog and Signal Processing card, Bias card, and Telemetry card. The data acquisition software of the instrument resides in a host PC. The NIPI controller receives commands from the data acquisition software residing in host PC via a fiber optic cable, generates the required waveforms and bias voltages for reading out PICNIC array and sends the digitized data back to host PC at the end of exposure. The readout scheme for NIPI has multiple modes - single sampling, correlated double sampling, ramp sampling and Fowler sampling and, any of which can be activated depending on the choice of the observer. A separate device known as Motion Controller is used to drive the stepper motor and to control the relay switches under command control from the host computer.

Once the design of the instrument was finalized, he started procuring various mechanical and optical parts. Some parts were available off-shelf, while others had to be manufactured with tight specifications.

Before starting the assembly of the instrument, tests were performed on severals parts and sub-assemblies in conditions similar to the final operational ones. For example, stepper motor assembly, consisting of gearings, bearings, vacuum feedthrough, filter wheel and the stepper motor itself was tested thoroughly before finalizing its design.

A highly reflective aluminum foil was glued to the outer side of radiation shield box and cover. The lens mounts, mirror holders, etc. were painted nextel black to reduce the problem of stray photons. Then the lenses were glued to their mounts using araldite and the mirrors were mounted in their holders using retainer strips. Once the lenses and mirrors were fixed in their respective mounts, the entire optical train was aligned on the base plate with the help of a laser. Minor adjustments during the alignment were done using shims and pads.

The data acquisition system was tested using an oscilloscope, to see that all the clock signals and bias voltages were being generated properly. The digitization process of NIPI controller was also checked independently. Once satisfied with the performance of data acquisition system, multiplexer testing was done. The image of an incandescent bulb filament was acquired using multiplexer as an imaging device. The speed and dynamic range of the array was also verified. The final tests were done using actual PICNIC array.

Gravitational waves from inspiraling binaries and cosmological ramifications

Sanjit Mitra

The past five years have ushered in a new era of observational astronomy. Ground based gravitational wave (GW) detectors - LIGO, TAMA and GEO - have started taking science quality data. Space based cosmic microwave background (CMB) experiments - WMAP - has produced a true image of the CMB temperature anisotropy sky and also has mapped the CMB polarization sky. Efficiently extracting maximum amount of science out of these data rich experiments pose challenges to the modern analysis techniques. Few of the issues regarding efficient analysis of data have been addressed in this thesis.

Detection of GW from inspiraling binaries is perhaps the most important experimental goal in experimental general relativity for the next few years. However, extracting the true GW strain signal from much stronger random detector noise is quite challenging. Current analysis strategy relies on matched filtering techniques, which is computationally expensive. He has developed an interpolation scheme for efficient implementation of matched filtering based analysis algorithms. He has used numerical simulations to show that this new method reduces computational cost, thereby, increasing the volume the parameter space that can be searched with the available computing resources.

Measurement of the anisotropy of the CMB and the gravitational wave background (GWB) are equally important challenges in experimental cosmology to probe the history of the early universe. Usually the imaged skymaps are convolved with the instrumental beam functions, also known as the point spread functions (PSF). Unbiased estimation of the anisotropies of these backgrounds requires development of smart analysis strategies. He has analytically formulated and numerically implemented complete analysis frameworks to account for the effects of beam functions in the analysis of CMB and GWB.

The thesis has been organized as follows:

- **Chapter 1** provides an overall introduction and motivation on the works presented in this thesis.
- **Chapter 2** provides an introduction to Gravitational Waves (GW) and its sources, detectors and data analysis, essentially

mentioning the features important for the detection of GW.

- The Chebyshev interpolated search algorithm for efficient detection of GW from inspiraling binaries and the results are presented in **Chapter 3**.
- A brief introduction to stochastic Gravitational Wave Background (GWB) and a detailed review of the general radiometer analysis for the detection of GWB has been presented in **Chapter 4**.
- Brief introduction to the theory and experiments of Cosmic Microwave Background (CMB) and its anisotropy, emphasizing points, which are relevant to the work presented in this thesis, is provided in **Chapter 5**.
- The analytical formulation of beams and deconvolution in CMB and GWB analysis is presented in **Chapter 6**.
- Implementation of radiometer deconvolution algorithm and application to GWB skymaps obtained from simulated detector outputs is presented in **Chapter 7**.
- The leading order correction to CMB power spectrum due to non-circular beams is estimated using a perturbative analysis in **Chapter 8**.
- General analysis framework for the pseudo-C_l approach to correct for non-circular beams including the effect of incomplete sky coverage is developed in **Chapter 9**.
- The summary of the main results obtained in this thesis and future directions are mentioned in **Chapter 10**.

(IV) PUBLICATIONS

By IUCAA Resident Members

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

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Books

Chauhan, T.S., **Kumar, N.**, Kumar, R. and Chauhan, J.P. (2007) Vectors and Geometry, Shiksha Sahitya Prakashan, Meerut.

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Supervision of Thesis

Chandra, Suresh (2007) Identification of molecules in cool cosmic objects. Ph.D. thesis of Shivprasad V. Shinde

Chakraborty, S. and **Debnath, U.** (2007) Gravitational collapse and astrophysical consequences in gravity and brane world scenario, Jadavpur University, Kolkata, Ph. D. thesis of Soma Nath.

Patil, K.D. (2007) End state of spherically symmetric gravitational collapse, R.T.M.Nagpur University, Nagpur, Ph.D. thesis of U.S.Thool.

Pradhan, A. (2007) A study on cosmological constant-the weight of the vacuum, V.B.S. Purvanchal University, Jaunpur, Ph.D. thesis of *Purnima Pandey.*

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MEAN IMPACT FACTOR OF PUBLICATIONS

The two conventional indices for measuring the scientific productivity have been (a) the number of publications in peer reviewed journals, and (b) number of citations. Both have obvious advantages and disadvantages. A possible alternative/additional indicator, when the average impact of an entire institute/community needs to be measured, could be the mean impact factor of the publications. This is calculated by multiplying the number of papers in a journal by the corresponding impact factor of the journal and averaging the result over the persons involved. Similarly, one can compute the mean impact factor per paper by dividing the total impact factor by the total number of papers published.

It is found that the Mean Impact Factor of an IUCAA member during 2007-08 was around 3.76 and the corresponding figure for the Associates was around 2.06. The mean impact factor of a paper by an IUCAA member during 2007-08 was around 4.4. The corresponding figure for the Associates was around 2.5.

(V) PEDAGOGICAL ACTIVITIES

(a) IUCAA-NCRA Graduate School

Sanjeev Dhurandhar
Methods of Mathematical Physics I

Ajit Kembhavi
Electrodynamics and Radiative Processes I

T. Padmanabhan
Quantum and Statistical Mechanics II

Maulik Parikh
Advanced topical course - Topics and Techniques in Theoretical Physics.
(40 hours of lectures and student-run seminars)

A. N. Ramaprakash
Astronomical Techniques I

Swara Ravindranath
Galaxies : Structure, Dynamics and Evolution

Tarun Souradeep
Methods of Mathematical Physics II

R. Srianand
Extragalactic Astronomy II

K. Subramanian
Extragalactic Astronomy I

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

Joydeep Bagchi
Astronomy and Astrophysics - I
(Lectures and Lab experiments).

Dipankar Bhattacharya
Astronomy and Astrophysics I (21 lectures)

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)

J. V. Narlikar
Astronomy and Astrophysics II

(c) Supervision of Projects

J. Bagchi

Jaydeep Belapure, June - July VSP
Faraday rotation effect (VSP-2007 project)

Aditya Rotti
Cosmological shock waves (University of Pune ,M.Sc.)

Jaydeep Belapure
The radio-halo source MRC~0016+111 (University of Pune, M.Sc.)

Viral Parekh
Using Faraday rotation effect for communication (Fergusson College, M.Sc.)

Jaydeep Belpure
*Faraday Rotation effect: Laboratory experiment and as an astrophysical tool (*KVPY)

Mona Saundankar, Jitendra Salunke, Vidhya Sutar
Fabrication of a complete 21-cm receiving system (COEP, Pune)

Ajit Kembhavi

Amruta Deshpande and Swati Deshmukh, S.R.T.M. University, Nanded, VSP - 2007)
Investing AGN's by relating central supermassive black holes mass with various galactic photometric properties.

Shilpa Gopalakrishnan, Amruta Joshi, Sneha Kadam and Tasneem Rashiq, Cummins College of Engineering for Women, Pune,
VOPlot 3D and its enhancements.

Rashmi M., B.V. Bhoomaraddi College of Engg. and Tech., Hubli,
(M.Tech.) VOCat-TNG-Server Application Module.

Aswale, Shailendra, B.V. Bhoomaraddi College of Engg. and Tech., Hubli,
(M. Tech,) VOCat-TNG-Client Application Module.

Ranjeev Misra

Aparna S. , C. M. S. College, Kottayam, Kerala (M.Sc.)
Structure of accretion disks around black holes.

J. V. Narlikar

Sandeep N. (VSP-2007)
Observational tests of cosmology- Counting of radio sources and quasars

Shreyashi Chakdar (VSP-2007)
Observational test of cosmology - Redshift magnitude relation

A. N. Ramaprakash

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

M. Deshmukh (Pune University)
Atmospheric effects in astronomical observations

M. Savai, S. Sane and S. Bendhale (Sinhgad Engineering College, Pune)
Single board computer with Nut OS

T. Krishna, N. Patil, A. Vilekar (Maharashtra Institute of Technology)
USB-RS232 and ethernet-RS232 bridge board testing

Tarun Souradeep

Tuhin Ghosh
Galactic and Cosmological signals in the microwave background anisotropy and polarization

Moumita Aich
CMB temperature and polarization anisotropies on an incomplete sky

Sandeep Kumar
Approximation to the CMB angular power spectrum

Juzar Thingna, University of Pune (M.Sc.)
[Co-supervised by Dr. Biswajit Pandey (IUCAA)].
Topological characterization of Random fields

Preshnath Jagannathan (University Pune) M.Sc.
[Co-supervised with Prof. Mihir Arjunwadkar, CMS, Univ. of Pune.]
Non parametric estimation of the CMB power spectrum

R. Srianand

Alok Mukherjee, Indian Academy of Science
Modelling QSO absorption lines

Parul Jain, Fergusson College, (B.Sc.)
Compact H II regions

Mukul Khaskey, Fergusson College, (B.Sc.)
Star formation at high-z

K. Subramanian

Bhargav Vaidya (VSP-2007)
Astrophysical outflows

Rahul Noronha (Pune University), (M.Sc.)
Astrophysical outflows

(d) Supervision of Ph.D.Thesis

Dipankar Bhattacharya (Guide)
By Atish Kamble (RRI), Bangalore.
An investigation of gamma ray burst collimation

Ajit Kembhavi (Guide)
Yashwant Gupta (Co-Guide)
By Amrit Lal Ahuja
A study of pulsar DM using the GMRT

R. Srianand (Guide)
By Hum Chand
Probing the universe using absorption lines seen in the spectra of quasars

A. N. Ramaprakash (Guide)
By Atul Deep
Near Infrared PICNIC Imager (NIPI)

Sanjeev Dhurandhar (Guide)
Tarun Souradeep (Co-Guide)
By Sanjit Mitra
Gravitational waves from inspiraling binaries and cosmological ramifications on disks around black holes"

(VI) SEMINARS, COLLOQUIA, etc. AT IUCAA

(a) Seminars

Tirthabir Biswas: *Non-perturbative and non-singular (?) gravity,* April 10.

Andy Fabian: *The X-ray background,* April 11.

Mikhail Marov: *Modeling of protoplanetary gas-dust disk evolution,* April 12.

Carolin Crawford: *The origin of the emission-line nebulae around central cluster galaxies,* April 13.

Sharmila Kamat: *Hunting for WIMPs - The search for dark matter in the universe,* April 18.

J. Maharana: *Novel symmetries of string theory,* April 30.

Jean Pierre Petit: *Geometrization of Sakharov model through group theory,* May 9.

Sayan Kar: *Quantum mechanics in volcano potentials,* May 17.

S. Guha: *A brief review of the work on embedding problems,* June 8.

R.S. Kaushal: *Role of metaphor and simile in mathematical sciences,* June 8.

S.K. Pandey: *The lighter side of observational astronomy,* June 8.

Mudit K. Srivastava: *Design and development of an optical fibre based integral field unit (IFU) for 2-D spectroscopy,* June 11.

Lalan Prasad: *Solar coronal heating,* June 14.

Himadri Sekhar Das: *Light scattering properties of cometary dust,* June 14

Abhishek Rawat: *Tracing the evolution in the merger-rate of galaxies out to redshift ~ 1.2,* July 5.

Susmita Chakravorty: *Warm absorber,* July 24.

Gaurang Mahajan: *Particle creation, classicality and related issues in QFT,* July 24.

Saumyadip Samui: *Probing the star formation history using the luminosity functions and its feedback through the galactic outflows,* July 24.

Sudipta Sarkar: *Quantum effects and thermodynamics of horizons in strong gravitational field,* July 24.

Arman Shafieloo: *Non-parametric reconstruction of the cosmological quantities from observational data,* July 24.

Mudit K. Srivastava: *Optical design of an optical fibre based integral field unit (IFU) for 2-D spectroscopy,* July 24.

Sharanya Sur: *Astrophysical magnetic fields and dynamo theory,* July 24.

Himan Mukhopadhyay: *Coherent and coincident strategies for detecting binary inspiral GW signals,* July 24.

Sudhanshu Barway: *The nuclear structure of Lenticular galaxies - A HST WFPC-2 imaging survey,* July 25.

Soumen Basak: *CMB data analysis,* July 25.

Rajesh Gopal: *CMBR anisotropies induced by magnetised scalar modes,* July 25.

Minu Joy: *A new feature in the inflationary perturbation spectrum,* July 25.

Ratna Koley: *Quantum mechanics in one dimension and cosmology in higher dimensions,* July 25.

Supratik Pal: *Braneworld gravity: some new features,* July 25.

Biswajit Pandey: *The luminosity-bias relation from filaments in the Sloan Digital Sky Survey data release four,* July 25.

Subharthi Ray: *Non-circularity of experimental beams in the CMB power spectrum estimation,* July 25.

Sanjiv Kumar Tiwari: *Measurements of helicity in the sun,* August 2.

Moumita Aich: *CMB temperature and polarization anisotropies on an incomplete sky,* August 22.

Tuhin Ghosh: *Foreground contamination of CMB maps,* August 22.

Saugata Chatterjee: *String cosmology,* August 22.

Rajib Saha: *Blind estimation of the angular power spectrum from multi-frequency CMB maps,* September 13.

Asaf Pe'er: *Early and late time evolution of thermal emission in gamma-ray bursts*, September 24.

Bhanu P. Das: *The search for the electric dipole moment of the electron: A new direction in laboratory astrophysics*, September 27.

Prateek Sharma: *Transport and heating in low luminosity accretion flows*, October 4.

T. Sivarani: *Probing the nature of first stars with observed abundance patterns of EMP stars*, November 26.

Sergey Chervon: *Non-linear fields in general relativity and cosmology*, December 6.

Ishwaree Neupane: *Inflation and dark energy: some lessons from string theory (or vice versa)*, December 7.

Manu Paranjape: *A modest appeal to conformal gravity*, December 10.

Sandeep Kumar: *Approximation to the CMB angular power spectrum*, December 26.

V.P. Nair: *Twistor strings: old and new, January 14.*

Roy Maartens: *Magnetic fields and vorticity*, January 16

A. Gopakumar : *TaylorEt GW templates and the SAPE, January 17.*

Prasant K. Samantray: *String thermodynamics, January 21.*

Ludwig Streit: *Feynman integrals as generalized functions on path space: Things done and open problems, February 4.*

Saumyadip Samui: *Constrained semi-analytical models of galactic outflows, February 14.*

Siddharth S. Malu: *CMB polarization: Instrumentation and analysis, February 21.*

Sudipta Sarkar: *Sub-leading contributions to the black hole entropy in the brick wall approach, March 6.*

Amitabh Virmani: *Stress tensor for asymptotically flat gravity, March 13.*

Dipak Munshi: *Probing the dark side of the universe: Cosmology with weak lensing surveys, March 17.*

Naseer Iqbal: *Archaeoastronomy and its importance, March 18.*

Dipak Munshi: *Finger-printing the universe: Error in error-bars*, March 19.

Naresh Dadhich: *Gravitational dynamics*, March 27.

(b) Colloquia

P. P. Divakaran: *Calculus under the coconut trees*, April 2.

Andy Fabian: *Probing strong gravity with broad iron lines*, April 9.

Peter Gillingham: *The attractions of antarctic astronomy*, October 12.

George Djorgovski: *Virtual astronomy and computationally enabled science for the 21st century*, October 16.

Arnab Bhattacharya: *N-lightenment*, November 19.

Praveen Chaddah: *Phase transitions using magnetic fields, and the physics of glass*, December 3.

Roy Maartens: *Dark energy and dark gravity*, January 21.

(VII) TALKS AT IUCAA WORKSHOPS OR AT OTHER INSTITUTIONS

(a) Seminars, Colloquia and Lectures

Dipankar Bhattacharya

Gamma Ray Bursts, IUCAA, VSP, June, 13.

Gamma Ray Bursts and their Afterglows, National Symposium on Gamma Ray Astronomy, Indian Institute of Astrophysics, Bangalore, November 24.

Plasma Flow on Strongly Magnetized Neutron Stars, 8th Asia Pacific Plasma Theory Conference, Institute for Plasma Research, Ahmedabad, December 11.

Astronomy at X-ray Wavelengths, Programme on Frontiers in Physics, Fergusson College, Pune, January 9.

Black Hole Studies with ASTROSAT, Workshop on Measuring Spin and Mass of Black Holes, IUCAA, December 19.

Measuring Magnetic Fields of Neutron Stars by Studies of Cyclotron Lines with ASTROSAT, ASTROSAT Science Meeting, Delhi University, January 17.

Discovery of the Progenitor of the Type Ia Supernova 2007, IDG, IUCAA, March 14.

Naresh Dadhich

Gravity in Higher Dimensions, Himalayan Relativity Dialogue discussion (organized by IUCAA in association with the IUCAA Reference Centre, North Bengal University at The Orange Country Retreat), Mirik, April 18.

Why Einstein [Had I Been Born in 1844!]?, North Bengal University, Darjeeling, April 20.

Why Einstein [Had I Been Born in 1844!]? Jadavpur University, Kolkata, April 21.

