IUCAA

INTER-UNIVERSITY CENTRE FOR ASTRONOMY AND ASTROPHYSICS

(An Autonomous Institution of the University Grants Commission)

Annual Report

(April 1, 2005 - March 31, 2006)

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HIGHLIGHTS OF 2005- 2006

This annual report covers the activities of IUCAA during its eighteenth year, April 2005-March 2006. 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 15 core faculty members (academic), 15 post-doctoral fellows and 18 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 anisotropy, observational cosmology, magnetic fields in astrophysics, active galactic nuclei, quasar and intergalactic medium, galaxies high energy astrophysics, stars and interstellar medium and instrumentation. These research activities are summarised in pages 15-39. The publications of the IUCAA members, numbering to about 75 in the current year are listed in pages 67-70. IUCAA members also take part in pedagogical activities, the details of which are given in pages 77-78 of this report.

The extended academic family of IUCAA consists of about 90 Visiting Associates, who have been active in several different fields of research. Pages 40-57 of this report highlights their research contributions spanning gravitational theory and gravitational waves, classical and quantum cosmology, galaxies and quasars, compact objects and X-ray binaries, stars, stellar systems and interstellar medium, Sun and solar system, plasma physics, dynamics, theoretical physics, e-content development, instrumentation and radio astrophysics. The resulting publications, numbering to about 95 are listed in pages 71-76 of this report. A total of about 1216 person-days were spent by Visiting Associates at IUCAA during this year. In addition, IUCAA was acting as host to about 400 visitors through the year.

IUCAA conducts its graduate school jointly with the National Centre for Radio Astrophysics, Pune. Among the research scholars, three students have successfully defended their theses and obtained Ph.D. degrees from the University of Pune during the year. Summary of their theses appears in pages 58-66.

Apart from these activities, IUCAA conducts several workshops, schools, and conferences each year, both at IUCAA and at different university/college campuses. During this year, there were 7 such events in IUCAA and 6 were held at other universities/colleges under IUCAA sponsorship.

Another main component of IUCAA's activities is its programme for Science Popularisation. On the National Science Day, several special events were organised. There were posters displayed by the academic members of IUCAA, which elaborated on the research work at IUCAA and topics in the field of astronomy. There were public lectures given by the faculty members and programmes for school students consisting of quiz, essay and drawing competitions. During the Open Day, more than 3000 people visited IUCAA.

These activities were ably supported by the scientific and technical, and administrative staff (20 and 33 in number respectively) who should get the lion's share of the credit for 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 101-106 of this report.

A major milestone which we reached during the year is the successful completion of IUCAA Girawali Observatory and the installation of the Telescope. The final acceptance was done in early February and the Telescope was handed over to IUCAA on February 14, 2006. IUCAA scientists are actively involved in the task of making the Telescope ready for observations as soon as possible.

T. Padmanabhan
Editor

CONTENTS

The Council and the Governing Board

The Council
(As on 31st March, 2006)

President

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

Vice-President

V.N. Rajasekharan Pillai,
Vice-Chairperson,
University Grants Commission, New Delhi.

Members

N. Mukunda,
(Chairperson, Governing Board),
Indian Academy of Sciences, Bangalore.

Mustansir Barma,
Department of Theoretical Physics,
Tata Institute of Fundamental Research, Mumbai.

A. N. Basu,
Vice-Chancellor,
Jadavpur University, Calcutta.

S. K. Dube,
Director,
Indian Institute of Technology, Kharagpur.

Ratnakar Gaikwad,
Acting Vice-Chancellor,
University of Pune.

Rajen Harshe,
Vice-Chancellor,
University of Allahabad.

Seyed E. Hasnain,
Vice-Chancellor,
University of Hyderabad.

A.K. Kembhavi,
IUCAA, Pune.

Vijay Khole,
Vice-Chancellor,
University of Mumbai.

Arvind Kumar,
Centre Director,
Homi Bhabha Centre for Science Education, Mumbai.

R.A. Mashelkar,
Director General,
Council of Scientific and Industrial Research,
New Delhi.

S. Mukherjee,
Department of Physics,
North-Bengal University,
Darjeeling, West Bengal.

K. Ramamurthy Naidu,
506, Dwarakamai Apartment,
Navodaya Colony, Hyderabad.

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

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

Deepak Pental,
Vice-Chancellor,
University of Delhi, Delhi.

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

V. S. Ramamurthy,
Secretary to the Government of India,
Department of Science and Technology, New Delhi.

Amitava Raychaudhuri
Director
Harish-Chandra Research Institute, Allahabad.

K.L. Sharma,
Vice-Chancellor
University of Rajasthan, Jaipur.

Mool Chand Sharma,
Secretary,
University Grants Commission, New Delhi.

C.V. Vishveshwara,
Honorary Director,
Jawaharlal Nehru Planetarium, Bangalore.

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

A.S. Nigavekar,
Chairperson,
University Grants Commission, New Delhi.

Ashok Kumar Gupta,
J.K. Institute of Applied Physics,
University of Allahabad.

Kota Harinarayana,
Vice-Chancellor,
University of Hyderabad.

A.S. Kolaskar,
Vice-Chancellor,
University of Pune.

Deepak Nayyar,
Vice-Chancellor,
University of Delhi.

Ved Prakash,
Secretary,
University Grants Commission, New Delhi.

H.R. Singh,
Vice-Chancellor,
University of Allahabad.

Member Secretary
N.K. Dadhich,
Director, IUCAA.

The Governing Board
As on 31st March, 2006)

Chairperson

N. Mukunda.

Members

S. K. Dube
Ratnakar Gaikwad
Rajen Harshe
Seyed E. Hasnain
A.K. Kembhavi
K. Ramamurthy Naidu
Rajaram Nityananda
G. Rajasekaran
Mool Chand Sharma
C.V. Vishveshwara

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

Ashok Kumar Gupta
Kota Harinarayana
A.S. Kolaskar
Ved Prakash
H.R. Singh

Member Secretary
N.K. Dadhich

Honorary Fellows

Geoffrey Burbidge,
University of California,
Centre for Astronomy and Space Sciences, U.S.A.

E. Margaret Burbidge,
University of California,
Centre for Astronomy and Space Sciences, U.S.A.

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

A. Hewish,
University of Cambridge, U.K.

Gerard 't Hooft,
Spinoza Institute, The Netherlands.

Donald Lynden-Bell,
Institute of Astronomy,
University of Cambridge, U.K.

Yash Pal, Noida.

Allan Sandage,
The Observatories of Carnegie Institute of Washington, U.S.A.

P.C. Vaidya,
Gujarat University, Ahmedabad.

Visiting Professors

Russell Cannon,
Anglo-Australian Observatory, Australia.

Anvar Shukurov,
University of Newcastle, UK.

Alexei Starobinsky,
Landau Institute for Theoretical Physics, Russia.

Statutory Committees

The Scientific Advisory Committee (SAC)

Abhay Ashtekar,
Center for Gravitation, Physics and Geometry,
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Rohini Godbole,
Centre for Theoretical Studies,
Indian Institute of Science, Bangalore.