Gravity in Higher Dimensions, Indian Institute of Technology, Kharagpur, April 23.

Why Einstein [Had I Been Born in 1844!]? (a Public Lecture), Jawaharlal Nehru Planetarium, Bangalore, April 25.

Universalization as Physical Guiding Principle, Refresher Course and VSP, IUCAA, May 18.

Black Hole from Pure Curvature, University of Barcelona, Spain, May 22

Why Einstein [Had I Been Born in 1844!]?, Centre for Space Science, Barcelona, Spain, May 23.

Black Hole from Pure Curvature, Federal University of Paraïba, Joa Pessoa, Spain, May 29.

Black Hole from Pure Curvature, Brazilian Center for Physics Research, Rio de Janeiro, Brazil, June 5.

Why Einstein [Had I Been Born in 1844!]?, Federal University of Rio de Janeiro, Brazil, June 7.

Black Hole from Pure Curvature, (a Colloquium) King's College, London, June 13.

Black Hole from Pure Curvature, Institute of Astrophysics, Paris, France, June 21.

Origin of Matter out of Pure Curvature, Alternative Theories of Gravity workshop held during the 18th International Conference on General Relativity and Gravitation, Sydney, Australia, July 9.

Gravity and Higher Dimensions - A Classical Motivation, Indian Institute of Astrophysics, Bangalore, August 7.

Why Einstein?, Science College, Nashik, August 16.

Gravity and Higher Dimension, Department of Physics, Jamia Millia Islamia, New Delhi, September 17.

Why Einstein [Had I Been Born in 1844!]?, Bogazici University, Turkey, October 17.

Gravity and Higher Dimensions, (Plenary talk), Hanno Rund Conference, Drakensberg Mountains, Kwa-Zulu Natal, South Africa, November 18.

Why Einstein [Had I Been Born in 1844!]?, International Conference on "Advances in Mathematics: Historical Developments and Engineering Applications" organized by G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, December 22.

Classical Motivation for Higher Dimension for Gravity, International Conference on "Non-Perturbative Gauge Theories and Gravity", S.N. Bose National Centre for Basic Sciences, Kolkata, January 7.

Gravity from Newton to Einstein and Beyond, Symposium on "Astrophysics with Spectroscopic and

Photometric Data", Department of Physics, Assam University, February 1.

Why Einstein [Had I Been Born in 1844!]?, St. Stephen's College, National Science Festival 2008, Delhi, February 9.

Science and Society, S.M. Joshi Socialist Foundation organized by Maharashtra Andhshraddha Nirmulan Samiti, Pune, February 24.

Gravity, M.Sc. students of Presidency College, Kolkata in IUCAA, Pune, February 25.

Science and Society, National Science Day celebrations of Agharkar Research Institute, Pune, February 27.

Why Einstein [Had I Been Born in 1844!]?, Department of Physics, Dr. Babasaheb Ambedkar Marathwada University, Aurangabad, March 1.

Why Einstein : A Journey from Newton to Einstein, SGGS Institute of Engineering and Technology, Nanded, during PRAGYAA 2008, March 2.

Sanjeev Dhurandhar

The Radiometric Search for Gravitational Waves: Stochastic and Pulsars, The Japanese Physical Society meeting, Kinki University, Osaka, Japan, March 25.

Gravitational Waves: The Dawn, (Professor Mahanta Memorial Lecture) Gauhati University, Assam, June 25.

The Global Search for Gravitational Waves, Indian Institute of Astrophysics, Bangalore, February 12.

Gravitational Waves: An introduction, Refresher Course, Physics Department, Pune University, January 17.

Ranjan Gupta

Stellar Spectroscopy, at Refresher course in Astronomy and Astrophysics for College and University Teachers, and VSP, IUCAA, May 24-25 (2 lectures).

Light Scattering Phenomenon and its Relevance to Atmospheric and other Studies, Mausam Bhavan, IMD, New Delhi, April 17.

Dust in Astrophysical Environments and its Modeling TIFR, Mumbai, July 13.

Dust and its Role in Astrophysics and Other Environments and its Modeling based on light Scattering Phenomena, School of Physical Sciences, JNU, New Delhi, October 4.

Spectroscopy with Small Telescopes, Workshop on Observations with Small telescopes, Bhavnagar University, November 20.

Discrete Dipole Approximation and its Applications to Astrophysical Dust, Workshop on Light Scattering Methods in Dust Modeling at SNBNCBS, Kolkata November 28.

Aspects of Practicing Observational Astronomy with the Telescope System Available, Kalyani University, November 30.

Dust and its Role in Astrophysics and ANNs and Stellar Spectral Classification, IASBS, Zanjan, Iran December 25-26. (2 talks).

Development of Artificial Neural Network (ANN) Scheme for Application to TAUVEX Satellite data; Interpretation of the Observed Extinction in the optical-UV Region from TAUVEX and ASTROSAT-UVIT Satellite Database, Respond Review Meeting at PRL, Ahmedabad, March 14. (2 talks).

ANNs and Application to Upcoming Satellite Missions, IPR, Ahmedabad, March 17.

Ajit Kembhavi

A Supermassive Black Hole Fundamental Plane, The Spring IVOA Interoperability Meeting, Beijing Oriental Cultural Hotel, Beijing, China, May 10.

Virtual Observatories: India, The Spring IVOA Interoperability Meeting, Beijing Oriental Cultural Hotel, Beijing, China, May 10.

Virtual Observatories: A Paradigm for High Technology and Joint Ventures, Computer Society of India, Pune Chapter, Damle Hall, Pune, May 23.

Supermassive Black Holes in Galaxies, National Research Institute of Astronomy and Geophysics (NRIAG), Cairo, Egypt, June 25.

Astronomy with Virtual Observatories, National Research Institute of Astronomy and Geophysics (NRIAG), Cairo, Egypt, June 26.

Fundamental Correlations in Galaxies, National Research Institute of Astronomy and Geophysics (NRIAG), Cairo, Egypt, June 27.

Data Analysis with Virtual Observatories, Workshop on Data Analysis and Simulation Techniques in Observational Astronomy, University of Calicut, Kerala, August 10.

Virtual Observatories, Workshop on Virtual Observatory and Astronomical Data, J.E.S. R.G.B. Arts, S.B.L. Commerce and R.B. Science College, Jalna, August 29.

Galaxies in the Universe, Workshop on Virtual Observatory and Astronomical Data, J.E.S. R.G.B. Arts, S.B.L. Commerce and R.B. Science College, Jalna, August 30.

Cosmic Illusion, Maharajas College, Kochi, Kerala, September 18.

Cosmic Illusions, One Day State Level Seminar on "Astrophysics", Basaveshwar Science College, Bagalkot, September 22.

Online Consortia and UGC Infonet, Workshop on 'Resource Sharing among Social Science Libraries in the Internet Era', Gokhale Institute of Politics and Economics, Pune, September 28.

Data Archives and Access, Workshop on Astronomy with Virtual Observatories, IUCAA, October 15.

VO-I tools, Workshop on Astronomy with Virtual Observatories, IUCAA, October 16.

Science Case: Search for New Quasars, Workshop on Astronomy with Virtual Observatories, IUCAA, October 19.

The VO from the Indian Perspective, SALT Science Workshop, University of KwaZulu -Natal, South Africa, October 27.

Virtual Observatories, Indian Institute of Technology, Kharagpur, West Bengal, November 3.

Cosmic Dust – An Overview, Workshop on Light Scattering Methods in Dust Modelling, S. N. Bose National Centre for Basic Sciences, Kolkata, November 28.

Supermassive Black Holes, Centre for Theoretical Physics, Jamia Millia Islamia, New Delhi, November 30.

Astrophysics of Stars (2 lectures), Refresher Course on Astronomy, Central Training Institute, Pashan, Pune, December 11.

Super-massive black hole mass systematics, Conference on Measuring Spin and Mass of Black Holes, YASHADA, Pune, December 18.

Cosmic Dust, IUCAA Reference Centre, Cochin University of Science and Technology, Kochi, Kerala, January 2.

Supermassive Black Holes, Young Astronomers' Meet, M.G. University, Kottayam, Kerala, January 3.

Astronomical Spectroscopy from Stars to the Universe, Symposium on Astrophysics with Spectroscopic and Photometric Data, Assam University, Silchar, Assam, February 2.

Web 2.0 Library 2.0, Workshop on Librarianship 2.0: Emerging Trends in Connecting People to Information, MCCIA, Pune, February 8.

Supermassive Black Holes – Here, There and Everywhere, Institute of Mathematical Sciences, Chennai, March 12.

The Physics of Warm Absorbers in Active Galaxies, Institute of Mathematical Sciences, Chennai, March 13.

Supermassive Black Holes – Here, There and Everywhere, Astronomy and Astrophysics Division, Physical Research Laboratory, Ahmedabad, April 10.

W2.0-L2.0 (Web Based Technologies and Web Based Library Services), H.V. Ganganna Memorial Endowment Lecture, Gulbarga University, Karnataka, April 22.

Ranjeev Misra

Interpreting the Power Spectra of Cygnus X-1, Workshop on Black Hole Accretion Disks, Peking University Beijing, China, November 8.

Interpreting the Power Spectra of Cygnus X-1, Conference on Measuring Spin and Mass of Black Holes, YASHADA, Pune, December 19.

Interpreting the Power Spectra of Cygnus X-1, Conference on Observational Evidence for Black Holes, Kolkata, February 13.

Vijay Mohan

Image Processing, Workshop on Data Analysis and Simulation Techniques in Observational Astronomy, University of Calicut, Kerala, August 9 - 10.

Astronomical Photometry, Workshop on Virtual Observatory and Astronomical Data, J.E.S. R.G.B. Arts, S.B.L. Commerce and R. B. Science College, Jalna, August 28 - 30.

Astronomical Detectors and Photometry, Workshop on Observations with Small Telescope,Bhavnagar University, Bhavnagar, November 19 - 21.

Applications of Photometry, Workshop on Data Analysis and Data Reduction, The American College, Madurai, February 4 - 6.

Jayant Narlikar

Gravitational Collapse with a Negative Energy Field, Universidad Nacional Autonoma de Mexico, Mexico, September 18.

Searches for Life in the Universe, Centro de Investigacion y de Estudios Avanzados del IPN, Mexico, September 19.

Universe and the Origin of Life, Universidad Autonoma de Zacatecas, Mexico, September 20.

A Case for Alternative Cosmology, European Southern Observatory, Santiago, Chile, October 3.

Searches for Life in the Universe, European Southern Observatory, Santiago, Chile, October 10.

A Critique of Standard Cosmology, Cerro Tololo Inter-American Observatory (CTIO), La Serena, October 19.

Minibangs in Cosmology, Center for Astrophysics and Space Sciences, University of California at San Diego, USA, November 28.

The Lighter Side of Gravity , Centre for Basic Sciences, University of Mumbai, Mumbai, March 12.

T. Padmanabhan

What Does Dark energy tell us About Gravity? Indo-Brazil Workshop on Cosmology, IUCAA, Pune, July 18.

Weight of the Cosmic Vacuum, National Conference on New Horizons in Theoretical and Experimental Physics, NHTEP-2007, Kochi, October 9.

Cosmology Today: *Facts, Hype and Myths*, Indian Conference on Cosmology and Galaxy formation, Harish-Chandra Research Institute, Allahabad, November 3.

Glimpses of General Relativity, Frontiers in Physics, Fergusson College, Pune, January 10.

Progress in Cosmology: Rumours and Reality, Science with Giant Magellan Telescope (GMT) Meeting, Canberra, Australia, March 26 - 28

Curiosities in Newtonian Gravity, Harish-Chandra Research Institute, Allahabad June 6.

Understanding the Universe: *New Insights and Challenges*, Cochin University of Science and Technology, Kochi, December 31.

The Weight of the Vacuum, Pt. Ravishankar Shukla University, Raipur, February 6.

Weight of the Cosmic Vacuum, Vainu Bapu Memorial Award Lecture, IUCAA, August 17.

Weight of the Cosmic Vacuum, Inter-UniversityAccelerator Centre, Delhi, November 1.

Weight of the Cosmic Vacuum, National Institute of Oceanography, Goa, December 20.

Gravity as an Emergent Phenomenon, Science with Giant Magellan Telescope (GMT) Meeting, Canberra, Australia, March 26-28.

Biswajit Pandey

Luminosity-bias Relation from Filaments in the Sloan Digital Sky Survey Data Release Four, Indian Conference on Cosmology and Galaxy formation, Harish-Chandra Research Institute, Allahabad, November 4.

The Luminosity - Star Formation Relation for Galaxies in the Sloan Digital Sky Survey Data Release Five (SDSS DR5), ICGC-07, IUCAA, December 18.

The Luminosity - Star Formation Relation and Filamentarity of Star Forming Galaxies in the Sloan Digital Sky Survey Data Release Five (SDSS DR5), Harish-Chandra Research Institute, Allahabad, weekly cosmology seminar, February 12.

Maulik Parikh

Mach's Holographic Principle, Penn State University, State College, Pennsylvania, USA, April ..

Mach's Holographic Principle, University of Maryland, College Park, Maryland, USA, April .

Mach's Holographic Principle, McGill University, Montreal, Quebec, Canada , April .

The Information Puzzle in de Sitter Space, Columbia University, USA, March.

A. N. Ramaprakash

IUCAA Girawali Observatory, Harish-Chandra Research Institute, Allahabad, April 17 .

Optical Astronomy: Instruments and Application, Training School for International Astronomy Olympiad participants, Homi Bhabha Centre for Science Education, Mumbai, September 26.

Instrumentation in Astronomy, Indian Institute of Technology, Kharagpur, November 2.

Optical Observational Techniques in Astronomy, Cochin University of Science and Technology, Kochi, January 4.

YAM - what next?: Mahatma Gandhi University, Kottayam, January 5.

Seeing Star Light, Workshop on Data Analysis and Data Reduction, The American College, Madurai, February 4 - 5. (2 lectures)

Swara Ravindranath

Properties of Morphologically-Selected Bulges at High Redshifts from GOODS, IAU Symposium on Formation and Evolution of Bulges, Oxford, UK, July 16 - 20.

Observational Constraints on Galaxy Formation from Multi-wavelength Surveys, International Conference on Gravitation and Astrophysics (ICGA-8) Nara Women's University, Nara, Japan, August 28 - September 1.

Morphological Diversities and Star Formation in z=2 Galaxies from GOODS, Indian Conference on Cosmology and Galaxy Formation, Harish-Chandra Research Institute, Allahabad, November 3-5.

Observing the Earliest Signatures of Hubble Sequence among the High Redshift Galaxies, Aspen Winter Conference on First Billion Years of Galaxy Formation, Aspen Physics Center, Aspen, February 10-16.

Varun Sahni

Reconstructing Dark Energy (Plenary talk), VIII Asia-Pacific Conference on Gravitation and Cosmology, Nara, Japan, August 29- September 1.

Braneworld Cosmology (Review talk) Indo-Brazil Workshop on Cosmology, IUCAA, July 16-21.

Reconstructing Dark Energy, Los Alamos National Laboratory, USA, September 2007.

Tarun Souradeep

Cosmic Microwave Background, Indo-UK Frontiers of Science Symposium, Hyderabad, March 4-7.

Cosmic Microwave Background at the Frontiers of Cosmology, (Plenary talk), National Space Science Symposium (NSSS-2008), RAC, Ooty , February 26-29.

Early Universe from CMB anisotropy and polarization, Invited special seminar, SINP, Kolkata. February 18.

CMB Physics and Cosmological Implications, Quarks to Astrophysics Meeting, Toshali Sands, Puri. February 16.

Primordial Spectrum from CMB: Making the 'Best' of our 'Ignorance', Gravity Group Seminar at Princeton University, February 5.

C_l Estimation: A Blind Approach to Evade Foreground Modeling, Aspen Winter Conference on CMB, Aspen, Colorado, USA, January 31.

Cosmology with the CMB anisotropy, Physics Department Colloquium, IIT Kharagpur, November 20.

Early Universe with CMB Anisotropy, Invited talk at the ICGA-8, Nara, Japan. August 29 - September 1.

Cosmology: An Unfolding Success Story, Frontiers of Theoretical Sciences, IACS, Kolkata, August 17.

Cosmology with CMB Anisotropy, Indo-Brazil workshop on Cosmology, IUCAA, July 19.

CMB anisotropy and Large Scale Structure: Dark Energy Perspective, Opening Introductory talk at ICSW-07, IPM, Tehran, Iran, June 3.

Observational Evidence for Dark Energy, Workshop Overview talk, ICSW-07, IPM, Tehran, Iran, June 8.

Cosmology with the CMB Anisotropy, IUT, Iran, June 6.

Towards Observing the Early Universe, Department of Theoretical Physics Colloquium, TIFR, Mumbai, May 22.

R. Srianand

Probing the Variation of Fundamental Constants, Indian Institute of Mathematical Sciences, *Chennai.*

Probing the Universe with QSO absorption line, Indian Institute of Science, Bangalore..

Probing the Variation of Fundamental Constants using Absorption lines, Physical Research Laboratory, Ahmedabad, December.

Measuring the Temperature of Cosmic Microwave Background at High Redshifts, Physical Research Laboratory, December 2007.

Astronomical Spectroscopy, Workshop on Data Analysis and Data Reduction, The American College, Madurai, February 4 - 6.

Kandaswamy Subramnian

Magnetizing the Universe, Invited Review talk at International Conference on From Planets to Dark energy: The Modern Radio Universe, Manchester, UK , October.

Constrained models of galactic outflows, University of Newcastle upon Tyne, UK, October.

Constrained Models of Galactic Outflows, Symposium on cosmological flows, ICTP, Trieste, Italy, October.

The Dirty Business of Galaxy Formation, Invited Review talk, Indian Conference on Cosmology and Galaxy Formation, Harish Chandra Research Institute, Allahabad, November.

Magnetizing the Universe, Indian Institute of Science Colloquium, Bangalore, November.

Magnetizing the Universe, Tata Institute of Fundamental Research Colloquium, Mumbai, February.

S. N. Tandon

Sensitivity of a Telescope, IUCAA Workshop on Observations with Small Telescopes, Bhavnagar University, November.

Space Astronomy, IUCAA Workshp on Data Analysis and Data Reduction, The American College, Madurai, February (2 lectures).

UV Astronomy, Nehru Science Centre, Mumbai, (Public Lecture), February 2.

Lecture Course

Joydeep Bagchi

Lectures and Radio Astronomy Experiments, Radio Astronomy School-2007, NCRA/TIFR, Pune.

Dipankar Bhattacharya

Fluids in Astrophysics, School on Astrophysical Fluid Dynamics, ICTP, Trieste, 15-18 October (4 lectures).

High Energy Astrophysics, Department of Physics, M.L. Sukhadia University, Udaipur, February 11-16 (9 lectures)

Naresh Dadhich

General Relativity, Department of Physics, University of Madras, Chennai, August 28- 31, and September 3-6, (8 lectures).

Gravity and Higher Dimensions, Tubitak-Bogazici University, Feza Gursey Institute, Turkey, October 16-19 (4 lectures).

Sanjeev Dhurandhar

Gravitational Waves, Introductory Summer School on Astronomy and Astrophysics, Pune, June 7-8 (2 lectures).

Ranjan Gupta

Centres of Modern Astronomical Research; Modern Astronomical Telescopes Astronomy with Small Telescopes; Photometry and Spectroscopy Basics, Refresher Course on Astronomy at CTI, IMD Training Centre, Pune, December 10-14, (4 talks)

Ajit Kembhavi

Stars and Compact Objects, Refresher Course in Astronomy and Astrophysics, IUCAA, May 14 – June 15, (8 Lectures).

Supermassive Black Holes, Refresher Course in Astronomy and Astrophysics, IUCAA, May 14 – June 15, (2 lectures).

Astronomical Photometry, Mini -School on Astronomy and Astronomical Data Analysis, Newman College, Thodupuzha, September 19-20, (4 lectures).

Stellar Structure and Evolution, Part of M.Sc. special paper in Astronomy at Presidency College, Kolkata, February 12-16, and IUCAA, February 21-29, (22 lectures).

Ranjeev Misra

Radiative and Accretion Processes in Astrophysics, Mini-School in Astronomical Data analysis, Newman College, Thodupuzha, September, (4 talks).

Radiative and Accretion Processes in Astrophysics, Workshop on VO and Data analysis, J. E. S. College, Jalna, August, (4 talks).

Radiative and Accretion Processes in Astrophysics, Referesher Course in Astronomy and Astrophysics, IUCAA, May, (6 talks).

J. V. Narlikar

Introduction to Cosmology, Vacation Students' Programme, IUCAA, May 22 -24 (4 lectures).

Some Conceptual Problems in Cosmology, European Southern Observatory, Santiago, Chile, October 2- 4. (3 lectures)

A. N. Ramaprakash

Astronomical Detectors and Instruments, Vacation Students' Programme and Refresher Course in Astronomy and Astrophysics, IUCAA, May 2007

Swara Ravindranath

Galaxies, Refresher Course in Astronomy & Astrophysics, (4 talks) and 2 demo sessions on Reduction and Analysis of Spectroscopic Data, IUCAA, May-June.

Tarun Souradeep

Cosmology with CMB Anisotropy, UGC-DRS Symposium, Utkal University, Bhubaneswar, January 11-12.

CMB Anisotropy and Polarization, Vacation Students' Programme, IUCAA, May-June, (3 talks).

CMB Anisotropy, International Cosmology School and Workshop (ICSW-07), IPM, Tehran, Iran, June.

Kandaswamy Subramanian

Fluids and MHD, Vacation Students' Programme and Refresher Course in Astronomy and Astrophysics, IUCAA, May, (4 talks).

Astrophysical Magnetic Fields and Dynamos, Les Houches summer school on Dynamos, Les Houches, France, August, (3 talks).

Magnetohydrodynamics, ICTP School on Astrophysical fluid dynamics, ICTP, Trieste, Italy, October, (4 talks).

S.N. Tandon

Telescopes, Refresher Course in Astronomy and Astrophysics, IUCAA, May-June, (3 talks).

(VIII) SCIENTIFIC MEETINGS AND OTHER EVENTS

Refresher Course in Astronomy and Astrophysics for College and University Teachers

The lecturers and participants of the Refresher Course in Astronomy and Astrophysics for College and University Teachers

The Refresher Course in Astronomy and Astrophysics for college and university teachers was held during the period May 14 to June 15, 2007. Participants were selected from all over India and thirteen highly interested participants took part in the course. The faculty, post-doctoral fellows, and students joined in the programme with great enthusiasm. The scientific and the administrative staff were of vital help in ensuring that the course ran smoothly. The lecture courses were designed by Ajit Kembhavi and Kandaswamy Subramanian, who were the coordinators of the Refresher Course, and the Vacation Students' Programme (VSP) respectively. The course consisted of introductory and advanced lectures, which covered the basics of astronomy and astrophysics. The participants were given assignments based on these lectures and tutorial classes were conducted to explain the solutions. An important aspect of the programme was the data analysis sessions, where the participants were given hands on experience on the use of computers and virtual libraries. They also extracted and analysed data from astrophysical data archives. A scientific visit to the IUCAA's 2 metre optical telescope at Girawali was arranged. Finally, lectures and useful reference material were copied on CDs, which were distributed to each of the participants. It was clear that at the end of the course, the participants benefited substantially and were inspired to take up research and teaching in astronomy and astrophysics at their home institutions. R. Misra assisted in the coordination of this course.

Vacation Students' Programme

The 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 14 - June 29, 2007. This year two exceptionally bright B.Sc. students were also selected. 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.One of the students has been pre-selected for research scholarship. K. Subramanian was the faculty coordinator of this programme.

SALT and Advanced Computing Facilities

IUCAA's main mission is to make available to students and scientists in the universities and in IUCAA, world class facilities for astronomical research. IUCAA has recently acquired a share in the Southern African Large Telescope (SALT), which is one of the biggest optical telescopes in the world. Another recent achievement has been the creation of new advanced computing facilities in IUCAA.

These resources were dedicated to the university community and users in IUCAA on Saturday, July 21, 2007. Sukhdeo Thorat, Chairman, University Grants Commission, who is also the Chairman of the Council of IUCAA, dedicated the access to SALT. Jayant Narlikar, dedicated the computing facilities. R. Srianand and Ajit Kembhavi provided brief introductions to SALT and to computing facilities respectively.

Sukhdeo Thorat and Jayant Narlikar addressing the gathering

S.A.L.T.

The Southern African Large Telescope (SALT) is located in Sutherland, near Cape Town, South Africa. It is the largest single optical telescope in the southern hemisphere of the world, with a hexagonal mirror array of 11 meters across.

The construction of SALT has already been completed. It was funded by a consortium of international partners from South Africa, the USA, Germany, Poland, the United Kingdom, and New Zealand. It is now in its commissioning phase. Instruments with the capability for imaging and spectroscopy are available on it, and more sophisticated instruments will be added in the future.

IUCAA has recently acquired a six percent share in SALT. This gives IUCAA part ownership of the telescope and a seat on the Board, which takes all decisions. IUCAA will now get about 15 nights of observing time. The observations will be carried out by astronomers from IUCAA and the Indian universities.

Advanced Computing Facilities

The IUCAA computer centre has always been known for its world class computer hardware, and its use of computer technology and applications. It has now made a number of important additions to its setup, which include:

(i) A high performance cluster, consisting of 16 computer nodes (128 core) and one head node, each having quad, dual core AMD Opteron processors from Hewlett Packard. The cluster has infiniband interconnect. It substantially adds to the existing HP-ES45 based 32 processor high performance cluster. The facility will be used in theoretical and observational research in exciting frontier areas of astronomy.

(ii) A centralized SAN storage system, with 28 terabytes storage capacity with a sophisticated robotic tape library and storage management system. This is used in maintaining very large data mirrors, including the Sloan Digital Sky Survey, and the Chandra X-ray database. IUCAA is one of a small number of places in the world to have such data mirrors.

(iii) A high speed intranet with wireless and high bandwidth connectivity to the outside world through the ERNET node, which operates at IUCAA. It has been possible to ftp very large databases of several terabyte size using the connectivity, which is a unique achievement in the country.

The vast processing power, data storage and bandwidth are at the heart of the Virtual Observatory and other projects at IUCAA, which enables scientists in IUCAA and universities in India to undertake ever new projects.

Indo-Brazil Workshop on Cosmology

The first Indo-Brazil workshop on Cosmology was held during July 16 – 21, 2007. The aim of the workshop was to bring together several Indian and Brazilian cosmologists for discussions and interactions. Participants of the workshop were drawn from various research institutes and universities in India with six scientists from Brazil (Raul Abramo, Carlos Alexandere Wuensche, Ioav Waga, Saulo Carneiro, Jose Ademir Lima and Jailson Alcaniz). The format of the workshop consisted of 22 one hour talks, spread over six days, with extensive discussions during and after the talks. Mainly, topics related to early universe and cosmology were covered. Overall, the workshop resulted in closer contacts being established between many of the participants.

Jailson Alcaniz of Observatorio Nacional, Rio de Janeiro, Brazil, and T. Padmanabhan of IUCAA jointly coordinated the workshop.

Participants of the Indo-Brazil Workshop

Workshop on Virtual Observatory and Data Analysis

Ajit Kembhavi lecturing at the Virtual Observatory and Data Analysis workshop

A two days workshop on Virtual Observatory and Data Analysis was organized at the Post-graduate Department of Physics, J.E.S. College, Jalna (Maharashtra) during August 29-30, 2007. Thirty college teachers from Marathwada and nearby regions of Maharashtra, fourteen teachers from local colleges of Jalna, twelve students of M.Sc. (Physics) and one Engineering student attended the workshop. Ajit Kembhavi, Vijay Mohan, and Ranjeev Misra of IUCAA and M.L.Kurtadikar of J.E.S. College were the resource persons for the workshop.

Vijay Mohan talked on observational photometry and data analysis, Ranjeev Misra dealt with the data from cosmic X-rays, and M.L. Kurtadikar discussed about CLEA laboratory exercise on photometry. Ajit Kembhavi delivered lectures on galaxies and virtual observatory. While introducing the concept of virtual observatory, Kembhavi discussed about the capability of such observatory for acquiring, storing and managing the huge astronomical data from telescopes on ground and in space. He also discussed the potential of virtual observatories to make this data available to the interested researchers, through internet. He further appealed the college teachers to use this facility by interacting with IUCAA. Kembhavi and Kurtadikar were the coordinators from IUCAA and J.E.S. College respectively.

Mini-School on Astronomy and Astronomical Data Analysis

Ranjeev Misra lecturing at the Mini-School on Astronomy and Astronomical Data Analysis

A Mini-School on Astronomy and Astronomical Data Analysis was conducted by IUCAA at Newman College, Thodupuzha, Kerala, during September 19-22, 2007. Invitations were sent to all the colleges and universities having post-graduate course in physics and 38 participants including seven teachers were selected in the region to attend the programme. The aim of the Mini-school was to acquaint students and teachers to the analysis of optical data from the telescopes and to give them training. The main attraction of the school was the data analysis sessions during the afternoons, where the participants were exposed to the state-of-the-art data analysis techniques and were given hands on experience on how to find out astronomical parameters from raw data, using IRAF software package.

Ranjeev Misra coordinated the programme along with Joe Jacob of the host institute and Ninan Sajeeth Philip of St. Thomas College, Kozhencherry, Kerala. The principal of the college, Fr. Paul Nedumpurath made available a computer laboratory for the workshop.

The Mini-school consisted of lectures on various aspects of astronomical photometry, spectroscopy and data analysis and special topics in astrophysics by Ajit Kembhavi (IUCAA), Ranjeev Misra (IUCAA), Ninan Sajeeth Philip (St. Thomas College, Kozhencherry, Kerala), C.D. Ravikumar (University of Calicut), V.C. Kuriakose (Cochin University) and K. Indulekha (M. G. University). Susmita Chakravorty (IUCAA), Vinu V. (M. G. University) and Vivek M. (Cochin University) led the demo sessions, which lasted well into the evening and covered linux, photometry and spectroscopy.

The participants were divided into pairs, and a computer was assigned to each pair. Evaluating the performance in the data analysis sessions, 10 groups were selected to be eligible for the participation in a forthcoming advanced data analysis workshop scheduled in December 2007. Six participants were adjudged as the best performers of the workshop. It is hoped that the workshop will lead to much activity in data analysis in the college as well as the surrounding region.

Workshop on Astronomy with Virtual Observatories

The sessions and participants

The workshop on Astronomy with Virtual Observatories, was conducted at IUCAA during October 15-19, 2007. It was organized by the Virtual Observatory India (VO-I) project, which is based at IUCAA and is a collaborative effort between IUCAA and Persistent Systems Pvt. Ltd. (PSPL), Pune. The aim of the workshop was to introduce the faculty and research students interested in astronomy and related areas to VO concepts, to recent technical developments in the field and the use of VO tools in astronomy.

Experts in the area from various VO projects in Europe, the USA, and India were invited to give lectures, conduct demonstrations and hands-on-sessions. Participants came from different institutions, university departments and colleges in India, as well as from other countries.

The workshop started with an overview of VO by Paolo Padovani of Euro-VO, and a review of data archives and methods of access by Ajit Kembhavi, IUCAA. These reviews were followed by a number of talks over the next five days, which covered specific technical aspects, science drivers, VO tools and specific applications to science cases, like the discovery of quasars and the initial mass function of massive stars. The demonstrations by experts provided introduction to important archives like SIMBAD, VIZIER, and tools like ALLADIN, VOPlot, etc. The demonstrations also covered SQL and data retrieval from the Sloan Digital Sky Survey. The demonstrations were followed by hands-on-sessions conducted in a sophisticated computer laboratory, which has been developed at IUCAA for the purpose. These sessions allowed participants to familiarize themselves with intricacies of the complex software with the help of people, who in many cases had actually developed the software themselves. The response of the lectures as well as practical sessions was excellent and many mature as well as young astronomers were enthusiastic participants.

The VO concept and tools have been developed over the last several years and are being adopted by the international astronomical community. The workshop at IUCAA has gone a long way in forging a link between the communities of developers and users. It was in fact the first workshop of its kind anywhere to combine technology and science in a very successful manner.

The workshop was funded by IUCAA, PSPL, DST, ISRO and the Ministry of Communication and Information Technology.

Workshop on Observations with Small Telescopes

Participants of the Workshop on Observations with Small Telescopes

This workshop was held at the Department of Physics, Bhavnagar University during November 19-21, 2007 and was attended by 29 participants comprising of college and university teachers, researchers, M.Sc. and B.Sc. students, and amateur astronomers from various corners of the country. There were 9 lecture sessions and 2 night observing sessions on the Bhavnagar Telescope.

On the first day, J.N. Desai (Ex-PRL) talked on the observations of cometary ion tails and various related studies using a small telescope and gave an informal evening talk later. A talk on astronomical detectors was delivered by Vijay Mohan (IUCAA). Fine details of astronomical imaging through PSF and error in CCD data were presented in a very illustrative way by S. N. Tandon (IUCAA). The second day began with S. D. Verma (Ex-Gujarat University) talking on the history and importance of gamma ray bursts and followed by a talk by S. P. Bhatnagar (Bhavnagar University). In his second talk, Vijay Mohan presented the nuances of photometry in quite effective way. A very informative talk by N. M. Ashok (PRL) on eruptive variables brought out the possibility of observations using small telescopes. Ranjan Gupta (IUCAA) showed another possible application of small telescopes in spectroscopy. R. V. Upadhyay, Head of the Department of Physics, (Bhavnagar University) gave a brief review of the development of the department activities. On the last day, T. Chandrasekhar (PRL) gave a talk on measuring the sizes of stars. The last talk of the workshop was on dust properties using extinction and polarization by D. B. Vaidya (Ex-Gujarat College). Overall, the workshop was very useful and interesting to the students, who want to have astronomy as their career.

S. P. Bhatnagar was the local coordinator of the workshop. S. K. Pandey of Pt. Ravishankar Shukla University, Raipur, and Vijay Mohan were the coordinators from IUCAA.

Glimpses of ICGC 2007

The sixth International Conference on Gravitation and Cosmology, ICGC 2007, was organized and hosted by IUCAA during December 17 - 21, 2007. This series of international meetings, held every four years under the auspices of the Indian Association for General Relativity and Gravitation (IAGRG), has now spanned two decades. Previous ICGC meetings were held at Cochin University of Science and Technology (2004), Indian Institute of Technology, Kharagpur (2000), IUCAA, Pune (1995), Physical Research Laboratory, Ahmedabad (1991) and Goa (1987). The meeting brought together active scientists from all over the globe to present the state-of-the- art at the frontiers of gravitation and cosmology and promising future directions. It also offered younger Indian researchers an opportunity to interact with experts from within India and abroad. The meeting was attended by about 160 participants selected from around 285 requests for registration.

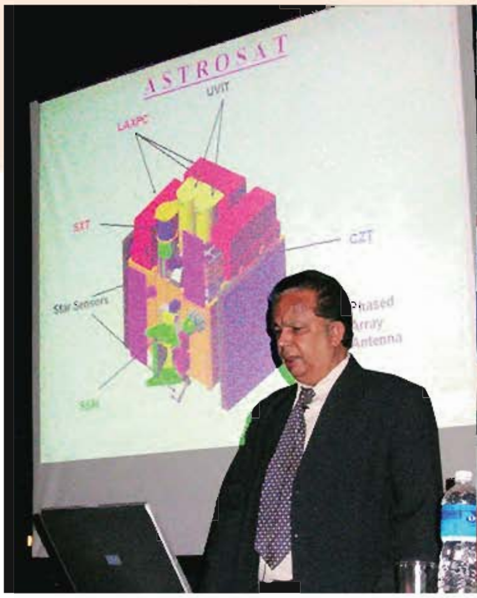
The scientific programme, put together by the SOC chaired by G. Date, IMSc., Chennai, had 19 plenary talks on current theoretical, observational and experimental topics in cosmology, general relativity, detection of gravitational waves, and various approaches of quantum gravity. The meeting also included four parallel intensive workshops focused on cosmology, classical general relativity and gravitational waves and quantum gravity. The workshops had around 75 oral presentations. The immensely rich and diverse scientific programme was aptly summarized by Juergen Ehlers at the end. A public lecture on `Oldest Light in the Universe' by NASA scientist, Gary Hinshaw, who is a member of the WMAP team (formerly, also a member of the COBE-DMR team that won the Nobel prize in 2006) was also organized as part of ICGC 2007 and drew sizable audience from the public in Pune. The cultural evening of splendid Indian classical dance by famous Kathak dancer, Shambhavi Vaze, whose troupe presented a blend of classical and contemporary items was a highlight and so was `deepavali' candlelight display of the IUCAA kund by our graduate students.