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

Umesh C. Joshi,
Physical Research Laboratory, Ahmedabad.

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

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

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

Ashoke Sen,
Harish-Chandra Research Institute, Allahabad.

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

The Users' Committee

N.K. Dadhich, (Chairperson)
Director
IUCAA, Pune.

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

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

Lakshman Chaturvedi,
Vice-Chancellor,
Pandit Ravishankar Shukla University, Raipur.

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

P.K. Abdul Azis,
Vice-Chancellor,
Cochin University of Science and Technology, Kochi.

T. Padmanabhan,
IUCAA, Pune.

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

The Academic Programmes Committee

N.K. Dadhich (Chairperson)
T. Padmanabhan (Convener)
J. Bagchi
S.V. Dhurandhar
Ranjan Gupta
A. K. Kembhavi
Ranjeev Misra
A.N. Ramaprakash
Swara Ravindranath (from 06.02.2006)
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

N. Mukunda (Chairperson)
P. Agarwal (till 25.09.2005)
N.K. Dadhich
A.K. Kembhavi
R. Nityananda
A. Pimpale
V. Prakash (till 30.11.2005)
M. Sharma (from 1.12. 2005)
S.K. Singh (from 19.12. 2005)
K.C. Nair (Non-Member Secretary)

Members of IUCAA

Academic

N.K. Dadhich (Director)
T. Padmanabhan (Dean, Core Academic Programmes)
A.K. Kembhavi (Dean, Visitor Academic Programmes)
J. Bagchi
S.V. Dhurandhar
R. Gupta
R. Misra
A.N. Ramaprakash
S. Ravindranath (from 06.02.2006)
V. Sahni
Tarun Souradeep
R. Srianand
K. Subramanian
S. N. Tandon

Emeritus Professor

J.V. Narlikar

Scientific and Technical

N.U. Bawdekar
S.S. Bhujbal
M.P. Burse
S.B. Chavan
V. Chellathurai
K.S. Chillal
P.A. Chordia
H.K. Das
S. Dhurde (from 25.07.2005)
S. Engineer
G.B. Gaikwad
S.U. Ingale
A.A. Kohok
V.B. Mestry
N. Nageswaran (from 04.05.2005)
A. Paranjpye
S. Ponrathnam
V.K. Rai
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
S.B. Gujar
R.S. Jadhav
B.B. Jagade
S.M. Jogalekar
S.N. Khadilkar
S.B. Kuriakose
N.S. Magdum
M.A. Mahabal
S. G. Mirkute
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
A.A. Syed
S.R. Tarphe
S.K. Waghole
K.P. Wavhal

Post-Doctoral Fellows

V. K. Agrawal
S. Barway (from 13.03.2006)
S. Basak (from 16.08.2005)
S. Joshi (from 04.07.2005)
M. Joy (from 13.03.2006)
A. Mahmood (till 09.12.2005)
M. Puravankara (till 08.07.2005)
Subharthi Ray
Suryadeep Ray
S. Roychoudhury (from 12.01.2006)
S. Sen (till 27.04.2005)
C.S. Stalin (till 31.05.2005)
P. Subramanian

Project (Post-Doctoral Fellows)

P. Hasan (Indo-French Project)
R. Sinha (Virtual Observatory Project)
(from 24.01.2006)

Research Scholars

A.L. Ahuja
U. Alam (till 14.11.2005)
S. Chakravorty
H. Chand
Josily Cyraic (till 06.05.2005)
A. Deep
A. H. Forushani (till 03.02.2006)
D. Kothawala (from 22.08.2005)

G. Mahajan
S. Mitra
H. Mukhopadhyay
T. Naskar
A. Rawat
S. Samui
S. Sarkar
A. Shafieloo
M.K. Srivastava
S. Sur

Temporary/Project/Contractual Appointments

A.P. Chordia (System Engineer) (till 10.02.2006)
M.B. Ghule (Steno-Typist, CEC Project) (till 06.03.2006)
J.A. Gupchup (Project Officer, Virtual Observatory) (till 21.07.2005)
M. S. Kharade (Project Officer , ERNET Project)
S. Koshti (Project Scientist, DST - WOSA Scientist)
V. Kulkarni (Scientific/Technical Assistant-I, Public Outreach Programme) (till 15.06.2005)
P.L. Shekade (System Engineer)
P. S. Barathe
V. Jagtap (till 21.03.2005)
A.P. Kadam (from 14.11.2005)
V. Mhaiskar (from 01.09.2005)
D. Nandrekar (from 13.03.2006)
S.M. Prabhudesai (from 25.07.2005)
A. Rupner (from 01.09.2005)
S.C. Shah
M. Shaikh (from 02.03.2006)

Part Time Consultants

S. S. Bodas (Medical Services) (till 31.08.2005)
V. S. Savaskar (Medical Services) (from 01.09.2005)

Long Term Visitors

Arvind Gupta
Vijay Mohan

Visiting Associates of IUCAA

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

D. Badruddin,
Department of Physics,
Aligarh Muslim University.

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

N. Banerjee,
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Jadavpur University, Kolkata.

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

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Assam University, Silchar.

Subenoy Chakraborty,
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Mira Dey,
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Presidency College, Kolkata.

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University of Delhi.

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D.D.U. Gorakhpur University.

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North Eastern Hill University, Shillong.

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B.D. College of Engineering, Sevagram.

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University of Delhi.

K. Shanthi,
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Santokh Singh,
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Yugindro Singh,
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D.D.U. Gorakhpur University.

Pradeep K. Srivastava,
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P.K. Suresh,
School of Physics,
University of Hyderabad.

R.S. Tikekar,
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A.A. Usmani,
Department of Physics,
Aligarh Muslim University.

J.P. Vishwakarma,
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D.D.U. Gorakhpur University.

Till June 30, 2005

Z. Ahsan,
Department of Mathematics,
Aligarh Muslim University.

Rashmi Bhardwaj,
Department of Mathematics,
Guru Gobind Singh Indraprastha University, Delhi.

S.P. Bhatnagar,
Department of Physics,
Bhavnagar University.

Satyabrata Biswas,
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Somenath Chakrabarty,
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D.K. Chakraborty,
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P.P. Hallan,
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Zakir Husain College, Delhi.

S.N. Hasan,
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Osmania University, Hyderabad.

K. Indulekha,
Department of Physics,
Mahatma Gandhi University, Kottayam.

Usha Malik,
Department of Physics,
Miranda House, Delhi.

K.K. Mondal,
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S.K. Popalghat,
Department of Physics,
J.E.S. College, Jalna.

P. Vivekananda Rao,
Department of Astronomy,
Osmania University, Hyderabad.

L.M. Saha,
Department of Mathematics,
Zakir Husain College, New Delhi.

R.V. Saraykar,
Department of Mathematics,
Nagpur University.

Bhim Prasad Sarmah,
Department of Mathematical Sciences,
Tezpur University.

Rajendra Shelke,
Space Research Centre,
Amravati.