The meeting was financially supported by generous contributions from Indian organizations: ISRO, CSIR, DST, BNRS, and IAGRG; and from Indian institutes: HRI (Allahabad), IIA (Bangalore), IMSc (Chennai), RRI (Bangalore), SINP (Kolkata), and IUCAA. The conference banquet was sponsored by Hewlett-Packard and the reception dinner was sponsored by the Bank of Baroda. The local organization was chaired by Tarun Souradeep, who was ably supported in this task by a very dedicated LOC team. They enjoyed full support and extensive help from members of the entire IUCAA `family'.

Details of the meeting, including the electronic version of the talks may be accessed online at the conference webpage

http://www.iucaa.ernet.in/~icgc07. The proceedings of ICGC 2007 will be published soon in the Journal of Physics: Conference Series (JPCS) of IOP publishers.

Conference on Measuring Spin and Mass of Black Holes



Mr. Madhavan Nair, Chairman, ISRO, at the ASTROSAT Session

Participants of the Conference on Measuring Spin and Mass of Black Holes

Over the last two decades, there has been mounting evidence for the existence of black holes. It is now believed that nearly all galaxies harbour super-massive black holes and that some galactic X-ray binary systems are powered by the accretion of matter onto black holes, which are formed by the collapse of massive stars. These systems are expected to serve as laboratories to study the behaviour of matter in extreme conditions and to test the general theory of relativity in the strong field limit. The study of the growth of super-massive black holes over cosmological times will shed light on the creation and subsequent evolution of galaxies. A fundamental challenge in the field is to find reliable techniques to measure the mass and spin of black holes and their implementation, which was the main agenda for this conference, which was held during December 18 - 20, 2007. The meeting was attended by the leading experts in the field from India and abroad including, A. Fabian (IOA, UK), R. Narayan (Harvard University, U.S.A), J. McClintock (Harvard University), H. Netzer (Tel-Aviv University of Israel), P. Charles (SAAO, South Africa), P. Ghosh (TIFR), A. R. Rao (TIFR), and D. J. Saikia (NCRA).

High quality spectral information and variability measurements of these black hole systems, especially in X-rays, UV and optical wavebands, will be crucial to further advancement of this field. The instruments on board the Indian satellite ASTROSAT, scheduled to be launched in 2009, would provide unprecedented multi-wavelength coverage of black hole systems and indeed observation of AGN and X-ray binaries are part of several ASTROSAT key projects. To increase the awareness of ASTROSAT and other related ISRO missions, especially among the international participants, a special evening session was organised on December 19. Madhavan Nair, Chairman, ISRO, started the session by describing ISRO's space capabilities and commitment to astronomical research. P. C. Agrawal (TIFR), and D. Bhattacharya (IUCAA) presented the descriptions of the instruments that will be on board of ASTROSAT and the science that is expected to be achieved. Ed van den Heuvel (University of Amsterdam, The Netherlands) highlighted the unique opportunities to do front line science that will be opened up by ASTROSAT.

The meeting was coordinated by R. Misra, A. K. Kembhavi, and D. Bhattacharya, and was supported by IUCAA, ISRO and DST.

Workshop on Data Analysis and Data Reduction

Participants and Lecturers of the Workshop

A workshop on Data Analysis and Data Reduction was conducted by IUCAA at The American College, Madurai during February 4-6, 2008. In all, about 110 students and teachers from host and colleges from the southern region participated in the workshop. Lecture topics covered in the workshop include Tools of astrophysics, Telescopes and instrumentation, Astronomy in space, Astronomical spectroscopy, and Photometry and applications. Each lecture was followed by question and answer session. In addition to these topics, there was a demonstration session, devoted to practical training on IRAF for few selected participants. Resource persons included R. Srianand, A. N. Ramaprakash, S. N. Tandon, Vijay Mohan, all from IUCAA, and Rajaram Nityananda of NCRA, Pune. R. Srianand from IUCAA and S.S.R. Inbanathan, Department of Physics, The American College, Madurai were the coordinators of this workshop.

Visit of Nobel Laureate, Professor George Smoot

Nobel Laureate, Professor George Smoot of the Lawrence Livermore National Laboratory and University of California, Berkeley, visited IUCAA on March 5, 2008. Professor Smoot was in Pune on a Nobel Initiative programme of Honeywell Automation India Ltd. to encourage young engineering students of the College of Engineering, Pune (COEP) to take up the remarkable instrumentation challenges in cutting edge Astronomy and Astrophysics experiments. Professor Smoot won the 2006 Nobel prize in Physics as the leader of the group that first detected tiny fluctuations in the temperature of the cosmic microwave background in the universe, using the measurements from the Cosmic Background Explorer (COBE) satellite mission of NASA. This result has been widely heralded as a major breakthrough in the field of cosmology and ushered in the dawn of precision cosmology. He gave a public talk and a more technical colloquium on the subject of Cosmic Microwave Background Experiments and Cosmology at the College of Engineering, Pune. The latter was especially arranged by Honeywell and COEP for the academic members of IUCAA and NCRA.

During the meeting with faculty members, he talked about the increasing important role that India could play in science due to its immense pool of talented and highly trained manpower. He highlighted the need for all basic sciences to get together in making the case for improvements in education and research environment and support from the government and industry. Professor Smoot had discussions with Tarun Souradeep and other researchers at IUCAA, who work on the Cosmic Microwave Background during sessions on instrumentation and data analysis at COEP. He provided useful insights and suggestions for embarking on collaborative experimental effort in measuring CMB anisotropy and polarization in India.

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 23 and 28, 2008 respectively. This year the National Science Day programme was extended to Ambegaon Taluka, where IUCAA Girawali Observatory is located. These Public Outreach Programmes are housed in the Muktangan Vidnyan Shodhika (MVS).

Activities for school students

Second Saturday Lecture and Demonstration Programme: School students from classes 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 students 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, in particular, study of Solar Limb Darkening. Bharati Bagul, Rajashree Dokhale, Sweety Hande, Varsha Jadhav, Poonam Jagtap and Suvarna Rahane of K. T. H. M. College, Nasik did project on Solar Limb Darkening and study of Fraunfoffer Lines. Gaurang Kumar Patel of Physics Department M. S. University, Vadodara and Chandan Ghosh of St. Xavier's College, Kolkata and Rajasekhararan of The American College, Madurai, built a solar photometer and carried out solar limb darkening measurements. Also, the following students from Pune did projects at MVS.

Pradnya Gholap, Fergusson College: Study of Solar Limb Darkening.

Priya Kakkar, Fergusson College: Solar Photometer.

Deepk Gaindar : Sudden Ionospheric Disturbance

Priyadarshini, S. P. College: Making of Astronomical Telescope and Study of Lunar Features,

Edusat

Satellite Interactive Terminal of Edusat, Vigyan Prasar was set up at MVS. This facility was extended to teachers and students from time to time. One of the major participations, was the Eratosthesnise experiment, in which shadow of a vertical pole was monitored. With Vigyan Prasar the POP group carried out a special session on Eratosthesnise experiment on December 23. About 10 stations from different parts of India participated in this activity.

Visits to IUCAA and sky shows

IUCAA organises visits of interested people from different professional backgrounds, to the campus. These visits, which are by invitation only, take 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. The Science Park was opened for free access to the general public on all days during the prenoon hours (except on Mondays). Regular one and half hour sky shows have been conducted on Fridays. On all clear evenings about 25 people visit MVS and see various celestial objects through 14 inch telescope.

Reaching general public directly and via media

The members of the POP continue to interact 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 by giving direct press releases and putting more information on the web. Details of occultation events of Mars, Regulus and Venus by the Moon on April 14, May 23 and June 18, and on observations of comet Holmes were put on the web.

The media also covered the POP programmes in the rural area near the location of the telescope. The POP provided up-to date information during opposition of Mars.

Members have been contributing weekly science features to local newspapers.

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. Committee setup by the Vice Chancellor of Amravati University was advised on setting up of astronomical observatory.

St. Xavier College, Kolkata and The American College, Madurai, were helped in setting up a few laboratory experiments related to observational astronomy.

Public outreach in Girawali region

In 2006 POP Outreach activities were extended to the rural areas near the location of the IUCAA 2m telescope and continued this year too. Mobile planetarium shows and direct interaction (lecture / demonstrations) to the students and workshops for teachers were carried out. The primary school teachers were invited to attend a day long EDUSAT workshop on physics experiments.

The National Science Day programme was extended to Girawali region by conducting essay and drawing competitions in the observatory premises on March 1. More than 50 students took part in these competitions. The winners were given prizes by the Director, IUCAA in a simple ceremony that was held in the Panchayat office on March 8. The list of winners appear in the box on page no 125.

Pu La Deshpande's birth anniversary celebrations

The 88th 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 Sunitabai Deshpande, relict of the famous P. L. Deshpande (Pu La).

An exhibition on do-it-yourself (DIY) science experiments was set up for the school students. 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

Highly successful usage of the Mobile Planetarium, Taramandal, prompted POP to acquire one more in November 2007. A group of teachers and amateur associates have been trained to use the planetarium. Most of the programmes were conducted in Pune region, however, the planetarium has travelled long distance and took part in various open events, where, over a period of 2 to 5 days, students took part in academic and cultural activities. Some of the notable events are: BITS Pilani Goa Campus - Quark 08 technology fair, Vikhe Patil Memorial School, Pune for National Science Day, Fergusson College, Pune for Quark 08 exhibition, Rajarshi Shahu College of Engineering, Pune for Innovision-2008, Government College of Engineering, Aurangabad for Wings 08.

POP Associate Programme (MViSA)

A programme, named MViSA (Muktangan Vidnyan Shodhika Associates) was started last year and continued this year too. Mostly, college students of Science and Engineering branches have been participating in this programme, which consists of discussion on various topics related to astronomy, in particular to observational astronomy.

International Year of Astronomy (IYA) 2009

With Ranjeev Misra, being designated as Single Point of Contact for India (SPoC), T. Padmanabhan, given charge by Indian National Science Academy (INSA) and National Committee of International Astronomical Union, POP is playing pro-active role in promoting aims and goals of IYA 2009. As first step, India National Node web portal for IYA2009 has been launched in March 08, and various pre-IYA activities have been chalked out.

The Open House for Public

About 5000 people from all age groups and different walks of life visited IUCAA on February 28,2008. 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 foyer of the Chandrasekhar Auditorium. Students of Jnana Prabodhini Prashala 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.

School Students' Summer Programme

Students In various activities of the MVS

The School Students' Summer Programme was conducted during April 16 -May 25, 2007. Invitation to participate in the programme was sent to all the students who scored good points in the elimination round of quiz programme in the school students competitions held in February on the occasion of the National Science Day. There were three students from each school. In addition, winners of essay and drawing competitions were also invited to participate. About 80 students participated in the summer programme.

Each week, a batch of about 15 to 18 students participated. Over a period of four days, the students were challenged to solve a particular problem that was assigned to him/her by a member of academic staff. In addition, question/answer sessions, visits to the science park and screening of scientific films were included in the progarmme. On the last day, the students were asked to give an 'academic' seminar on the problem they worked on.

Sunitabai Deshpande pays visit to Muktangan Vidnyan Shodhika

On June 18, 2007, Sunitabai Deshpande paid a visit to Muktangan Vidnyan Shodhika (MVS), to which P. L. Deshpande (Pu La), has given a handsome donation. She participated in the scientific toy making session for children as an observer and later acquainted herself with the working of the mobile planetarium. She also planted two apple trees next to the "Pulastya" building.

Planting an Apple tree by Sunitabai Deshpande

Mobile Planetarium

Taramandal, an igloo shaped inflatable and portable planetarium

In June 2006, the public outreach programme of IUCAA acquired a new and a very valuable asset – Taramandal, which is an igloo shaped inflatable and portable planetarium. It is developed by the National Council for Science Museums, Kolkata. It requires about 8 m x 8 m of clear ground space and 3.7 m of clear unobstructed height, normally available in any school. The complete mobile planetarium packs into, two small boxes for the projector, one bag for the inflatable dome, and one box for the blower fan. It can be inflated to its full capacity in less than 10 minutes. The planetarium has a novel tunnel like entry to the dome, which serves as light trap, but children (and also the elders) do enjoy crawling in and out of the planetarium. The seating arrangement is on the floor and about 35 children or 25 adults watch the planetarium programme at a time. Generally, a programme consists of 4 to 6 shows of about half an hour each, for half a day session. A full day programme would have 4 more shows with a break for lunch. These programmes are essentially carried out by the members of the MVS, but some amateur astronomers and volunteer science educators have been trained to run these programmes.

The planetarium projector is capable of simulating night sky at any place on earth for any moment of time. The most important feature of this system is that it is interactive and gives the science educator the possibility of directly communicate with the audience, and can modify the programme as and when required. It is a good tool to explain the basic concept of observations.

Since its acquisition, IUCAA has carried out a large number of programmes in Pune and in Girawali region, where IUCAA's 2 m telescope is located. In addition, a few programmes at other cities, such as Kolhapur, Walchandnagar, etc. were conducted, but these are exceptions. After a good success of running the mobile planetarium show by amateur astronomers and volunteer science educators, IUCAA has placed an order for one more unit.

PuLastya Week

Muktangan Vidnyan Shodhika, the Science Centre of IUCAA, celebrated a Science Festival during November 11 - 14, 2007. This was to commemorate the birth anniversary of late Pu.La. Deshpande, which fell on November 8. Fondly called "PuLa", Deshpande was one of the visionaries behind the IUCAA Science Centre. The centre building is named "Pulastya" after him.

The first event, on November 11, was a Poster Competition on the "Sun-Earth Relationship". This was planned as a part of IUCAA's participation in the International Heliophysical Year. The participants were science-minded high school students. A brief lecture on the topic "Sun and Us" was given by Samir Dhurde. The ideas gathered by the kids from it were very adeptly put onto paper. The posters were displayed on the rest of the days. Three posters were chosen as winners. They are:

1. Maitreyi Gogate of St. Mary's Girls' School

2. Madhu Kumari of Army School, Kirkee

3. Kaushik Raychaudhuri of St. Ursula High School.

On the next three days, there were interactions with 51 schools, and about 1500 students and teachers from various schools have participated. Three full-day sessions allowed the MVS team to do science experiment demonstrations, screening of scientific films, stellarium shows, and science-based question-answer sessions. The response was good, with full houses on all days. The Science Centre was kept open to all teachers and students so as to make them familiar with its working and the programmes they can attend here. The students also had fun with the exhibits in the science park and the new exhibition of medicinal plants. The programme ended on the Children's Day, November 14.

EDUSAT at MVS

The first EDUSAT programme in progress

On September 20, 2007 from Muktangan Vidnyan Shodhika (the science Exploratorium) the first EDUSAT programme was conducted. EDUSAT is the first Indian satellite, built exclusively for serving the educational sector. It is mainly intended to meet the demand for an interactive satellite based distance education system for the country.

This Satellite Interactive Terminal (SIT) facility for IUCAA was created by Vigyan Prasar (VP), New Delhi.

Seventeen teachers from Ambegaon Taluka participated in this programme. In-training programme on Modern Physics Kit was conduced by Arvind Ranade, and Irfana Begum of VP. SITs from Nagpur, Kolhapur, Bhubneswar, Midnapur, and Lucknow also participated in this programme.

'Emergence of Modern Physics - An activity kit' developed by Vigyan Prasar was distributed to the participants. This kit has 28 experiments/activities. During the programme, the participants carried about 20 experiments. These activities consisted of understanding of x-ray images, application of x-rays, discovery of radioactivity, making of CD spectroscope and simple electroscope, photoelectric effect and others.

Naresh Dadhich, Director, IUCAA, spent some time with the participants and addressed them encouraging them to teach science in the schools. In his short address, he highlighted the importance of doing simple scientific experiments.

We thank Vinod Kamble, Director, Vigyan Prasar, and T. V. Venkateswaran, Principal Scientific Officer, and their entire team at VP for taking keen interest in setting up SIT at IUCAA.

Thanks also goes to Shri Shivajirao D. Adhalrao Vidyalaya, Landewadi, for co-ordinating the programme at Ambegaon.

Taramandal, the Mobile Planetarium Show at Ahmednagar

Two day mobile planetarium show for the school students, orphan and HIV infected children and general public was conduced by Dhinesh Nisang of Bhaskaracharrya Astronomy Research Centre in association with Rotary Club of Ahmednagar Central.

Shekhar Patki, Tushar Purohit and Aalok Deshpande, MViSA (Muktangan Vidnyan Shodhika Associates) members and members of Akashmitra volunteered to take the Taramandal to Ahmednagar and conducted the planetarium shows on September 22 and 23, 2007. More than 1000 students, teachers, and parents enjoyed the programme.

National Science Day Celebrations

Some of the partcipants and winners of various events like quiz, essay and drawing competitions

The school students programme, consisting of quiz, essay and drawing competitions, was conducted on Saturday, February 23, 2008. (The list of prize winners is given in the following page.) Naresh Dadhich had an interactive session with the teachers and highlighted the importance of inculcating scientific temperament among the students. Based on the teachers' suggestions, it was decided to have some activities dedicated for teachers. The students and teachers were given a presentation on sky watching using the digital planetarium.

IUCAA premises were kept open on the National Science Day on February 28, from 11 a.m. onwards, and around 5000 people visited the institute. Posters and a video show were organized highlighting the recent developments in astronomy and astrophysics and the work at IUCAA. There were exhibits that demonstrated physics principles, like the working of a radio telescope, Faraday rotation, the effects of atmosphere on astronomical observations, etc.

Volunteers from Jnana Prabodhini School and Akashmitra (an amateur astronomers club) showed the visitors, intriguing science toys, amateur telescopes and the exhibits of IUCAA's Science Park. They explained various physical phenomena, like optical properties of matter and solar limb darkening. Video screening of films on astronomical topics was carried out in Chandrasekhar Auditorium and lectures were presented on "Some Aspects of Astronomy" and "Raman Effect".

Jayant Narlikar and Ajit Kembhavi answered questions on astronomical topics and careers in astronomy asked by the audience. Arnab Bhattacharya of the Tata Institute of Fundamental Research, gave a public lecture on Nobel Prize in Physics 2007.

A night sky observations were conducted in three time slots of one hour each. About 1000 people observed Mars, Saturn, Orion Nebula, Pleiades Cluster through a telescope set up by the volunteers of Akashmitra.