R.C. Verma,
Department of Physics,
Punjabi University, Patiala.

From July 1, 2005

A. Bhattacharya, (upto February 28, 2006)
Department of Physics,
St. Xavier's College, Kolkata.

Asis Kumar Chattopadhyay,
Department of Statistics,
Calcutta University.

Rabin Kumar Chhetri,
Sikkim Government College, Gangtok.

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

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

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

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

Naseer Iqbal Bhat,
PG Department of Physics,
University of Kashmir, Srinagar.

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

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

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

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

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

The sixteenth batch of Visiting Associates, who were selected for a tenure of three years, beginning July 1, 2005.

Abhijit Bhattacharya

Asis K. Chattopadhyay

Rabin Chhetri

Ujjal Debnath

P.S. Goraya

Naseer Iqbal

Pradip Mukherjee

Nagalakshmi A. Rao

Pankaj Kumar Shrivastava

The photographs of the following Visiting Associates from the sixteenth batch are not available: Alok Kumar Durgapal, Naveen Gaur, C. Mukku and E. Saikia.

Appointments of the following Visiting Associates from the thirteenth batch were extended for three years : G. Ambika, Narayan Banerjee, Subenoy Chakraborty, Sarbeshwar Chaudhuri, Sushant G. Ghosh, K.P. Harikrishnan, Chanda J. Jog, Kanti R. Jotania, R.S. Kaushal, Nagendra Kumar, Yogesh Kumar Mathur, Kamal Kanti Nandi, P.N. Pandita, Harinder Pal Singh, K. Yugindro Singh, D.C. Srivastava, 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 and Publications
(T. Padmanabhan)

Head, Instrumentation / Telescope
(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)

The Director's Report

The highlight of the year was successful completion of the Telescope project. The telescope was successfully installed and commissioned with all the required tests meeting the specification and it was finally handed over to IUCAA by PPARC/TTL in February 2006. Though the project was quite delayed due to various reasons, it was gratifying to see that we had ultimately got a very fine telescope which had so far performed better than our expectation.

An instrument of this kind is indeed a very complex and challenging endeavour involving very exacting demands on various aspects of engineering, optics, software and logistics. It is a tribute to the TTL team and our instrumentation as well as administrative support teams for the job well done. Particularly they had combined and resonated beautifully in installation and commissioning of the telescope. I greatly appreciate Mr. Jeff Down of PPARC and Dr. Paul Rees of TTL for the understanding and concern they brought upon for completion of the project. I thank them all warmly.

With the telescope in place and functioning, it is wonderful to see a bubbling observational group crystalizing. Suddenly the air around tea tables breathes of spectrum and arc-seconds rather than dark energy and Hamiltonians. I hope it will have a similar effect on the university colleagues and there would be a welcome emergence of observational activity in the universities.

The telescope will be a good optical compliment to NCRA's Giant Metrewave Radio Telescope and the two together will form a strong astronomical axis in the country.

As a tribute as well as an inspiring and motivating force for young students, we have made documentary films in collaboration with Vigyan Prasar (DST, Delhi) on the two legendary academics and Honorary Fellows of IUCAA, Professors A.K. Raychaudhuri and P.C. Vaidya, who symbolized excellence in teaching and research in universities. The films have been widely circulated and greatly admired.

It is very unfortunate that Professor Raychaudhuri could not see the finished film as he suddenly passed away on June 18, 2005, shortly after the shooting of the film was over. Ever since the conception of IUCAA, he was a great source of inspiration and support. In his demise we have truly lost a friend, philosopher and guide. On behalf of IUCAA family and on my personal behalf, I pay deepest and warmest homage to him and to what he meant to all of us.

We have also made a 12 minute flyer film, "Joy and Truth of Science", on the activities of the Science Centre, *Muktangan Vidnyan Shodhika*, which is also circulated widely and is greatly appreciated. I hope that this experiment of learning and enjoying science through toys will spread in schools all around far and wide.

The Scientific Advisory Committee of IUCAA visited us during January 3-7, 2006. As usual, they reviewed all our programmes and activities and then made a detailed report. One of the main recommendations was to open IUCAA to visitors from universities outside India. The Committee expressed its unqualified admiration for the work being done at IUCAA and full satisfaction on its performance on various fronts. In particular, it was very appreciative of dedication and commitment exhibited by our administrative and support staff, and Professor Abhay Ashtekar, who has seen IUCAA growing right from its conception, wrote "*....It has been a pure joy to see how well the Institute has blossomed to become a strong international presence over a relatively short period of time. A lot of the credit goes to the vision of its Founding Director, Professor J. V. Narlikar and there was some concern about what would happen after he retired. The fact that IUCAA has remained so robust and has continued to rise is largely due to the sense of dedication and pride everyone has. It is very rare to see this spirit -- especially among the administrative staff. On behalf of the international community, I would like to thank all the staff......*"

Professor Arun Nigavekar who was the Chairperson of UGC as well as President of IUCAA Council, demited the office in September 2005 on completion of his term. I thank him warmly for his guidance and support all through and particularly for the understanding and support shown by him for the telescope project at a very critical juncture. He is a good friend of long standing and it is wonderful to have him back in Pune, which is indeed assuring.

I extend a very warm welcome to Professor S. K. Thorat, who has assumed office of Chairperson, UGC and thereby President of IUCAA Council in February 2006. I look forward to his guidance and wise counsel. I would like to assure him that IUCAA would as before continue to provide a resource base for scientific and educational programmes of national importance.

Naresh Dadhich

Congratulations to ...

Ajit Kembhavi

UGC National Hari Om Ashram Trust Award - Outstanding Social Scientist/ Scientist for interaction between Science and Society for the year 2004.

J. V. Narlikar

Mohamed Sahabdeen Award for Science (2004) from the A.M.M. Sahabdeen Trust Foundation, Sri Lanka, June 28, 2005.

Vikram Sarabhai Lifetime Achievement Award (2004) from the Consortium for Educational Communication (CEC), New Delhi, September 16, 2005.

Doctor of Science (Honoris Causa) from the Hemwati Nandan Bahuguna Garhwal University, Srinagar, Garhwal, October 16, 2005.

Jeevangaurav Puraskar from the Chaturang Pratisthan, Mumbai, October 30, 2005.

T. Padmanabhan

Elected to International Union of Pure and Applied Physics, Commission 19 [Astrophysics].

Received a Honorable Mention in the Gravity Research Foundation Essay contest, 2005, for his essay "*A new perspective on Gravity and the dynamics of Spacetime*".

Calendar of Events

2005

April 18-May 27	**School Students' Summer Programme** at IUCAA
May 6	**IUCAA-NCRA Graduate School** Second semester ends
May 16-June 17	**Refresher Course in Astronomy and Astrophysics for College and University Teachers** at IUCAA
May 16-July1	**Vacation Students' Programme** at IUCAA
August 8	**IUCAA-NCRA Graduate School** First semester begins
August 7-8	**Introductory Workshop: From Stars to the Universe** at University of Calicut, Kozhikode
August 29-31	**Workshop on Observing Projects with Small Telescopes** at IUCAA.
November 21-23	**Introductory Workshop: Sun and Stars** at St. Xavier's College, Kolkata
November 29-December 2	**Young Astronomers' Meet (YAM 2005)** at IUCAA
December 5-7	**Introductory Workshop: Instruments and Observations** at Karnataka University, Dharwad
December 9	**IUCAA-NCRA Graduate School** First Semester ends
December 15-22	**International Conference on Einstein's Legacy in the New Millennium** at Toshali Sands, Puri, Orissa (Organized jointly by IUCAA; IOP, Bhubaneshwar and Department of Physics, Utkal University, Bhubaneshwar)
December 21-23	**Workshop on Astrostatistics** at Calcutta University, Kolkata
December 26	**School on Cosmology and Very Early Universe** (Dedicated to the memory of A.K. Raychaudhuri) at IUCAA)
December 29	**Foundation Day**

2006

January 2	**IUCAA-NCRA Graduate School** Second semester begins
February 28	**National Science Day** at IUCAA

ACADEMIC PROGRAMMES

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

(I) RESEARCH BY RESIDENT MEMBERS

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

Quantum Theory and Gravity

Holographic framework for semiclassical gravity

The elegance of general relativistic description of gravity rests on the geometric structure, which in turn is based on the Principle of Equivalence. In its simplest form, principle of equivalence allows the description of gravity in terms of a metric tensor and determines the kinematics of gravity ('how gravity tells matter to move') by invoking special relativity in the local inertial frames.

Contrast this with the description of dynamics of gravity ('how matter tells spacetime to curve') for which we completely lack a similar guiding principle. Classical dynamics has to arise from semiclassical limit of quantum gravity through the variation of the semiclassical action functional. But we lack a guiding principle to choose such an action functional! There are several serious issues which crop up when we try to determine the action functional:

- If g_{ab} are the dynamical variables, the natural action functional should be quadratic in the derivatives ∂g of g_{ab}. But principle of equivalence — which allows us to reduce $g_{ab} \rightarrow \eta_{ab}, \partial_c g_{ab} \rightarrow 0$ in any local region — prevents the existence of such a generally covariant action. So, general covariance, combined with principle of equivalence, forces us to include $\partial^2 g$ terms in the action; but then the variational principle becomes ill-defined and needs a special treatment. This situation is unparalleled in any other theory in physics like, e.g., Yang-Mills models.

- Further, any such action can only provide a low energy effective description of gravity. The semiclassical theory is likely to exist in some D dimensional spacetime with $D > 4$ and quantum corrections will add higher order correction terms involving squares of the curvature etc. We have no guiding principle or symmetry to determine these higher order terms.

A closely related question is: What are the true degrees of freedom of gravity? The description in terms of g_{ab} may be most geometrical but it is highly gauge redundant. Any description in terms of an alternative set of variables has important conceptual implications for dynamics — especially for the problem of the cosmological constant. For example, if the degrees of freedom of gravity in a spatial volume V scale as the area S of the bounding surface rather than the volume, then the bulk cosmological constant cannot produce gravitational effects. The reduction from volume to area changes the energy density of the vacuum, that is, coupled to gravity from the gigantic L_P^{-4} to the observed value $L_P^{-4}(L_P^2/S)$ with $S \approx H^{-2}$, as shown by *T. Padmanabhan* a few years back.

More recently, *Padmanabhan* has produced a paradigm in which all the above issues can be successfully tackled at one go.

In particular, he shows that theories which obey principle of equivalence and general covariance have a generic structure for their low energy action functional, using which one can systematically obtain corrections to classical gravity. He proves that the (a) principle of equivalence, (b) general covariance and (c) the demand that the variation of the action functional should be well defined, lead to a generic Lagrangian for semiclassical gravity of the form $L = Q_a{}^{bcd} R^a{}_{bcd}$ with $\nabla_b Q_a{}^{bcd} = 0$. The expansion of $Q_a{}^{bcd}$ in terms of the derivatives of the metric tensor determines the structure of the theory uniquely. When the action is expanded in the powers of curvature, one obtains the Einstein-Hilbert (EH) action as the *unique* zero-order term along with Gauss-Bonnet (GB) type correction as the *unique* first-order term. What is probably even more remarkable is that *all these action functionals allow a natural, holographically dual, description*; that is, the action functional can be expressed as a sum of bulk and surface terms with a definite relationship between the two. The gauge redundancy of geometric description therefore allows all these theories to be described *entirely* in terms of surface degrees of freedom, thereby, suggesting a natural solution to the cosmological constant problem.

Further, just as in the case of EH action, it is possible to reformulate the theory retaining *only* the surface term for the gravity sector. If we consider an action principle based on $(A_m + A_s)$ where A_m is the matter action and A_s is the action obtained from $-L_{sur}$ then, for variations that arise from displacement of a horizon normal to itself, one gets the equation $(E_{ab} - \frac{1}{2}T_{ab})\xi^b\xi^a = 0$, where ξ^a is a *null* vector. Combined with the (generalised Bianchi) identity $\nabla_a E^{ab} = 0$ this will lead to standard field equations with a cosmological term $E_{ab} = (1/2)T_{ab} + \Lambda g_{ab}$ just as in the case of Einstein-Hilbert action.

In this approach, which uses only surface degrees of freedom for gravity, the basic field equations are $(E_{ab} - \frac{1}{2}T_{ab})\xi^b\xi^a = 0$, where ξ^a is a *null* vector. So the addition of a cosmological constant — by the change $T_{ab} \to T_{ab} + \Lambda g_{ab}$ — leaves the equations invariant. *Gravity ignores the bulk vacuum energy density!* When generalised Bianchi identity is used, the cosmological constant does arise as an integration constant; but now, it can be set to any value as a feature of the *solution* to the field equations. It has a status similar to mass in the Schwarzschild metric. This provides a basic reason for ignoring the bulk cosmological constant *and its changes* during various phase transitions in the universe. The thermodynamic paradigm also impies that if an observer has a horizon, we should work with the degrees of freedom confined by the horizon. This changes the pattern of vacuum *fluctuations* and leads to the correct, observed value of the cosmological constant, as mentioned before. These features arise purely from principle of equivalence and general covariance and is not specific to Einstein's theory. Any theory of gravity described by a metric will have similar features and hence *higher order quantum gravitational corrections are likely to respect these principles.*

Casimir effect confronts the cosmological constant

According to the uncertainty principle of quantum mechanics, any quantum system is subject to fluctuations, even in the ground state. The vacuum of any quantum field is thus far from empty, and has a non-zero energy (E_0), which can be obtained by summing over the zero-point energies of the entire spectrum of field modes. When non-trivial boundary conditions ($\partial\Gamma$) are imposed on the field, the zero-point fluctuations of the vacuum get modified, leading to a finite shift in energy to some other value $E[\partial\Gamma]$ given by $\Delta E = E[\partial\Gamma] - E_0$. A realistic example of this is the perturbation of the electromagnetic field due to the presence of metallic bodies. This change in the vacuum energy, ΔE, manifests as a tangible force between the macroscopic bodies, which distort the vacuum. This phenomenon, known as the Casimir effect, is one of the remarkable observable consequences of the existence of quantum vacuum fluctuations. A well-studied example is the case of two neutral, perfectly conducting parallel plates; in free space, the spectrum of possible wave modes of the vacuum forms a continuum, but the presence of plates restricts the normal components of the allowed wave modes between them to discrete values. This discreteness leads to a finite lowering of the vacuum energy, resulting in a force of *attraction*. In $(3+1)$ dimensions, the force per unit area has the form

$$\frac{F(a)}{A} = -\frac{\pi^2}{240}\frac{hc}{a^4} \tag{1}$$

where a denotes the plate separation. The existence of this force has been verified to a high degree of precision in several laboratory experiments over the past decade.