This year the National Science Day celebrations were extended to Ambegaon taluka, where the IUCAA Girawali Observatory is located. On Saturday, March 1, 2008, fifty students from different schools participated in essay and drawing competitions. Naresh Dadhich gave away the prizes to the winners in a simple ceremony conducted on Wednesday, March 12, in the auditorium of Ghodegaon Panchayat Office. He also felicitated I. Jadhav of Arts and Commerce College, Mugdha Khandeshi, the Administrative Officer of Landewadi School, and Ajit Kale of New India Hotel for their support to IUCAA Outreach Activity in Ambegaon taluka. Satyajeet Bade, the Block Development Officer was also present.

Results of Various Competitions at IUCAA

Drawing

1st prize: Poorva Naigaonkar, Jnana Prabodhini, Nigdi.

2nd prize: Ashwini Sadhale, Abhinav Vidyalaya English Medium High School.

Honorable Mention (Drawing): (i) Apurva Suhas Kulkarni, Abhinav Vidyalaya Marathi Medium High School, and (ii) Sachin Vijay Shirse, Modern High School, Shivajinagar.

Essay (Marathi)

1st prize: Komal Gaikwad, Huzurpaga, Katraj.

2nd prize: Onkar Gokhale, Sau Vimlabai Garware Prashala

Honorable Mention : Deepali Dattatrya, Sagar Mahilashram High School.

Essay (English)

1st prize : Anubhav Chattoraj, Delhi Public School.

2nd prize: Tripur Mahajan, Symbiosis Secondary School.

Honorable Mention : Srushti Anil Paranjpe, S. P. M. English School, and Vipluv S, Loyola High School.

Quiz Competition

1st Prize: Jaideep Satyajit Pathak, Rohit Hemant Sant, and Mugdha Rajesh Todkar, from Vidya Bhavan High School.

2nd Prize: Suhit Dutta, Saurabh Rao, and Maneesh Manoj Arora, from The Army Public School.

3rd Prize: Saket Sanjeev Patwardhan, Ashutosh Chandrashekhar Kulkarni, and Rutvij Rajeev Bhagwat from Muktangan English School and Jr. College.

The prize winners at Ambegaon Taluka

Essay (Marathi)

1st Prize: Rajesh Shivaji Bonawat,
Shri Hanuman Vidyalaya, Gangapur Budruk.

2nd Prize: Swapnil Ankush Gavade,
Hirkani Vidyalaya, Gavdevadi

Drawing

1st Prize: Akshya Satish Bankdele,
Mahatma Gandhi Vidyalaya, Manchar

2nd Prize:Vishakha Vishwas Said,
Hutatma Babu Genu Vidyalaya, Maha Padwal.

Popular Talks and Articles by the IUCAA Faculty

(a) Popular Talks

Dipankar Bhattacharya

The Raman effect, National Science Day, IUCAA, February 28.

Naresh Dadhich

Why Einstein, Indian Institute of Astrophysics, Bangalore, August 6.

Ranjan Gupta

Our solar system: A brief review talk at Karimganj College, Karimganj, Assam, July 18.

Need for small telescopes at planetaria, IIIrd Conference on 'New Generation Planetarium' Y. C. Planetarium, Nashik, January 16-17.

Ajit Kembhavi

Vaishvik bhram aani vibhram (Cosmic Illusion), (in Marathi.) J.E.S. R.G.B. Arts, S.B.L. Commerce and R.B. Science College, Jalna, August 29.

J.V. Narlikar

Scientific temper, a lecture delivered at the 6th FIRA National Conference organized by the Federation of Indian Rationalist Association (FIRA), Maharashtra Andhashraddha Nirmulan Samiti (MANS) and B.J.S. College at the B.J.S. College, Wagholi, Pune, April 27

Khagolshastratil suras ani chamatkarik goshti (Amusing and strange tales from astronomy) (in Marathi) a lecture delivered at the Ratnagiri Nagar Vachanalaya, Ratnagiri, April 30.

Paragrahavaril jeevshrushti (Extraterrestrial life) (in Marathi) organized by Navanirman Yuvak Sanghatana at Baramati, May 5.

Outstanding problems in astronomy, organized by the Homi Bhabha Centre for Science Education for the astronomy olympiad students, IUCAA, May 12.

Vidnyan, samaj ani patrakarita (Science, society and journalism) (in Marathi) , Late Padmashri Dr G.G. Jadhav Memorial Lecture, Kolhapur, May 20.

Strange and remarkable facts about the universe, lecture delivered in the Summer Programme for school children at Bose Institute, Darjeeling, June 2.

The challenges and rewards of creating and managing a scientific institution, a lecture delivered during the programme "Strategic Leadership and Shaping Change" organized by the Foundation for Liberal and Management Education (FLAME), Hotel Blue Diamond, Pune, June 8.

Cosmic illusions, Akashmitra, Pune, July 12.

Cosmic illusions, Second Saturday Lecture and Demonstration Programme, IUCAA, July 14.

Antaralatil drushtibrahm (Cosmic illusions) (in Marathi) Second Saturday Lecture and Demonstration Programme, IUCAA, July 14.

Vishwat jeeva-srishticha shodh (Search for life in the universe) (in Marathi) to the Marathi community in Phonenix, Arizona, December 15.

Khagolshastratil suras ani chamatkarik goshti (Amusing and strange tales from astronomy)(in Marathi) (a set of 3 lectures under the Ujawala Deshmukh Memorial Lecture Series, Udgir, January 19 and January 20.

Searches for life in the universe, Assam University, Silchar, January 28.

Jeevan ani vaidnyanik drushtikon (Life and the scientific temper) (in Marathi) organized by Kavi Mukteshwar Sahitya Pratisthan and delivered at S.P. High School, Kurundwad, February 17.

Search for life in the universe, Vishwakarma Institute of Technology, Pune, February 21.

The lighter side of gravity, International Institute of Information Technology, Pune, February 25.

Some ideas in cosmology, (to the students from Presidency College, Kolkata) at IUCAA, February 27.

Vishwat etaratra jeevshrushti aahe ka?, (Is there life elsewhere in the universe?) (in Marathi), Giant Metrewave Radio Telescope, Khodad, February 29.

Vishwarachaneche adhunik siddhanth, [Modern ideas on the structure of the universe] (in Marathi), Senior Citizen Association, Navasahyadri, Pune, March 11.

T. Padmanabhan

Understanding the universe: New Insights and challenges, India International Centre, New Delhi , May 29.

Excitement of doing science, Newman College, Thodupuzha, Kerala , October 9.

Weight of the vacuum, Cummins College of Engineering, Pune, November 15.

Universe: Past, Present and the Future, Ernakulam Public Library, Ernakulam, December 29.
The excitement of cosmic physics, Rotary Club of Pune Metro, December 12.

The story of calendar, Jamia Millia islamia, New Delhi, January 29.

The enigma of gravity, Girls' College, Bhilainagar, Raipur, February 7.

The story of the calendar, Pt. Ravishankar Shukla University Raipur , MBA Lecture Hall, February 7.

The enigma of gravity, Pune Vidyarthi Grih College of Engineering and Technology, Pune, March 3.

Maulik Parikh

Truth and beauty, Fergusson College, Pune , January.

A. N. Ramaprakash

Light for astronomy, Akashmitra, June 6.

Kandaswamy Subramanian

Galaxies and AGN, Astronomy Olympiad students, IUCAA, May.

Structure formation in the universe, Fergusson College, Pune, January 9.

(b) Popular Articles

J. V. Narlikar

Exciting research out of labs into universities, India Empowered, 199.

Journey without maps, The Times of India, July 28.

Cultivating the right scientific temper, One India One People, August, 56.

From scientific literacy to scientific research: the Indian experience, The Republic of Science: Golden Jubilee Vignettes, 15.

Where time stands still, The Times of India, November 10.

My greetings to Bhal, B.M. Udgaonkar: Eminent Scientist and Educationist, 23.

Pune in 2020 : A dream, DNA, February 26.

Why study astronomy?, The Joy of Physics, October 5.

An astronomer's cricket puzzle, Safari, March 15.

The role of science fiction in the present age of science, Proceedings of the Eighth National Conference for Science Fiction Writers, 7.

The great escape to space, The Indian Express, March 15.

Bhari dopahari mein andhera, (in Hindi) [Darkness at noon], Navbharat Times, August 8.

Him yug ki vapsi, (in Hindi) [Return of the Ice Age], Navneet, February, 101.

Chitthi aiyee hai, (in Hindi) [The letter has come], Chakmak, March 1.

Malo ho krishnavivar disale...!(in Marathi) [Oh! I saw the black hole], Sakal, April 10.

Paradhin nahi jagati putra manavacha...(in Marathi) [Man in this world is not a helpless animal], Sakal, May 9.

Vidnyanyugat vidnyankathanchi bhumika (in Marathi) [The role of science fiction in the age of science], Pudhari, May 20.

Paradhin nahi jagati putra manavacha...(in Marathi) [Man in this world is not a helpless animal], Vidnyan Vichar, June 6.

Anubhav gairvyavasthapanacha, ayogya manovruticha (in Marathi) [The result of bad management and wrong mindset], Sakal, June 12.

'VVIP' yeti ghara | jaee shanti deshantara || (in Marathi) [When VVIPs arrive, we lose all our peace], Sakal, July 10.

Aajachya antaralyugatil kahi andhashradha (in Marathi) [Some space-age superstitions of modern times], Sakal, August 7.

Vidnyan sahitya (in Marathi) [Science fiction], Sathottari Marathi Vangmayatil Pravah, 299.

Udatya tabakadya: antaral yugatil andhashradha (in Marathi) [Flying saucers: superstitions of the space age], Sakal, September 5.

Samratachi navi vastre: Adrushya padarth ani adrushya urja (in Marathi) [The Emperor's new clothes : Dark matter and dark energy], Sakal, October 9.

Svayamsphurta prashna ani vidnyan shikshan (in Marathi) [Science teaching and spontaneous questions], Sakal, November 6.

June te sone : Kharokhar ka paishapurte? (in Marathi) [Old is Gold : In reality or just for money?], Sakal, December 4.

Khagolshastradnyanna avahan (in Marathi) [A challenge to astronomers], Loksatta, March 20.

T. Padmanabhan

Potentials of potatoes: A surprise in Newtonian gravity, Resonance, January, **13,** p 4.

Angular momentum of electromagnetic field, Resonance, February, **13**, p 108.

Qantum mechaics on the run, Resonance, March **13**, p 212.

Cosmic Snapshots - *(published in The Telegraph)*

Sun's merry-go-round, March 5.

Heavens in the grip of science, April 2.

Scaling the cosmos, April 16.

Star power, May 7.

Violent explosions out there, May 21.

Star attraction, June 4.

Explaining black hole, June 18

Black holes are hot, July 2.

The expanding universe, July 16.

The hot universe, August 6.

Why cosmologists like inflation, August 20.

Dark side of the universe, September 3.

Maulik Parikh

Column on *quantum mechanics*, in **Outlook,** April 2007.

Column on *extra dimensions*, in **Outlook**, May 2007.

Column on *meteor collisions*, in **Outlook**, June 2007.

Tarun Souradeep

Cosmology with the Cosmic Microwave Background, Joy of Physics (2007).

(c) Radio/TV Programmes

Ajit Kembhavi

The new planet, Radio Mirchi, April 27.

New earth like planet, All India Radio, Pune, April 30.

New projects at IUCAA, All India Radio, Pune Telecast on August 5.

J. V. Narlikar

Khagolshastra ani vishwachi nirmiti (Astronomy and origin of the universe) (in Marathi), Virtual Learning Classroom (in collaboration with Yashwantrao Chavan Maharashtra Open University, Nashik and Chanakya Mandal, Pune for UPSC and MPSC students), May 3

Chintan (in Marathi), Akashwani, Pune, August 1, August 2, August 3 and August 4.

Marathi bhasheche bhavitavya (Seminar talk in Marathi), Akashwani, Pune, February 27.

(d) MISCELLANEOUS

Ajit Kembhavi

Question and Answer Session, Face to Face, Bal Shikshan Mandir, Pune, April 21.

Question and Answer Session, Science Day, IUCAA, February 28.

Jayant Narlikar

Participation in question-answer programmes on key channels on television.

FACILITIES

(I) Computer Centre

The IUCAA Computer Centre continues to equip itself with the state-of-the-art computing resources to cater to the needs of the academic as well as the administrative activities of the Institute.

Email has become one of the most important modes of communication for everyone. An undesirable consequence is that in just a few years, unsolicited commercial email, known as "spam", has gone from being a minor nuisance to becoming a significant social and economic issue. Software such as Examine and Openprotect were used in the past to combat the above nuisance. The best solutions available are in the form of appliance, which is costly and it needs to be upgraded periodically. In April 2007, IUCAA opted for a cost effective solution, i.e., getting emails relayed through a secure email relay service provider M/S Logix, that delivers 99% spam/virus free emails. Benefits of this service include:

- Saves the Internet bandwidth and storage
- Platform independent
- Only a simple MX change is required to enable the service
- No additional hardware or software required
- No installation and maintenance hassles
- Acts as a Message Queue in case of any downtime at the client mail server end
- Quicker to implement than any software based solution
- Keeps spam/viruses away from the local network.

Increased use of laptop computers and increase in worker mobility have fuelled the demand for wireless networks in the entire campus. Previously, the wireless access was available only in the Computer Centre, Library, Bhaskara 3, Conference Hall and Seminar Room A3. In the past year, wireless access was made available in the Guest House, and the entire office building. The outdoor antennas also have been added to boost the signal strength of the wireless network.

In January 2008, personal computers (PC) with 1 GB RAM, 19" TFT monitor, DVD writer were provided for the academic community. Centos 5.0 Operating System (LINUX), identified by IUCAA research scholars, has been installed on all the PCs in the academic VLAN, so that centralized management of updates and patches could be maintained across the PCs in the campus.

Although, the price of storage hardware has been steadily decreasing, the voracious demand for data and the associated administrative and maintenance costs continue to strain budgets and staff. One way of surmounting this challenge is to consolidate storage into a storage area network (SAN), which centralizes storage resources and reduces points of management. Not only does a SAN facilitate scaling and enhance availability, it makes it possible for disparate platforms and applications to share the same storage environment, greatly improving utilization, efficiency, and storage administrator productivity. As a first phase to storage consolidation, 20 TB EVA 4000 SAN (Storage Area Network) storage from HP, was commissioned last year. In February 2008, EVA 4000 SAN was upgraded to EVA 6000 SAN having storage capacity of fifty six terabyte (128 * 500 GB = 56 TB), four disk enclosures and two loop switches to increase its overall performance.

The IUCAA Computer Centre continues to extend support to University departments and colleges for configuring networks, obtaining hardware and software, setting up applications and training personnel.

(II) Library and Publications

In the period under review, the Library has added 207 books and 400 bound volumes to its existing collection, taking the total collection to 21994. One hundred fifteen journals were subscribed by the library. Fifty-three books were added to the Muktangan Science Exploratory library, which now has 987 books in its collection.

With a base of 39 university academics availing the monthly table of contents services, a total of 100 full-text articles requested were dispatched by the library staff. In addition to the above, 258 full-text article requests were received through e-mail/post from 34 academics, students as well as other institute libraries. The library received inter-library loan requests for 33 books from 7 libraries.

One of the significant initiatives undertaken by the library was the implementation of open source software called Open Journal System (OJS), a journal management and publishing system for the IUCAA publications, viz. Khagol (quarterly bulletin) and Annual Report. OJS has been developed by the Public Knowledge Project (PKP), which operates through a partnership among the Faculty of Education at the University of British Columbia, the Simon Fraser University Library, the School of Education at Stanford University, and the Canadian Centre for Studies in Publishing at Simon Fraser University. The implementation was handled by N. Nageswaran and was successfully deployed from July 2007. Not only is the entire text available in pdf and html formats, but more importantly, content-wise search and retrieval in both the formats are possible. OJS adheres to the Open Archive Initiative Protocol for Metadata Harvesting (OAI-PMH), which ensures global retrieval, visibility and archiving.

The IUCAA Library is an active member of the Forum for Resource Sharing in Astronomy (FORSA), comprising the twelve institute libraries given below:

(1) Aryabhatta Research Institute of Observational Sciences (ARIES), Nainital; (2) Bose Institute, Kolkata; (3) Harish-Chandra Research Institute (HRI), Allahabad; (4) Indian Institute of Astrophysics (IIA), Bangalore; (5) Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune; (6) National Centre for Radio Astrophysics (NCRA), Pune; (7) Osmania University Centre for Advanced Studies in Astronomy, Hyderabad; (8) Physical Research Laboratory (PRL), Ahmedabad; (9) Raman Research Institute (RRI), Bangalore; (10) Saha Institute of Nuclear Physics (SINP), Kolkata; (11) S.N. Bose National Centre for Basic Sciences (SNBNCBS), Kolkata; (12) Tata Institute of Fundamental Research (TIFR), Mumbai.

The members of FORSA will be jointly organizing the Sixth International Conference on Library and Information Services (LISA), to be hosted by the Inter-University Centre for Astronomy and Astrophysics (IUCAA) and National Centre for Radio Astrophysics (NCRA), Pune during February 14-17, 2010. The broad theme of the conference is the 21st Century Astronomy Librarianship: From New Ideas to Action.

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 main emphasis of work carried out in the instrumentation laboratory continues to be that of meeting the demands of the IUCAA Girawali Observatory. The earlier efforts of the laboratory staff to minimize downtime at the observatory due to instrument or auxiliary support issues have begun to bear fruit with less than 1% of the total scheduled time being lost due to these causes. As part of this programme, it was reported last year that a standby 2k x 2K CCD system was developed in the laboratory. This system was tested with IUCAA Faint Object Spectrograph and Camera (IFOSC), aligned and calibrated by P. Chordia, H. K. Das and others.

M. Shaikh along with M. P. Burse put in substantial efforts to stabilize the operating version of the instrument control system software based on feedback from the user community. Once this was achieved, they turned their efforts to testing and commissoning a new USB-based data acquistion system for IFOSC. This system was released for use post-monsoon of 2007 and has since been working reliably over two cycle periods now. With this success, the data acquisition system has become very robust and portable since the need for custom made PCI-based expansion cards and associated specific drivers have been eliminated.

IFOSC's capabilities have been further enhanced by building in an integrated polarimetric mode. This mode has been quite popular among the user community, and polarimetry based proposals were received for every cycle till date. A. Kohok and H. K. Das worked on the opto-mechanical design and commissioning, while A. Kadam and A. Kohok developed the software control programme for implementing this mode.