Both the quantities $E[\partial\Gamma]$ and E_0 are formally divergent. In order to extract a finite difference, a suitable regularization procedure has to be adopted. One such method involves introducing an ultraviolet cut-off function that suppresses the contribution of the high-frequency modes and renders the difference well-defined, and then, at the end of the calculation, letting the cut-off frequency go to infinity to obtain a finite result, that turns out to be independent of the functional form of the cut-off.

Any modification of the intrinsic spectrum of zero-point quantum fluctuations will also leave an imprint on the Casimir effect. In particular, if there exists a cut-off length L_c in nature, due to some unknown physics, it would act as a natural UV regulator, suppressing the field modes with wavelengths $\lambda \lesssim L_c$ and leading to a modification of the Casimir force between bodies. In the case of parallel plates separated by a distance a, for example, the maximum wavelength allowed between them is $\lambda_{max} \sim 2a$, and it is the modes with wavelengths lying in the range $L_c \lesssim \lambda \lesssim 2a$, which will contribute to the Casimir effect. This is indistinguishable from the standard result, if $L_c \ll a$, which is usually the case since the cut-off lengths suggested in the literature are usually of the order of Planck length. But if this cut-off length is significantly larger, there would be significant corrections to the standard result when $L_c \gtrsim a$. Presently, there is a strong experimental evidence for the electromagnetic Casimir force between metallic bodies up to separations around 100 nm and no significant deviations from the predicted results have been observed. This suggests that any possible cut-off length scale L_c must lie below this value. This translates into a lower bound on the vacuum energy density of $\rho_V \gtrsim 1\ (eV)^4$.

There are some proposals in the literature that the zero-point energy of vacuum — made finite by a cut-off — may contribute to gravity and lead to a non-vanishing cosmological constant responsible for the currently observed accelerated expansion of the universe. Current cosmological observations seem to favour a cosmological constant as the candidate for dark energy and constrain the energy density contributed by it to be roughly $\rho_{DE} \approx 10^{-11}(eV)^4$, with a corresponding length scale of the order of 0.1 mm. The significant discrepancy of this value with the bound obtained from the Casimir effect measurements, makes it unlikely that the cosmological constant has anything to do with zero-point energy rendered finite by a cut-off of unknown physical origin but having the correct length scale.

Gaurang Mahajan, *Sudipta Sarkar* and *T. Padmanabhan* have recently performed a detailed analysis of this issue by studying the effect of such a cut-off on the behaviour of the Casimir force between parallel conducting plates. By assuming that the presence of this cut-off manifests through modification of the dispersion relation for field modes, they show that it can significantly alter the standard result, and even lead to repulsive Casimir force when the plate separation is smaller than the cut-off scale length. On the basis of current laboratory data, they conclude that any such cut-off, which is consistent with the observed Casimir effect will lead to an energy density at least about 10^{12} times larger than the presently observed value of the cosmological constant driving the accelerated expansion of the universe, if gravity couples to these modes. This invalidates the recently proposed idea that the observed cosmological constant may arise from the zero-point energy made finite by a suitable cut-off.

Classical Gravity

Gravity is one of the fundamental forces of nature, but it distinguishes itself from the others by being universal. It links and affects all that physically exists in the universe, and it is present everywhere and is unshieldable. This remarkable character puts it on a different pedastal. It is, therefore, understandable that its dynamics and description may be different from the other forces.

Einstein was the first to bring out the first difference and showed that gravity could truly be described by curvature of spacetime itself. No other force makes such a demand on spacetime. Einstein's theory of gravitation, known as general relativity, imbibes this feature and Einstein's equation is valid in all dimensions, $n \geq 2$.

Next question arises, in how many dimensions should gravity live? It turns out that 2 and 3 dimensions are not big enough to let gravity propogate from one point in space to the other. So one is led to the usual 4 dimensional spacetime. Does gravity remain confined to 4 dimensions? The source for gravity is matter/energy distribution which generally lives in 3 dimensional space. Gravity is self interactive, it interacts with itself. Self interaction can only be evaluated iteratively. The first iteration is, however, included in Einstein's equation through square of first derivative of the metric.

How does one go beyond the first? This could be achieved by inclusion of a specific combination of square of Riemann, Ricci and Ricci scalar, known as Gauss-Bonnet term, in the action. But this term makes no contribution to Einstein equation in dimensions, $n < 5$. Thus, we have to go to higher dimensions to realise second iteration of self interaction. As 2 and 3 dimsnions are not big enough to accommodate propagation of gravity, similarly 4 dimension is not sufficient for its self interaction. This is purely a classical consideration and motivation for higher dimensions. On the other hand, string theory, which is one of the attempts for quantum theory of gravity, necessarily requires higher diemsnions for its formulation.

Gauss-Bonnet gravity (GB) has been *N.K. Dadhich's* main concern. It turns out the generic feature of GB is to weaken black hole singularity in higher dimensional black hole. It would be interesting to bring these desirable properties through dilaton coupling and suitable choice of topology down to the 4 dimensional universe we live in. There are some encouraging indications in this direction.

Gravitational Waves

The existence of gravitational waves (GWs), predicted in the theory of general relativity, has long been verified *indirectly* through the observations of Hulse and Taylor. The inspiral of the members of the binary pulsar system named after them has been successfully accounted for in terms of the back-reaction due to the radiated GW. However, detecting such waves with man-made 'antennas' has not been possible so far. Nevertheless, this problem has received a lot of attention in the past several years, especially, due to the arrival of laser-interferometric detectors, which are expected to have sensitivities close to that required for detecting such waves. Most of the interferometric detectors are either taking science data or nearing operation. Detailed description of the detectors as well as detection techniques have been given in previous annual reports.

Obtaining the gravitational wave sky map of the stochastic background

The gravitational wave background can arise from a variety of sources. Not all GW sources have well modelled signals. Supernovae with asymmetric core collapse and binary black hole (BBH) mergers can be very strong sources of GWs. In addition to the above objects, GWs from low-mass X-ray binaries (LMXBs) and hydrodynamical instabilities in neutron stars (r-modes) will be observable by earth-based detectors like LIGO. But the waveforms of none of these objects is well understood. This is a subject of active investigation among numerical relativists. While currently suggested waveforms will be used for matched-filtering the data, the dismissal rates of such searches can be extremely high owing to the imperfect nature of these waveforms. Such a situation requires the exploration of other search statistics that are optimal (with minimum false dismissal rate for a given false alarm rate) when the knowledge of the waveforms is incomplete. Moreover, LIGO-type detectors will likely observe GWs from astrophysical objects that we never knew existed.