Over the last one year, another major thrust was on making an integrated instrument control system (CCU) ready for release. A lot of time has gone in for testing the CCU hardware in the lab with simulators and at site with actual instruments. The CCU with its new associated GUI has also been tested and improved upon over the time. This system meets all the current instrument control needs at the telescope focal stations and provides for future generation instruments in an expandable and configurable way. The screen shots in figure 18 show some of the interface's software components while in figure 19 is shown one of the hardware units. The system provides for two access privilege levels - one for the regular operators and the other password protected one for maintenance and diagnostic operations. Apart from the regular laboratory staff, three software developers, namely, A. Kadam, M. Shaikh and S. Punnadi worked on this project. The CCU system has been installed on the telescope now and will be released for regular use during the next observing cycle.

In a related project, the communication capabilities of the CCU system is being enhanced considerably by providing for fibre, USB and ethernet based links in addition to the built-in RS232 link. While it is planned to have the CCU working across the telescope LAN by exploting the ethernet link in the normal course, the other channels will offer standby alternatives in case of failures as well as provide for easy communication with the CCU hardware during engineering work. This development was primarily carried out through a couple of B. Tech students' projects and the card is currently undergoing laboratory tests.

Development of a multi channel data acquition system, which will cater to the needs of the future generation of instruments on the telescope has

Figure 18: A screenshot of the new instrument control interface for IUCAA Girawali Observatory. This software package developed on Linux platform provides a unified interface for instrument control and data acquisition.

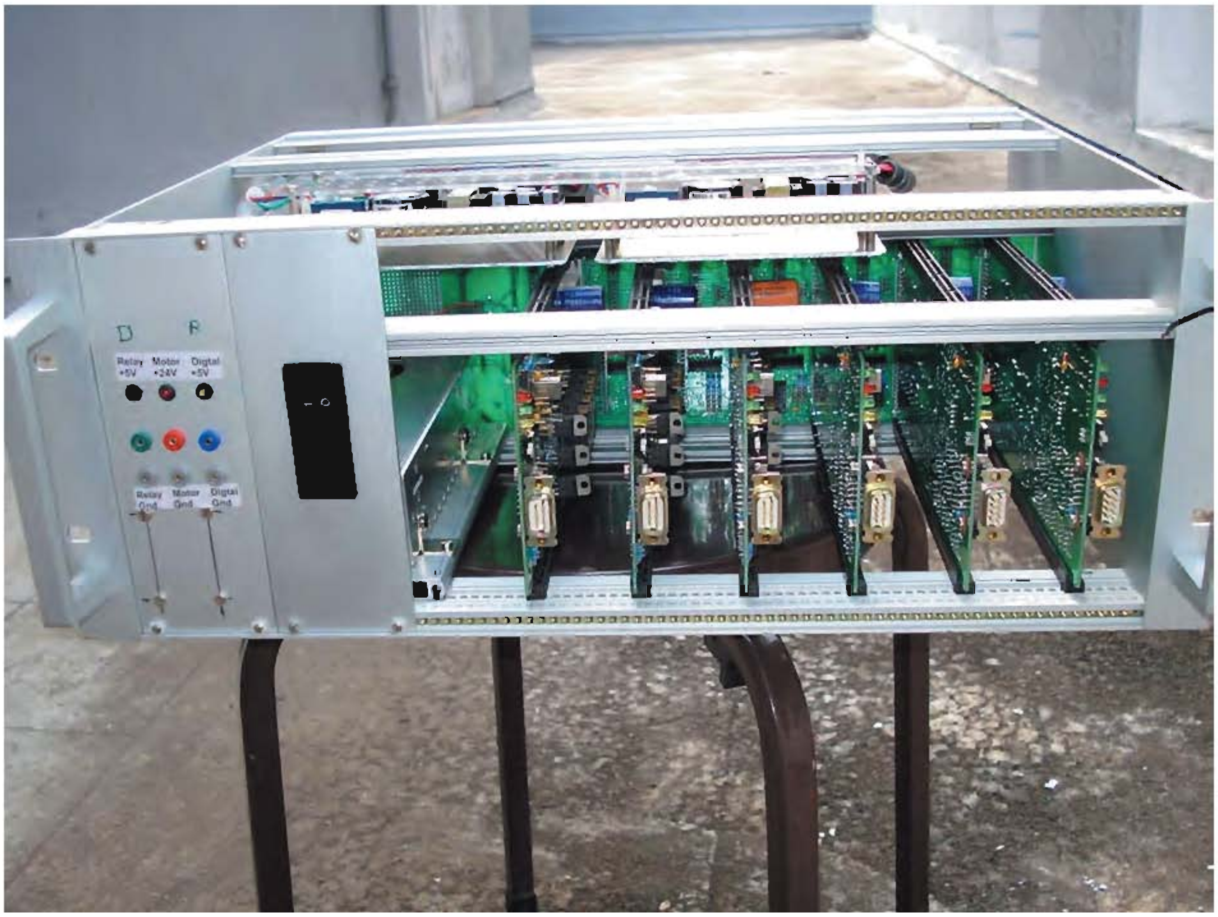


Figure 19: The new unified instrument control system hardware for IUCAA Girawali Observatory. This system is made up of identical control cards, and can be expanded and configured to meet a variety of instrument control requirements.

also been progressing. An FPGA-based card has been designed and fabricated for the purpose (see fig. 19). Once this card has been populated, the firmware program has been developed by S. Sinha. This VHDL programme has already been validated on simulators and is undergoing final tuning. A single channel mode of this code has been demonstrated to be working on the actual hardware. Once this mode has been tested and debugged, work will turn towards the realization of the multi-channel mode.

(IV) IUCAA Girawali Observatory (IGO)

IGO has completed two years of operation in May 2008, since the handover of the telescope. Details of the observation cycles, the constitution and operational principles of the IGO Time Allocation Committee and the proposal statistics of the first observational cycle (2006B) were all presented in the last Annual Report. The year that has gone by saw a few ups and downs, which is anticipated in the early years of operation of a facility at this scale. One of the main issues of concern was a failure of the Cassegrain axis drive system, which severely restricted the sky coverage of the telescope, as all objects south of about 19 degree declination were practically rendered unavailable, except for very short integration exposures. There were also a series of failures, primarily of IT-related equipment. This along with the Cassegrain motor failure led to a relatively low data efficiency of about 34% during Cycle 2007A. Both of these issues have been resolved now. The cause of the issue with the Cassegrain axis drive system was diagnosed to be due to the misbehaviour of one of the two motor-gear assemblies which work in an anti-backlash arrangement. The harmonic drive gear in one of these assemblies, jammed when it was driven in the reverse direction by the other motor, as happens during tracking of objects in the southern hemisphere. These motor-gear assemblies are of TTL proprietary design and have several months lead time for delivery. A new assembly has been procured from TTL and was installed on the telescope in late September 2007. The system has been working quite well since then. It is duly acknowledged here that Peter Gillingham, (Commissioning Engineer of Anglo-Australian Observatory and ex-Operations Director of Keck Observatories) visited IUCAA and IGO during the period to investigate the possibilty of finding alternative solutions to drive the Cassegrain system.

The built-in autoguider system of the telescope was diagnosed to show strong pickups, which last for about the first 10,ms of the image readout. The performance of autoguider was severely affected by these pickups. Investigations revealed that this was due to the inadequte regulation specification of a transformer, which was used for the autoguider systems, +/ − 15V power supply combined with a dip in the UPS power supply to about 225V a/c, (from the nominal setting of 230V a/c), whenever the telescope's hydraulic systems were turned on. Replacement of the transformer with one that is adequately specified and fixing of a failed cooling fan on the autoguider CCD head assembly resolved this problem. A spare autoguider system is being procured from TTL as a standby.

During the previous monsoon periods, the telescope was, by and large, shut down due to the condensing humidity conditions prevailing over most of months from June to September. However, not carrying out at least basic level of operations would lead to a number of issues being accumulated till they are discovered at the end of monsoon. Also, the need to exploit the monsoon period productively for carrying out annual maintenance of the telescope was recognized. Therefore, it was necessary to reduce the humidity within the telescope area to sufficiently low levels, while at the same time maintaining acceptable working conditions. To achieve this, given the limitations of power available at the site, it was necessary to considerably reduce infiltration of moisture into the enclosure area through ventilation channels (which are numerous, as the enclosure was carefully designed to be well-ventilated to minimize seeing effects) as well as permeation through the walls. Ventilation sealing technique should be repeatable year after year, and also easy to remove at the end of monsoon. Another concern was the large scale rain water leaks, which were seen in the telescope building including the telescope enclosure and the control room. A major initiative was undertaken to investigate and resolve these issues. The solution, which was finally implemented prior to the monsoon of 2007, has been successfully put into operation.

During this period, a high attrition rate among operational support staff was another issue that the observatory had to deal with. A multi-prong approach has been identified to bring down the attrition rate to manageable levels. This includes, pro-actively looking for sufficiently qualified candidates, who live in the vicinity of the observatory, buffer the effect of attrition by appointing extra permanent laboratory staff who are specifically required to spend a given amount of their time at the observatory and identifying avenues for career growth for these staff. Reduction and flexible scheduling of working hours, better compensation packages etc. are other steps taken. V. Mohan has been largely handling the training of operational support staff as well as observer scheduling and management.

Figure 20: A view of the mirror re-aluminization plant installed at IUCAA Girawali Observatory. This magnetron sputtering based system was manufactured to IUCAA's specifications by Hind High Vacuum Company Ltd., Bengaluru. The trolley seen in the front carries the mirror cleaning tank.

It was seen that in images taken with IFOSC, there was a central glow of scattered light with a contrast of about 10% to 15% level. Very large scattered light background was also seen in the PI-CCD instrument, which was mounted on one of the side ports. Most of this light was found to be due to light entering the primary mirror baffle finding its way to the detector planes. Since IFOSC has a re-imaged pupil, considerable reduction (to about 2%-5% level) in the scattered background could be achieved by providing a pupil stop. In order to achieve a more general solution for the problem covering all the Cassegrain focal ports, the telescope's primary mirror baffle was modified with a three-prong approach, (i) reduce the light entering the baffle, (ii) provide extremely low reflectivity coatings inside, and (iii) ensure that scattered light can reach the detector plane only after multiple reflections off the internal walls of the baffle.

Another source of scattered light inside the instrument was traced to the near-IR LEDs, which were used in different home and limit markers for instrument control. A suitable modification of the instrument control hardware and software was made to ensure that these sources were kept turned OFF except when required. The fact that the primary mirror itself had a layer of scattering dust cover, which also was contributing to the scattered light, particularly during relatively bright nights. This effect also would be considerably reduced now that the primary mirror has been freshly aluminized.

A major facility upgradation at IGO was the installation of the mirror aluminization plant during early 2007 (see Figure 20). A number of tests were carried out subsequent to the installation, in order to verify the performance of the plant vis--vis critical parameters, like coating thickness uniformity, reflectivity, etc. In September 2007, the primary mirror of the telescope was taken out and re-aluminized. The resultant 70-80% reflectivity was a substantial improvement from the 30% prior to the re-aluminization. R. Gupta, along with H. K. Das, A. Kohok and others led the effort for realizing the mirror coating plant. Support of two staff members from TTL during removal and re-installation of the primary mirror is to be acknowledged here. In order to minimize the effect of dust on the mirror's reflectivity, a regular CO2 snow cleaning regime has been put in place now.

Other facility enhancements like the release of a new USB-based data acquisition system, deployment of an automated polarimetry mode for IFOSC, upcoming implementation of a new integrated instrument control system, etc. are mentioned elsewhere in this report. Largely through the efforts of S. Ravindranath, H. K. Das and others, a set of five narrow band filters (8.0 nm FWHM) have been procured and installed in the calibration unit of IFOSC. These are particularly suitable for local and red-shifted H-alpha studies and were used by many investigators during cycle 2008A.

Table 1: Usage details of IGO

USERS	Requested	Allotted	% USED
IUCAA	90 (20)	52 (18)	39
Universities	99 (16)	44 (14)	70
Others	117 (22)	37 (16)	66
Total	306 (58)	133 (48)	59

Usage of IUCAA Girawali Observatory during three observing cycles namely 2006B, 2007A, 2008A. The second and third columns show the number of nights which were requested and were actually allotted by TAC. The corresponding numbers of proposals are shown in brackets. The last column shows the percentage of utilization out of the allotted nights after accounting for weather, technical downtime etc.

Work was also undertaken to find replacement spare solutions for the IT-hardware used on the telescope. This hardware includes the computers, which populate the IT-Rack (off-mount) and telescope (on-mount), as well as the cards, etc., which are used in them. Most of these hardware components have become obsolete now, and so are the operating system versions running on them. Even if hardware could be found, which accept the old operating system versions, there was further the issue of ensuring that the layered software products which form part of the telescope system, can be (adapted to, if needed) run on them. This effort was part of a larger scale effort to procure an adequate spare holding for the telescope. Most of the efforts were directed to find locally available spare options while procuring these items. Parts like Industrail PCs, etc were actually tried after installing the required OS and configuring according to the requirement. A large consignment of spares being procured through TTL, is expected to arrive soon at the time of this report.

As part of the downtime minimization efforts, a database has been set up for reporting and recording all the technical problems, their diagnostics as well as solutions in a category wise structured and searchable format. This database has been populated with the history of all the major issues that have occurred over the last two years of operation and is continuosuly updated. Authorized users can log in to the system from anywhere using a standard browser, search for reported bugs, generate summary charts, report new bugs, track the progress of their resolution online, etc.

Work is underway to set up a web-based proposal submission and management system for IGO, under the Virtual Observatory (India) project.

This is further to be upgraded to an integrated proposal and data managment plus archival system in the near future. Initial work for the next generation of scientific instruments for the telescope has picked up momemtum.

Publications resulting from IGO Data

(i) Joydeep Bagchi, Gopal-Krishna, Marita Krause and Santosh Joshi (2007) A Giant Radio Jet Ejected by an Ultramassive Black Hole in a Single-lobed Radio Galaxy, *The Astrophysical Journal*, **670**, L85.
(ii) M. Lpez-Corredoira,C.M. Gutirrez, V. Mohan,G.I. Gunthardt, M.S. Alonso, (2008) Analysis of possible anomalies in the QSO distribution of the Flesch and Hardcastle catalogue, *Astron. Astrophys.*, **480**, 61.

(V) Virtual Observatory - India

The Virtual Observatory - India (VOI) project, located at IUCAA, is a collaborative venture between IUCAA and Persistence Systems Pvt. Ltd. (PSPL), a software company based in Pune, which has significant expertise in databases. PSPL provide six software engineers to the project, at the company's cost, as well as the expert help of senior personnel from the company. The project is partially funded by the Ministry of Information and Communications Technology of the Government of India. VOI is a member of the International Virtual Observatory Alliance (IVOA), and works in collaboration with other Virtual Observatory projects in the world, in the framework of the IVOA.

The aim of VOI is to provide astronomical data, along with tools for data analysis to the astronomical community in India and abroad. The tools are all developed in conformity with VO standards for interoperability. They are made available in stand alone versions, which can be installed on the users machine, and as web based versions which run on VOI servers, and can be used from any machine, which has access to the internet. VOI also provides software services to the astronomical community. which include the development of sophisticated codes for specific applications, data analysis tools and data archives.

The data provided to the community now includes the Chandra database, and the Data Release 6 of the Sloan Digital Sky Survey (SDSS-DR6), and many other smaller databases. Mirror copies of these large databases are available in a limited number of centres in the world. VOI plans to archive even larger image databases in the near future.

Two important tools which have been developed by VOI are VOPlot and VOStat. VOPlot is a comprehensive graphics and visualization package, which allows the user to view data in two and three dimensions, in a highly flexible manner. A new version of this package has been released recently. VOPlot is PLASTIC compatible, which means that it can freely exchange data with other packages using the PLASTIC protocol. VOPlot is made available on important international services like Vizier and MAST. VOStat is a statistical tool, which makes use of the publicly available statistical package called R, which is the industry standard. VOStat provides the user easy access to a large number of statistical tests. VOPlot and VOStat work in tandem, thus, greatly increasing the efficacy of each package. Over the period of the report, VOStat has been made available in a Java version for standalone use, as well as a web based version developed in jsp/servelets. VOStat will soon be made available on VIZIER and other data services.

Towards the end of 2007, VOI finished the development of a FITS package in C number. This was done at the request of the SDSS group at Johns Hopkins University, as a part of the software services provided by VOI.

A very interesting and challenging project, which has been taken up by VOI is the development of a data archive and proposal submission system for the Giant Metrewave Radio telescope (GMRT) of the National Centre for Radio Astrophysics (NCRA). The GMRT is being extensively used for observations at relatively low frequencies by the national and international community of astronomers, and archiving the data will allow astronomers from all over the world to make use of it, after an embargo period during which, the data is exclusively available to the proposers of the observation. The archive has to be developed in a VO compatible manner, so that the database can be searched easily using any of the many VO tools, which are now available, or are being developed. VOI has taken up the task of developing such a database, in collaboration with astronomers from the NCRA. A web based proposal submission system, to be used by everyone making a proposal for GMRT observations, is also being developed. It is expected that the archive will be ready by the end of 2008. The experience should be useful in the development of the proposed ASTROSAT Data Centre at IUCAA.

The VOI project has set an example for partnership between an academic institution and a software company for the development of highly sophisticated products, which are being used internationally. Such partnerships will be crucial to the success of the very large astronomical projects, which are being planned for the next two decades.

(VI) IUCAA-NCRA Radio Physics Laboratory Facility (RPL)

J. Bagchi, in collaboration with TIFR's National Centre for Radio Astrophysics (NCRA) has initiated and implementing this novel facility, the main goal of which is to impart practical hands-on training in specialized concepts of radio astronomy to university students and teachers. Also, an important aim is to make them technically trained and motivated enough to use the GMRT, for high quality research work. To fulfil these goals, over the last few years extensive efforts have been made towards implementation of the ideas behind the project, and all major plans were finalized for setting up this Radio-Physics Laboratory (RPL), jointly in IUCAA and NCRA. In January 2008, with the signing of a formal MOU between IUCAA and NCRA towards bilateral co-operation, the RPL project has started to take shape exactly as planned. Currently, the set-up activities are in full swing at both the institutes, involving active help provided by many local science and engineering students (as integral part of their training). We have also involved skilled manpower from university sector.