Individually, the above mentioned sources can be categorized as short-duration, e.g., SN core collapse, BBH merger, and r-modes, or long-duration, viz., LMXBs. On the other hand, when a collection of any subset of these sources is unresolvable, it can appear as a stochastic GW background of a variable duration in our detectors of interest.

The signal from the unmodelled sources will not typically stand above the broadband noise of the interferometric detectors; the concept of an absolutely certain detection does not exist in such a case. Only probabilities can be assigned to the presence of an expected signal. In the absence of prior probabilities, such a situation demands a decision strategy that maximizes the detection probability for a given false alarm probability. Maximum likelihood methods will be explored to obtain the optimal network statistic for detecting excess GW power. Apart from this, the fundamental aspects of the formalism required for creating a sky-map of the astrophysical/cosmological gravitational wave background arising from a host of unmodelled or unresolved sources while using the full potential of the operating network of detectors by coherently combining their data.

The formulation of the problem of mapping the gravitational-wave sky has three critical elements: (a) Measuring the excess power per pixel, (b) estimating the GW background per pixel after deconvolution of the synthesized network antenna-pattern from the data, and (c) Testing the "search and map" algorithm on simulations.

The raw sky map of the GW background is the signal convolved with the antennae pattern. We must invert this equation in order to obtain the GW power from each direction. For this purpose, theoretical analysis of the excess power kernel has been undertaken, which will indicate to us the appropriate method of inversion. Depending on whether the kernel is non-degenerate or degenerate, either matrix inversion or maximum entropy or Richardson-Lucy type of methods will be employed. From IUCAA, Sanjit Mitra, Sanjeev Dhurandhar and Tarun Souradeep are involved in this work.

This is the gist of the Indo-US proposal with A. Lazzarini of Caltech and S. Bose of WSU which has been submitted to DST and NSF. *Sanjit Mitra* and *S. V. Dhurandhar* have analysed the kernel of the integral equation by means of the stationary phase method. The method gives a rough estimate of the kernel and the result could be used towards a first guess for the solution, which is then obtained iteratively by numerical means. The kernel or the point spread function for a typical point source is shown in Figure (1) on the left of the figure, while the right hand side of the figure depicts the stationary phase approximation - the point source spreads into a figure of eight.

This work should also benefit two other searches. First, since the long-duration integration of the data will essentially comprise a sum over short stretches, a large signal in a short stretch will constitute a candidate for a transient or burst (short-duration) event. Unlike the coincidence search being currently conducted for such events, this work will combine coherently the outputs of several detectors and, thus, improve their detectability.

Second, the long-duration integration of the data should be able to find gravitational wave signals from modelled sources, such as pulsars. Although this method is optimal for searching unmodelled sources, it is not so for pulsars, the signals from which can be matched filtered. The problem with the latter method is that owing to the very large parameter space volume, an all-sky, all-frequency search for pulsars with matched filtering is not computationally viable. This method is not handicapped by this problem, since it does not use the intrinsic source parameters for the search; rather it uses the data from one detector to 'filter' that from others in the network, after appropriately time-shifting them and weighing them with the respective antenna patterns. Thus, our method can be used as the first step in a two-step hierarchical search for pulsars, where triggers from our method are followed up with matched filtering.

This project pursued at IUCAA is especially

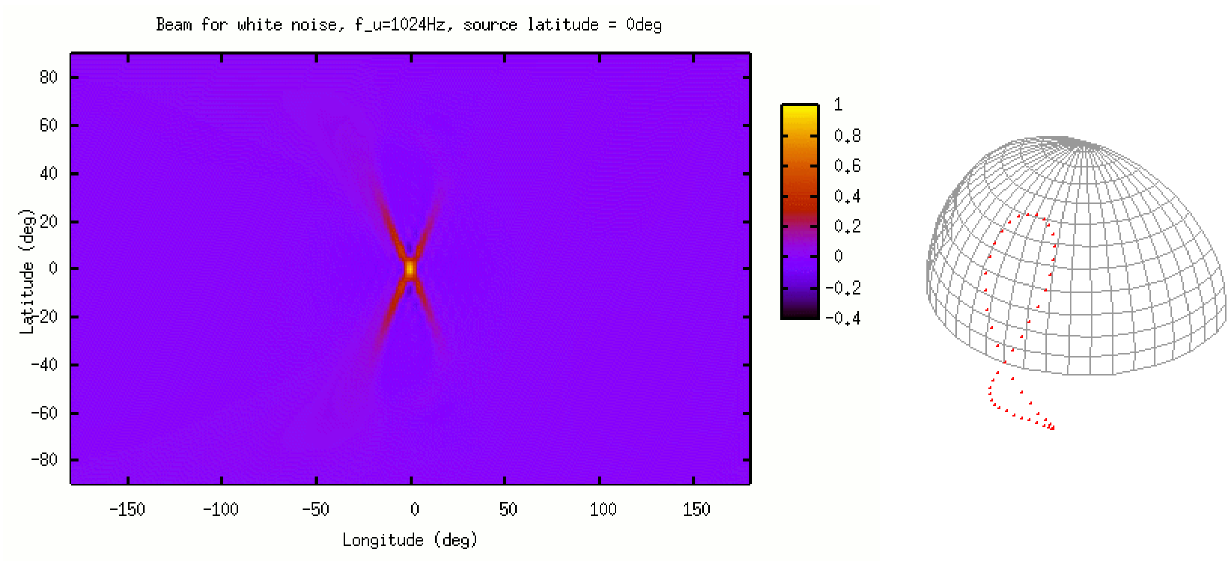

Figure 1: On the left, the kernel or the point spread function is shown for a source on the equator for the two LIGO detectors at Hanford and Louisiana in the US, for which a bandwidth of a kHz is assumed. On the right is shown the kernel obtained from the stationary phase approximation.

important, because it will obtain the best ever bounds on the strengths of gravitational waves from unmodelled sources while using the full potential of the operating network of detectors by coherently combining their data. Such a combination will account for the time-varying network antenna patterns as well as the relative shifts in the phase of a gravitational wave at the different detectors. It will also be able to detect a stochastic astrophysical GW background, which might arise from a superposition of a large number of independent and unresolved GW sources. If excess power is detected in certain patches of the sky, then the tools developed will be used to construct the GW map of those regions of the sky. When integrated over time, these excess powers in different time segments will add up to give the physical equivalent of the energy captured by the network from a given patch in the sky.