Current Status and Significant Achievements

• IUCAA, in collaboration with NCRA utilized profitably and reasonably the majority of funds allocated by UGC to this project in the Xth plan. Basic radio astronomy infrastructure; such as a 3.5 m radio telescope (MIT Haystack Observatory design), 21-cm hydrogen line spectrograph and continuum receivers, couple of 21 cm VLBI receivers for interferometry, a 6.8 GHz Methanol line system, a 408 MHz pulsar receiver, Solar and Jupiter radio antenna and receivers, numerous front end amplifiers and filters, and feed horns, etc. were acquired. These are now formally shifted to NCRA as part of the agreement. We have already started to utilize these systems for educational and training purposes.

• The 3.5 m MIT radio telescope has been unpacked and now completely installed on the terrace of the NCRA radio-lab (see Figure 21). Basic tests show satisfactory operation in 21-cm Hydrogen line and in radio continuum. More test and calibration work are being carried out. Eventually, we aim for its extensive use in student training programs of IUCAA and NCRA. During the Radio Astronomy Summer School (RAS-2008) programme of NCRA, the 3.5 m radio telescope was extensively used by participants for hands-on radio astronomy experiments.

• NCRA has contributed in terms of lab building, manpower, security, workshop facility, and in particular with another 4 m radio telescope fitted with a new motor drive. A 21 cm hydrogen line and radio continuum receiver is available on this telescope. NCRA also is erecting a 15 m radio antenna, which eventually will become part of the RPL facility. This antenna will enable observations of weak radio sources. All the three radio telescopes may eventually form an interferometer array (with closure phase) for higher resolution experiments.

• The RPL is being readied with experiments to augment training programs carried out by IUCAA and NCRA, such as Summer Schools and Student Training Programmes. For the first time, RPL is providing hands-on experience to graduate students of IUCAA-NCRA Graduate School and Introductory Astronomy and Astrophysics courses of Department of Physics, University of Pune (see Figure 21). We plan to eqiup the RPL with more interesting experiments in near future.

• For creating a better awareness for the radio-physics lab, a new RPL web page has been launched, which is hosted from both NCRA and IUCAA. This webpage is being periodically updated with resource material, observational and student project reports, tutorials and links to radio astronomy oriented and other informative websites. The IUCAA-NCRA Radio Physics lab homepage is available from the following URLs:

`http://www.ncra.tifr.res.in/~rpl /radio_physics_laboratory.htm`

`https://www.iucaa.ernet.in/Resources.html`

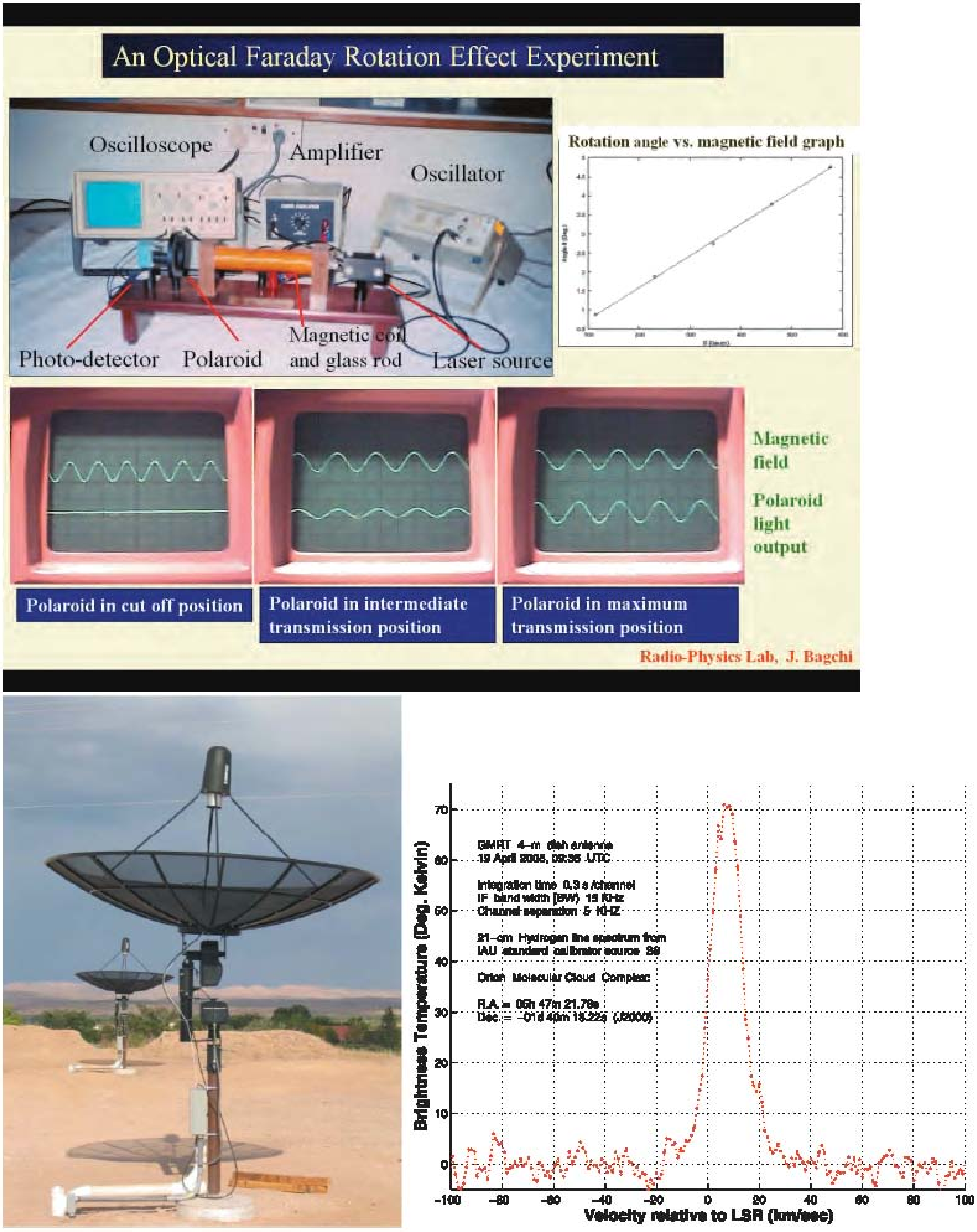


Figure 21: A sample of experiments performed in the IUCAA-NCRA Radio Physics Lab. Upper panel: Optical Faraday Rotation Experiment for probing solid (photonic glasses) and liquid media in an external magnetic field. The enclosed graph shows Faraday rotation of the polarization angle increasing linearly with magnetic field strength (For SF-52 glass). Lower left: A 3.5 m MTT radio telescope recently commissioned in NCRA/TIFR campus. Lower right: Strong detection of 21 cm Hydrogen line of neutral hydrogen (HI) in the direction of Orion molecular cloud complex is shown, obtained with a similar radio telescope of 4 m diameter in NCRA/TIFR campus. The brightness temperature at the peak of the line is $\sim$ 72 Kelvin, and line velocity relative to the local standard of rest (LSR) is $\sim$+8 km/sec.

IUCAA REFERENCE CENTRES (IRCs)

[1] Delhi University
(Coordinator : T. R. Seshadri)

Talks held at IRC, Delhi University

L. Sriramkumar : The primordial spectrum as a probe of Planck scale physics, July 2007

Banibrata Mukhopadhyay: Neutrino under gravity and its implication to astrophysics and cosmology, August 2007.

Shinichi Nojiri: Modified Theories of Gravity and Dark Energy, November 2007

Ishwaree Prased Neupane : Inflation and Dark Energy: Understanding the Physics of the Universe, December 2007.

Smriti Mahajan: The effect of environment on star formation of galaxies, January 2008

Madhavan Varadharajan: Quantum Gravity and Information Loss, March, 2008

Visitors to IRC, Delhi :

L. Sriramkumar (Harish-Chandra Research Institute, Allahabad) July, 2007 ; Banibrata Mukhopadhyay (Indian Institute of Science., Bangalore) August, 2007; Ishwaree Prased Neupane, December, 2007; Shinichi Nojiri (Nagoya University, Japan) November, 2007; Smriti Maha jan, (University of Birmingham) January, 2008; Madhavan Varadharajan (Raman Research Institute, Bangalore) March, 2008.

A number of seminars and journal club talks have been arranged jointly with the Centre for Theoretical Physics, Jamia Milia Islamia

[2] Pt. Ravishankar Shukla University, Raipur
(Coordinator: S. K. Pandey)

(1) Summary of activities :
Facilities available at IRC were used by the faculty members, research scholars and M. Sc./M. Phil. students of the department as well as visitors, in strengthening their teaching/ research activities.

(a) Teaching: During the year, five students were allotted project work in A & A as a part of for their M. Sc. course. They used IRC facilities(Internet and library) to carry out their project work; this included observational exercises using the observing facility (8" CGE series telescope from Celestron) as well as data analysis using archival data.

(b) Research : The research activity of the faculty members and the research students is mainly focused in the following areas:
(i) Dynamical modeling of elliptical galaxies carried out by D. K. Chakraborty and his research students.
(ii) Multi-wavelength surface photometry of galaxies carried out by S. K. Pandey and his research students as part of collaboration with A. K. Kembhavi and researchers from other institutes/observatories.

Paper/Poster presentation in national/international conferences:

A poster was presented at the ASI meeting held during February 7 - 9, 2007, at Osmania University, Hydrabad, entitled, "Redshift of galaxies in Palomar Large Format Camera Fields: Preliminary Results".

Paper entitled, "Intrinsic shapes of elliptical galaxies : An improved technique", presented at "Young Astronomer Meet-2008" held at Mahatma Gandhi University, Kottayam, Kerala, January 2-5, 2008.

A poster entitled, "Intrinsic shapes of individual elliptical galaxies", was presented at the 15th National Symposium NSSS-2008 organized by Radio Astronomy Centre, TIFR, Udhagamandalam, Ooty, held during February 2008.

(2) Visitors to the centre:

Vijay Mohan, IUCAA, Pune. (May9-10, 2007)

Arvind Paranjpye, IUCAA, Pune. (July 21-24, 2007)

Manoj Patel and Vinod Prasad, Gorakhpur University (January 20 - February 8, 2008); they made use of the observing facility as a part of training to learn the techniques of astronomical photometry.

T. Padmanabhan, IUCAA, Pune (February 6 - 7, 2008)

(3) **Seminars/lectures**

M. Sc. and M. Phil., students of the department made use of IRC facilities for the preparation/presentation of weekly seminars organized in the department.

(4) Lectures organized in and around Raipur city.

Arvind Paranjpye: Search for Extraterrestrial Intelligence, July 23, 2007, (S.O.S. in Physics, Pt. Ravishankar Shukla University, Raipur)

T. Padmanabhan: (i) Weight of the Vacuum, February 6, 2008 (S.O.S. in Physics, Pt. Ravishankar Shukla University, Raipur).

(ii) The Enigma of Gravity February 7 , 2008 (Bhilai Mahila Mahavidyalaya, Bhilai).

(iii) The Story of the Calandar, February 7, 2008 (Pt. Ravishankar Shukla University, Raipur).

S.K.Pandey : (i) An Overview of the Universe, (ii) Structure and Evolution of Stars at Govt. P.G. College, Baloda Bazar, December 15, 2007.

Other activities:

Other 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 2008 held at Kottayam, GRB workshops at IIA, VO workshop at IUCAA, Workshop on Small Telescope at Bhavnagar. ASI meeting at Osmania University, Hyderabad, NSSS-2008 at Ooty, Mini-School on Astronomy and Astronomical Data Analysis held at Newmann College, Thodupuzha, Kerala, Advanced Data Analysis and Research in Astronomy held at University of Calicut, Calicut, Kerala.

Sky Gazing Programme were organized from time to time during December 2007 to March 2008 as a part of popularizing Astronomy among young students and general public. This got attention of local new papers as well as of Raipur Doordarshan news.

Research project :

(i) A research project entitled, " Photometric and spectroscopic studies of galaxies in deep survey fields" was approved by ISRO, Bangalore under RESPOND programme, with S. K. Pandey as PI and A. K. Kembhavi as Co-PI during March 2008. Total cost of the project is Rs 18.24 lakhs. The process of appointing SRF and JRF in the project is in progress.

Research Publications (journals/proceedings):

1. D.K. Chakraborty, A.K. Singh, and Firdous Gaffar, (2007) Variation in the intrinsic shapes of elliptical galaxies, MNRAS, **383**, 1477.

2. Pandey S. K.(2007) Teaching and research in astronomy using small aperture optical telescopes, IAUSS, **5**, 245.

[3] North Bengal University, Siliguri (Coordinator : B. C. Paul)

IUCAA Reference Centre at North Bengal University has provided facilities for research work in cosmology and theoretical astrophysics since its inception under the supervision of S. Mukherjee. During this year, a meeting on Himalayan Relativity Dialogue at Orange Country Retreat (Swiss Cottages), Mirik, in the lap of the Himalaya was held during April 18-20, 2007 on the eve of S. Mukherjee's retirement from NBU. It was organized jointly by IRC, NBU and IUCAA, Pune. About 22 participants from India and abroad attended the meeting with day night discussion sessions in addition to the usual scheduled programme. Lynden Bell from UK was among the distinguished speakers present in the meeting. A few M. Sc. Students, using IRAF software facilities of the centre were doing seminar work. Teachers from the neighbouring colleges were visiting the centre regularly for doing research work. The centre initiated group discussions and organizes seminar by the local resource persons at least once in every month.

Visitors :

D. Lynden Bell (Institute of Astronomy, Cambridge University), N. K. Dadhich (IUCAA), P. Dasgupta (Delhi University), H.S. Das (Kokrajhar College, Assam), P. Chakraborty (Alipurduar College), P. Thakur (Alipurduar College), R. Sharma (St. Joseph College, Darjeeling), A. Saha (Darjeeling Govt.College), Shibshankar Karmakar (Coochbehar), D.Paul (Siliguri), P. S. Debnath (Jalpaiguri), Biplab Raychaudhuri (Surya Sen Mahavidyalaya, Siliguri), Eric R. Christian (NASA, USA), S. Mukherjee (IUCAA), Mehdi Kalam (N. N. College for Women, Kolkata), R. Banerjee (S. N. Bose National Centre of Basic Sciences, Kolkata), S.Ananthakrishnan (Formerly NCRA-TIFR, Pune).

Invited Lectures :

1. **D. Lynden Bell**: Relativistic Spinning Charged Conductors (Institute of Astronomy, Cambridge University), April 20,2007 .

2. **N. K. Dadhich**: Why Einstein? Had I been born in 1844 (IUCAA), April 20, 2007.

3. **P. Dasgupta**: Time and its Enigma (Department of Physics and Astrophysics, Delhi University, Delhi), April 23, 2007 .

4. **Prabasaj Paul**: Raleigh hypothesis and photonic crystals (Denision University,USA), (July 27, 2007).

5. **Himadri Sekhar Das**: Comets and its important role in solar system studies (Kokrajhar College, Assam), (August 27, 2007).

6. **Eric R. Christian**: Voyager and the edge of the Solar system (NASA, USA), December 24, 2007.

7. **S. Mukherjee**: Cosmological Models-Present Status, (IUCAA) , February 4, 2008.

8. **Mehdi Kalam**: Negative Energy, Worm holes and Time machine, (N N College for Women, Kolkata) February 12, 2008.

9. **R. Banerjee**: A series of lecture on Hawking Radiation and Anomaly, (S. N. Bose National Centre of Basic Sciences, Kolkata) February 22-25, 2008.

10. **S. Ananthakrishnan**: An Introduction to Astronomy, Radio Astronomy and the Giant Metrewave Radio Telescope of India - (NCRA-TIFR, Pune) April 1, 2008.

Other activities :

Seminar / Workshop organized :

1. Himalayan Relativity Dialogue held at Mirik (April 18-20, 2007).

2. IRC, NBU and Raiganj (University) college jointly organized a seminar on Recent advances in Physics and Astrophysics at Raiganj (University) College,Raiganj.

The Speakers were :

(a) Twin Paradox : Do we Need GTR ?: S. K. Ghosal (NBU)
(b) Universe with Dark Matter and Datk Energy : B.C.Paul (NBU)
(c) Liquid Crystal Displays from wrist watch to TFT monitor: B.Adhikari Das (SIT,Siliguri)
(d) The Mysterious Balck Hole: A. Chatterjee (Malda College, Malda)
(e) Father of Modern Observational Astronomy : S. Gupta (Raiganj College)
(f) Large Hadron Collider: G. Choudhuri (Raiganj College)
(g) Space-Time – Rabiul Islam (Raiganj College)

Present and past faculty members, students of Science streams from the host and neighbouring colleges have participated in the seminar.

3. Observed National Science Day on February 28th with invited talk and Quiz competition for the PG students of the university. The students of physics and mathematics took active part in this program. There were six prizes for quiz competition. P.K. Mandal, Head, Physics Department, NBU gave a popular lecture.

Publc Outreach :

B. C. Paul gave a popular lecture on 50 years celebration of Space Exploration at Matigara Science Centre on October 4th 2007. Exploring Earth from outer space on National Science Day was organized centrally in the university.

[4] Cochin University of Science and Technology, Kochi
(Coordinator : V.C. Kuriakose, Co-Coordinator: Ramesh Babu T.)

The facilities at the IRC have been regularly used by M.Sc. and M.Phil. students for their project work, and research scholars and teachers. Students and teachers from neighbouring colleges also use the library and computer facilities. Talks, seminars and colloquia were held under the joint auspices of IRC and the Department of Physics. The IRC library contains 56 books and internet connectivity. A number of research papers have been published using IRC facility.

Talks/colloquia.

1. C V Vishveshwara: Black holes: October 8, 2007.

2. M.S.Sriram: Tradition of mathematical astronomy in India, October 8, 2007.

3.T. Padmanabhan: Weight of the cosmic vacuum, October 9, 2007.

4.A. Kembhavi: Cosmic dust, January 2, 2008.

5.A N . Ramaprakash: Seeing star light, January 4 , 2008.

6.Annapurni Subramaniam : Current advances in the study of star formation, January 31, 2008.

7. V.C.Kuriakose: Elements of cosmology, February 28, 2008

8. V.C.Kuriakose : Elements of soliton dynamics, March 24, 2008

IRC colloquium on February 2, 2008

9. P. A. Subha : Soliton switching in non-linear dynamics.

10. E.G. Goplalkrishna Panicker : Epistemological foundations of quantum gravity theories and problem of time.

11.Moncy V John: Trajectory formulations of quantum mechanics.