The usefulness of this work cannot be underestimated in the cosmological context either. There exist alternative cosmological models (e.g., the string-inspired pre-big-bang model) that predict a stochastic cosmological GW background that should be detectable by Advanced LIGO. If any of these models is found to be borne out by observations, then the sky-map construction given above can, in principle, be used to seek any anisotropies (including a possible dipole component) in it. This process in turn can unravel useful clues on how the universe began. On the other hand, an astrophysical background will provide information about our immediate neighbourhood.

Coherent versus coincidence search for inspiraling binaries

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

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

H. Mukhopadhyay, S.V. Dhurandhar, N. Sago, H. Tagoshi and N. Kanda are comparing the two approaches by plotting the Receiver Operating Characterstic (ROC) curves. The simplest and

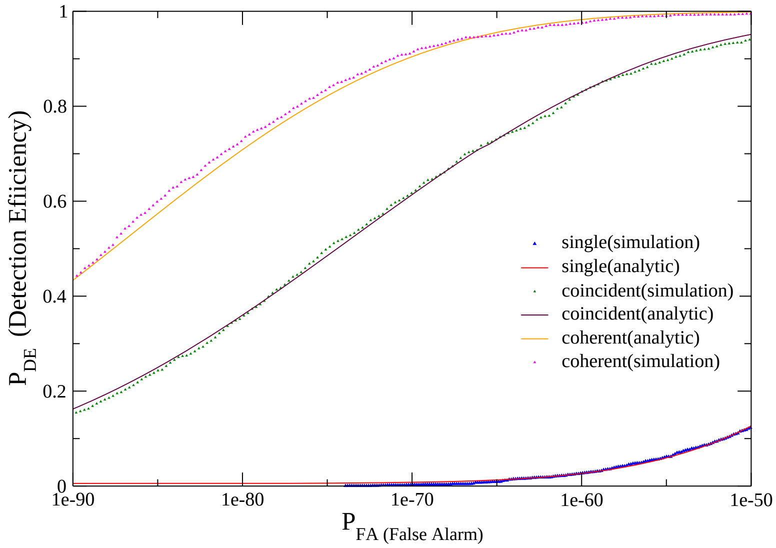

Figure 2: ROC curves are shown for two identical LIGO type detectors in the same location with the same orientation and having the same power spectral density of noise when coherent and coincident detection criteria are used. Coherent detection is substantially a better approach as seen from the curves.

the worst scenario case (from the point of view of the coherent search) is being investigated, in which two identical detectors are considered in the same location and the same orientation. Analytical results and Monte-Carlo simulations are being used to quantify the performance of the two methods. The ROC consists of plotting the false dismissal (or equivalently detection probability) versus the false alarm. The higher the false dismissal for a given false alarm, the better the performance of the method. The Indian team consisting of *H. Mukhopadhyay and S. Dhurandhar* have been involved in the simulations of plotting the ROC curves based on analytics given by the Japanese and then comparing the results. A slightly more general case has been considered, where the detectors may not have the same orientations, but otherwise are identical and coincident. The two approaches are being tested using Gaussian stationary noise with the noise power spectral density of advanced detectors. Figure (2) shows that the coherent method is far superior to the coincident one justifying the extra computational cost.

During*S.V. Dhurandhar's* visit to Osaka, the case of two detectors can have correlated noise has been also investigated. It remains to perform simulations to validate the analytical results. This work will be extended to a network of several detectors having arbitrary locations and orientations. This work comes under the Indo-Japanese collaboration and has been funded by DST (India) and JSPS (Japan).

A general relativistic analysis of LISA dynamics and optics

The joint NASA-ESA mission LISA relies crucially on the stability of the three spacecraft constellation. Each of the spacecraft is in heliocentric orbits forming a stable triangle. In order for LISA to operate successfully, it is crucial that the three spacecraft which form the hubs of the laser interferometer in space maintain nearly constant distances between them. The distance between any two spacecraft is $\sim 5 \times 10^6$ km, which must be maintained during the LISA's flight. However, in order to thoroughly study optical links and light propagation between these moving stations, one requires detailed analysis of the LISA configuration. *S. V. Dhurandhar*, R. Nayak, *S. Koshti* and J-Y Vinet have examined the principles of a stable formation flight and also presented an analytical treatment of the problem in the context of LISA. They first study three Keplerian orbits around the Sun with small eccentricities and optimise the orbital elements so that the spacecraft form an equilateral triangle with nearly constant distances between them.

LISA sensitivity is limited by several noise sources. A major noise source is the laser frequency (phase) noise, which is expected to be several orders of magnitude larger than other noises in the instrument. Thus, cancelling the laser frequency noise is vital to LISA for attaining the requisite sensitivity.

A systematic method based on modules over polynomial rings was given *S. V. Dhurandhar*, R. Nayak and J-Y Vinet. The method guarantees all the data combinations, which cancel the laser frequency noise. The data combinations consist of suitably delayed data streams added together to produce data streams free from laser frequency noise. These noise free data streams constitute the module of syzygies. However, this problem has been solved with the assumptions that LISA is stationary and has essentially constant arm-lengths. This approach needs to be generalised to the realistic motion of LISA, where the LISA triangle rotates about its centre - which leads the Sagnac effect, which must be accounted for - and where the laser light rays follow null geodesics in the background gravitational field mainly produced by the Sun.

The first goal was to analyse the motion of LISA spacecraft with a view to determine those spacecraft configurations, which are stable from the point of view of laser frequency noise cancellation. With this goal in mind, R. Nayak, *S. Koshti, S.V. Dhurandhar* and J-Y Vinet have analysed the motion of the spacecraft to octupole order of the Sun's gravitational field. It is further shown that this level of approximation gives near exact results by performing relevant numerical computations. Also the stablest configurations of LISA have been determined within the scope of this model by varying the orbital elements of the spacecraft orbits.

The next goal is to determine the optical links - the path lengths - between spacecraft in the Sun's field taken to be Schwarzschild and compute the phase development of the laser beam along a null geodesic. This approach automatically takes into account the special and general relativistic effects which have so far been estimated in an adhoc manner and perhaps with substantial errors. Such effects are (i) the Sagnac effect because of the rotation of the LISA constellation, (ii) gravitational red-shift, (iii) Shapiro effect, etc. The final goal is to determine the data combinations cancelling laser frequency noise taking into account the general relativistic model of LISA so that the LISA simulator can be built based upon this complete model. This is the work proposed in the Indo-French project, which has been cleared and should begin in the near future.

Cosmology and Structure Formation

Higher dimensional cosmology

Varun Sahni and Yuri Shtanov have studied some cosmological consequences of extra dimensions. Higher dimensional cosmology has had an impressive history ever since Kaluza and Klein's pioneering efforts to unify the laws of gravitation and electromagnetism within a single five dimensional setting. In the Kaluza-Klein approach, the extra dimensions were assumed to be 'curled up' and small. An alternative to this approach of hiding extra dimensions by curling them to sufficiently small radii is the *braneworld paradigm*, according to which, our universe is a submanifold, or slice, of a higher dimensional space-time. In contrast to KK compactification in which the extra dimensions are small and compact, extra dimensions in the braneworld approach can be large and even infinite.