12. K. Babu Joseph: Some reflections on physics, logic and category theory.

IRC colloquium on March15, 2008

13. C. P. Jisha: Spatial solitons.

14. C. D. Ravikumar: Astronomical observations – telescope and detectors.

15. M. Vivek: Astronomical data analysis - spectroscopic studies.

The colloquium on March 15th ended with a live demonstration on data analysis for the benefit of M.Sc. Students

Visitors

C. V. Vishveshwara (IIA, Bangalore), T. Padmanabhan (IUCAA), M.S. Sriram (Madras University, Chennai), A.Kembhavi (IUCAA), A.N. Ramaprakash (IUCAA), Annapurni Subramaniam (IIA, Bangalore), Minu Joy (IUCAA, Pune), Moncy V. John (St.Thomas College, Kozhencherri), Ninan Sajeeth Philip (St.Thomas College, Kozhencherri), C. D. Ravikumar (Calicut University), K.P. Harikrishnan (Cochin College, Kochi), Joe Jacob (Newman College, Thodupuzha), K.Porsezian (Pondicherry University).

Other activities:
Workshops/Conferences organized.

1) IRC, in collaboration with the Department of Physics and SPIE CUSAT Chapter, organized a workshop during April 16 - 26, 2007 for High School students who completed class IX Standard. There were 30 school students who attended the programme. They were introduced to the basic concepts in physics and they were able to do some fascinating experiments in the laboratories of the physics department. They were also given training to construct small telescopes. The students enjoyed this programme.

2) IRC, in collaboration with the Department of Physics and SPIE CUSAT Chapter organized a National Conference during October 7-10, 2008 on "New Horizons in Theoretical and Experimental Physics". There were about 160 participants from all over India. The programme consisted of plenary talks, contributed presentations and poster sessions.

3) IRC, in collaboration with the Department of Physics, University of Calicut organized an advanced workshop on "Data Analysis and Research in Astronomy" at the Department of Physics, University of Calicut during December 12-14, 2007. The programme consisted of talks, demonstration and hands on experiment by participants. V. C. Kuriakose gave an introductory lecture on "Observation and data analysis in Astronomy and Astrophysics". B.R.S. Babu gave a lecture on "Fundamentals of linux" C. D. Ravikumar led the tutorials on "Linux installation" with live demonstration. He also gave a presentation on "Overview of research projects in Astronomy". Ninan Sajeeth Philip introduced the basic concepts on "Neural networks" and to using the "Algorithm in different Astronomy projects". He also presented a demonstration of "Automatic Trans Migration Algorithm", with which one can work from a USB drive, without using the resources from the hard disk. The last day of the workshop was fully dedicated to hands on experiment by the participants with data acquisition from different data archives over Internet, and analysing them using different Virtual Observatory tools. M. Vivek led this session. There were 27 outstation participants from Kerala, Tamil Nadu and Chhattisgarh. They were selected from among the participants of the "Mini School on Astronomy and Astronomical Data Analysis", conducted by IUCAA at Newman College, Thodupuzha, during September 19-22, 2007.

4) IRC, Kochi, was a Co-sponsor of the "Young Astronomers Meet" (YAM 2008) held at M.G. University, Kottayam, during January 3-5, 2008.

[5] Jadavpur University
(Coordinator : Narayan Banerjee)

During the period 2007-08, regular Tuesday seminars were organized. Around 25 lectures were given by speakers from different institutes. The talks were mostly on the dark energy problem, brane world scenario and gravitational collapse.

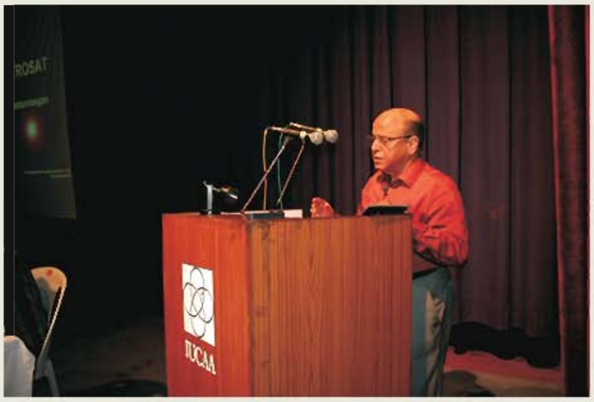
With the aid of a DAE project, computer facilities and internet connections have been improved.

The prize winners of the Year of Physics essay competition for high school students were invited to a small but nice function. Naresh Dadhich distributed the prizes and talked about the scope of research in astronomy, astrophysics and allied subjects.

During this period, Ajit Kembhavi visited the centre. Tapas Das from HRI, Sudipta Sarkar from IUCAA and Ramgopal Vishwakarma from Mexico visited the centre and delivered seminars.

Extracts from the Nineteenth IUCAA Foundation Day Lecture

ASTROSAT
by K. Kasturirangan



Professor Kasturirangan delivering the Nineteenth IUCAA Foundation Day Lecture

At the outset, I would like to thank Professor Naresh Dadhich for the invitation to deliver the Foundation Day lecture at IUCAA. The theme I have chosen for my lecture is Astrosat, a project in which IUCAA is one of the important partners. In this lecture, I would like to go through the background that led ISRO to undertake a mission like Astrosat. As we shall see from the initiatives that ISRO has taken, the idea was not just that we have our own satellite up there, but much more than that. Astronomy and Astrophysics is going to be one of the leading areas of science across the world and India has its own rightful role to play in this area. It is, therefore, the right time that institutions like IUCAA get involved in a mission like Astrosat to promote astronomy and astrophysics in the country, so that we have our own share and position in the respective scientific community around the world.

As we look at the sky through different wavelength windows, we encounter a major diversity in appearance. At radio wavelengths, a map of the sky primarily shows the diffuse synchrotron radiation in action, while the X-ray sky shows a distribution of sources in complete contrast to the radio map. In infrared, we see yet another distribution primarily dominated by heated dust grains. In gamma rays, the diffuse emission seen from the plane of our galaxy originates in the interaction of cosmic rays with interstellar clouds of hydrogen and molecules. Multi-wavelength study of the sky is, therefore, very important in uncovering the diverse physical processes going on in the universe.

The key concept of Astrosat is based on this premise - that multi-wavelength observations are essential to better understand celestial objects. Apart from the static sky revealed in the maps taken at various wavebands, there are many sources that are time variable, and a proper study of these sources requires simultaneous observation at multiple wavebands. How can this be done? That was the genesis of the thinking that gave rise to the Astrosat mission concept. Of the many wavebands one needs to study, only a few small windows, like the visible range, near infrared and the microwave range are accessible from ground, because at other bands the radiation does not penetrate the atmosphere. It is clear, therefore, that if one wishes to study the sky over a wide range of the electromagnetic spectrum then a space based platform like Astrosat, located above the atmosphere, is a major requirement.

I would like to recall at this stage the history we have since the forties that enables us to undertake a complex mission like Astrosat. After his return from the UK, Dr. Homi Bhabha set in motion a series of balloon-based experiments for cosmic ray studies, which involved building a variety of nuclear radiation detectors such as multiphase chambers, Cerenkov systems, total absorption calorimeters, emulsions for cosmic ray studies such as Lithium, Beryllium, Boron, etc., and even neutron detectors. Similarly, Dr. Vikram Sarabhai started cosmic ray research at PRL. He along with his team members including Dr. Chitnis, who is in the audience today, made very important contributions to the understanding of the propagation of cosmic rays through the interplanetary medium.

Then in 1961 when cosmic X-ray sources were first discovered by Ricardo Giacconi and his colleagues at American Science and Engineering, there was a sudden switch in several of these activities towards the study of electromagnetic radiation. Here again, I am happy to recall that Dr. Chitnis was one of the pioneers in X-ray astronomy done with rockets in this country. In fact, the first instruments that were flown were designed under his leadership at PRL. Simultaneously, TIFR also started getting into major payload building for balloon-borne studies of X-ray sources. One of the early instruments, sensitive to hard X-rays above 20 keV, was made of Sodium Iodide crystal of about 100 square centimetre area, which was used to study the variability of a number of cosmic sources, including Cygnus X-1, Cygnus X-3, Centaurus X-3, Scorpius X-1, Hercules X-1, etc. So there was a whole host of things that came up because of the discovery of X-ray sources in the sky. New detectors including proportional counters and other telescope systems were developed at TIFR.

Finally, these developments opened up the possibility of the use of our small satellite programme, called the Rohini propgramme in those years, for astronomical studies. The very first satellite flown by India, called Aryabhata, carried two X-ray astronomy instruments covering the energy range from 2 to 200 keV between them, In addition, TIFR had an interesting instrument consisting of a Cesium Iodide phoswich detector along with a plastic scintillator anticoincidence to study surface nuclear reactions on the sun by detecting solar neutrons and gamma rays. The next satellite Bhaskara, primarily meant for remote sensing. also carried a wide field X-ray pin-hole camera system for doing a sky survey for steady and variable sources. All this set the stage for flying a large proportional counter with a 600 to 800 square centimetre area on a satellite platform by early 1990s. This was really in a sense, the first major space astronomy experiment in the country. It produced many significant results, including the evidence of matter passing through the event horizon of a black hole candidate. This experiment provided a wealth of experience to the Indian scientific community, and also proved to be a very good step in mastering the technology of flying a proportional counter in a long-duration space mission.

This successful experiment provided the background, in which the Astrosat mission concept arose. At ISRO, on the one hand we had built satellites, and on the other hand had developed our launch vehicle technology to the point that the PSLV was by then capable of launching about 1.5 ton payload in a near earth orbit. By about 1996 all these elements were in place. Based on this experience, and the scientific community that was available, it was felt that the time was right to embark on a major astronomy mission in space. We also had a major responsibility to fix a time by when it should go. When the requirement for necessary instruments was drawn up, it was clear that a developmental phase had to be gone through as several of the instruments were much more sophisticated than what we were experienced in at that time. Some of the technology required a scale up, and some others completely new development in the country. So we did not fix a launch date until these developments matured and we had the confidence in launching the instruments. Today, the project is approved, and there is full scale development going on in several national labs, and ISRO is planning to launch it some time in 2009.

Parameters that define the requirements of an astronomical experiment include the field of view, the angular resolution and above all the sensitivity, which is linked to the effective area or the size of the photon bucket. The typical approach of the American or European space astronomy missions is to push envelopes in all these areas, leading to progressively larger, heavier and high technology payloads. The Japanese approach, on the other had is to go for smaller, niche area missions with limited, focussed objectives. We felt that the Japanese model was more suited to us, and the niche area we chose was simultaneous multi-wavelength observations of variable sources. Some of these sources have been studied before at different wavebands, but simultaneous observations covering wavelength range from optical/UV to X-rays have rarely been possible, because multiple systems, multiple platforms had to be coordinated. To have a wide wavelength, coverage on a single platform was thus an exciting prospect that interested Indian astronomers and astrophysicists. It was also pragmatic in the sense of the realizability of the instruments required.

We chose a mix of technologies - proven ones like the proportional counter and emerging ones like x-ray foil mirrors and cadmium zinc telluride arrays. A set of instruments was decided upon:

(1) A large area x-ray proportional counter, being built by Professor P.C. Agrawal and his group at TIFR. This is the kind of instrument for which the largest amount of familiarity existed through balloon borne and satellite borne experiments performed previously. It would be one of the largest area instruments of this kind ever flown, and could be used to detect new sources as well as to measure variability in source intensity over very fine time scales of better than a millisecond,
(2) A soft x-ray imaging telescope with grazing incidence foil mirror optics and x-ray CCD - not the best of the imaging telescopes when compared with Chandra x-ray observatory, for example - but adequate to complement the other x-ray instruments by extending energy coverage down to lower energy bands. Fabricating the mirror optics consisting of a large number of nested shells is a very delicate operation which is being directed by Professor K.P. Singh at TIFR.
(3) A pixellated cadmium zinc telluride imager system. The advantage of this is that it has a very good energy resolution. This is a new technology system, being built by Professor A.R. Rao and his group at TIFR, for inclusion in Astrosat. The imaging element of this is a Dicke coded mask on top, which has been carefully designed by one of the scientists here, in IUCAA, Professor Dipankar Bhattacharya, while he was at the Raman Research Institute.
(4) An x-ray sky monitor, consisting of proportional counters with position sensitive wires operating in conjunction with coded masks, yielding both large field of view and good position resolution. This will be used to mount a sky patrol at regular intervals to forewarn other instruments of sudden appearance

or brightening of sources, which would be interesting objects for study.

(5) A major instrument on board will be an ultraviolet imaging telescope. This will be a twin telescope system with an angular resolution of 1.8 arc second, the best at UV wavelengths so far. The two telescopes will allow simultaneous observations in three different bands lying in the far UV, near UV and visible regions of the spectrum. This instrument is being built at the Indian Institute of Astrophysics but significantly this institution has the prime responsibility for the realisation of this instrument, with Professor Shyam Tandon, from IUCAA, supervising its development. This will be a very powerful instrument with a significant capability to address science problems as a standalone system, apart from the multiwavelength observations that it would be involved in.

(6) And finally, there is a charge particle monitor to measure the charged particle environment that the satellite would be passing through at any given time. A high charged particle flux has serious implications on the operation of several detectors on board, and precautionary measures have to be taken when the monitored count rises.

All these instruments will be integrated on a spacecraft platform, which is the same as what we use for remote sensing earth observations. It will be customized for stellar observations in this case. The launch vehicle will be the PSLV, which will be used to place the satellite in a near-equatorial orbit at a height of 650 km. The height is decided based on the fact that at higher altitudes the charged particle background will be high and at lower altitudes the atmospheric drag will reduce the orbital life time. If injected at 650 km height, then in 5 years the orbit will decay to about 500 km, which is acceptable for Astrosat operations. To maximize the duty cycle of operation, the orbit will need to be as close to equatorial as possible in order to avoid the South Atlantic Anomaly region which has a high density of charged particles. However, launch constraints from India, with a safe margin for jettisoning the spent stages, will limit the orbital inclination between 6 and 8 degrees.

Astrosat will be capable of addressing a wide variety of science problems. One example of key multi-wavelength science that can be pursued with Astrosat is the study of UV and X-ray emission from active galaxies. In many of these sources, the UV emission arises in an accretion disk around a central supermassive black hole, while the X-ray emission is thought to be primarily produced by Compton upscattering of UV photons. Simultaneous variability in these two components would validate this model, but such observations have been very difficult so far because sustained observations at multiple wavebands are required for a long period of time. Astrosat will provide the right platform to do this kind of experiment. Similarly in Blazars, the UV component originating in synchrotron emission and the X-ray component originating in Compton scattering can be studied in the same way.

The last point I would like to discuss in this lecture is about the role that IUCAA and other such institutions can now play to maximise the science utilisation of this mission, As we have seen, all the premier astronomy research institutions in the country, including TIFR, IIA, RRI, PRL and IUCAA are already deeply involved in the project. The instruments are getting ready and will now need to be put through a very extensive and thorough calibration phase. This is a fairly large effort and requires the participation of a large number of people. In fact in a typical international mission, several Ph.D.s will come out from the work carried out in this phase. So this is one area, where new institutions can join in and contribute.

The next possible area is data interpretation. Once observations are carried out by Astrosat, the data obtained need to be interpreted through detailed modelling of physical processes at the source. Our current capability in this area is rather limited, in fact, there are only a handful of people in the country who can carry this out. So there is ample scope for a wide variety of institutions, including universities to get involved in this kind of work. The institutions should play a pro-active role in creating this capability not only within their own institutions but also in other sister institutions. There is no reason why this cannot become an activity involving a large group of scientists from multiple institutions to address this challenging and very interesting aspect of a major new national mission like Astrosat.

Lastly, a third possible area is complementary observations. Complementary observations using ground based facilities at wavebands not covered by Astrosat can be planned and coordinated with Astrosat observations to make the experiments more meaningful. So institutions with facilities in optical, radio, infrared, TeV and other wavebands should come together in this activity to provide this complementary support to Astrosat.

The potential user community of Astrosat within the country is still rather small, consisting of about 30-40 scientists. To make full use of the goldmine of information that Astrosat will provide, the size of this community needs to be increased to 150-200 scientists. So an institution like IUCAA, which has already made a significant contributions in the definition and the realisation of the mission, and is currently getting ready for data analysis, can play a lead role in the scientific exploitation of Astrosat by ensuring wide participation, not only within the institution, but also in national and international scale.

I conclude by wishing this mission all success.

The Bombay Public Trust Act, 1950. Schedule VIII [Vide Rule (1)]

Name of the Trust : INTER-UNIVERSITY CENTRE FOR ASTRONOMY & ASTROPHYSICS

Address: Post Bag-4,Ganeshkhind, Pune-7. **Registration No. :F-5366 (PUNE) dated 27.1.1989.**

BALANCE SHEET AS AT 31ST MARCH 2008

Sr No.	FUNDS & LIABILITIES	Schedule No.	31.03.2008 Rs.
1	Trust Fund / Corpus	6	2,94,13,120
2	Grant-In-Aid from UGC	7	79,83,41,579
3	Other Project Grants	8	2,28,70,832
4	Projects and Other Payable	9	14,93,224
5	Current Liabilities	10 & 10A	15,74,003
6	Income and Expenditure a/c	14	(1,62,80,119)
	Total		83,74,12,640

Sr No.	ASSETS & PROPERTIES	Schedule No.	31.03.2008 Rs.
1	Fixed Assets (At cost)	11	63,05,39,074
2	Investments / Deposits	12	10,84,92,170
3	Project & Other Receivables	13AA	13,99,266
4	Current Assets -	13	
	a) Stocks		35,912
	b) Cash, Bank balances & Revenue Stamps		1,19,02,920
	c) Loans and Advances	13A	70,92,177
	d) Deposits		9,66,620
	e) Prepaid Expenses		47,40,478
	e) Advance to Suppliers	13B	7,22,44,023
	Total		83,74,12,640

For Inter-University Centre for Astronomy & Astrophysics

As per Report of even date
For A.H.Joshi & Co.
Chartered Accountants

Prof. N.K.Dadhich
(Director / Trustee)

Chairperson
Governing Board

S.A.Joshi
(Partner)
Membership No.37772

Place : Pune
Date : 23.6.2008.

N. V. Abhyankar
Admn.Officer (Accounts)

K.C.Nair
(Sr.Admn.Officer)