Sahni and Shtanov have studied the cosmological consequences of this approach in which, our observable universe is a (3+1)-dimensional 'brane' which is embedded in a (4+1)-dimensional 'bulk' space-time. Their work shows that the expansion dynamics on the brane can be quite different from that predicted by conventional Einstein gravity. The braneworld can accelerate at late times, thus providing one possible explanation for the phenomenon of *dark energy*.

The braneworld cosmology developed by *Sahni* and Shtanov has several attractive and distinctive features. For instance the effective equation of state in braneworld models can be both $w_0 \geq -1$ as well as $w_0 \leq -1$. This is due to the fact that the brane can be embedded in the bulk in two complementary ways.

A subclass of braneworld models shows the fascinating property called *loitering* in which, the Hubble parameter dips below its value in ΛCDM at a modest redshift. Loitering models predict a larger age of the universe (at modest redshifts) and a lower redshift of reionization than in ΛCDM. A remarkable feature of *braneworld loitering* is that it arises in a spatially flat universe and is sourced by the projection of five dimensional degrees of freedom on the brane. Loitering is characterized by the fact that the Hubble parameter slows down a bit over a narrow redshift range referred to as the 'loitering epoch'. During loitering, density perturbations are expected to grow rapidly. In addition, since the expansion of the universe slows down, its age near loitering dramatically increases. An early epoch of loitering is expected to boost the formation of high redshift gravitationally bound systems such as $10^9 M_\odot$ black holes at $z \sim 6$ and lower-mass black holes and/or population III stars.

Cosmic mimicry

Varun Sahni and Yuri Shtanov have discovered a new possibility within the braneworld paradigm,

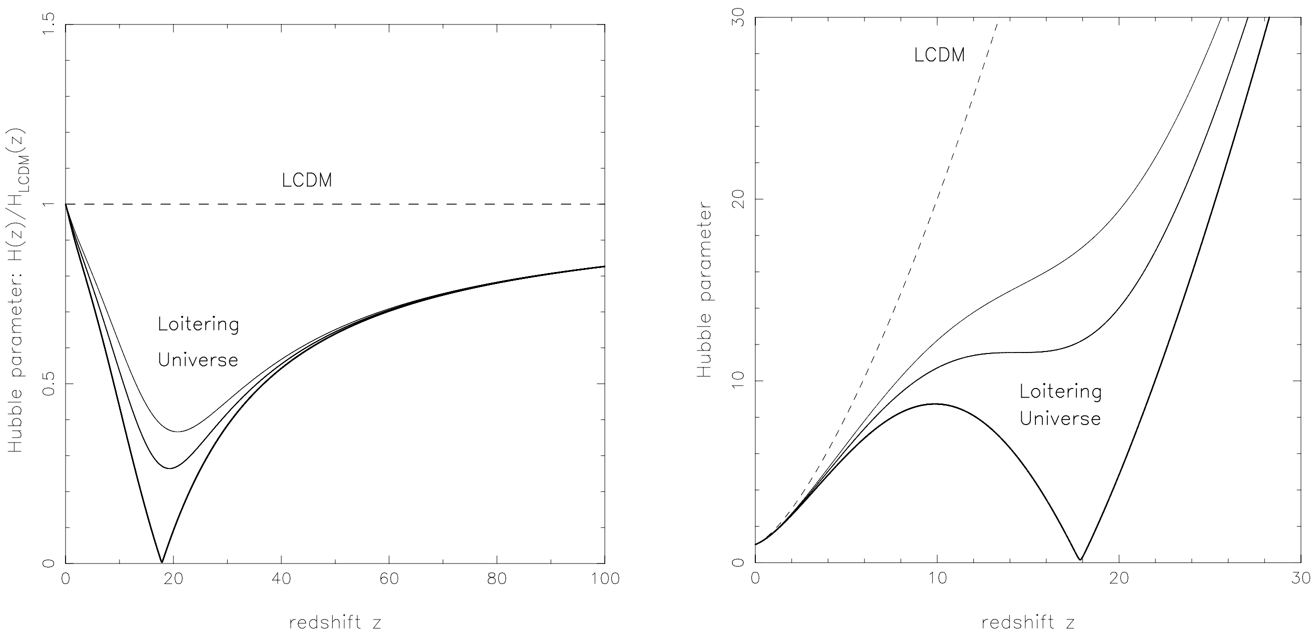

Figure 3: The Hubble parameter for a universe that loiters at $z_{\rm loit} \simeq 18$. The left panel shows the Hubble parameter with respect to the LCDM value while, in the right panel, the LCDM (dashed) and loitering (solid) Hubble parameters are shown separately. Three distinct loitering models are shown for illustration.

called *Cosmic Mimicry*. Cosmic mimicry is characterized by the fact that, at low redshifts, the Hubble parameter in the braneworld model is virtually indistinguishable from that in the LCDM (Λ + Cold Dark Matter) cosmology. An important point to note is that the $\Omega_{\rm m}$ parameter in the braneworld model and in the LCDM cosmology can nevertheless be quite different. Thus, at high redshifts (early times), the braneworld asymptotically expands like a matter-dominated universe with the value of $\Omega_{\rm m}$ inferred from the observations of the local matter density. At low redshifts (late times), the braneworld model behaves almost exactly like the LCDM model but with a *renormalized* value of the cosmological density parameter $\Omega_{\rm m}^{\rm LCDM}$. The value of $\Omega_{\rm m}^{\rm LCDM}$ is smaller (larger) than $\Omega_{\rm m}$ in the braneworld model with positive (negative) brane tension. The redshift which characterizes cosmic mimicry is related to the parameters in the higher-dimensional braneworld Lagrangian. Cosmic mimicry is a natural consequence of the scale-dependence of gravity in braneworld models. The change in the value of the cosmological density parameter (from $\Omega_{\rm m}$ at high z to $\Omega_{\rm m}^{\rm LCDM}$ at low z) is shown to be related to the spatial dependence of the effective gravitational constant $G_{\rm eff}$ in braneworld theory.

Model independent analysis of an accelerating universe

Arman Shafieloo, Ujjaini Alam, Varun Sahni and Alexei A. Starobinsky have developed a new non-parametric method of smoothing supernova data over redshift using a Gaussian kernel in order to reconstruct important cosmological quantities including the Hubble parameter and the equation of state of dark energy in a model independent manner. This method was shown to be successful in discriminating between different models of dark energy when the quality of data is commensurate with that expected from the future SuperNova Acceleration Probe (SNAP). *Shafieloo, Alam, Sahni* and Starobinsky have found that the Hubble parameter is especially well-determined and useful for this purpose. The look back time of the universe may also be determined to a very high degree of accuracy ($\lesssim$ 0.2%) in this method. By refining the method, it is also possible to obtain reasonable bounds on the equation of state of dark energy. They also explored a new diagnostic of dark energy the 'w-`probe`', which can be calculated from the first derivative of the data. They found that this diagnostic is reconstructed extremely accurately for different reconstruction methods even if Ω_m is marginalised over. The w-`probe` can be used to successfully distinguish between ΛCDM

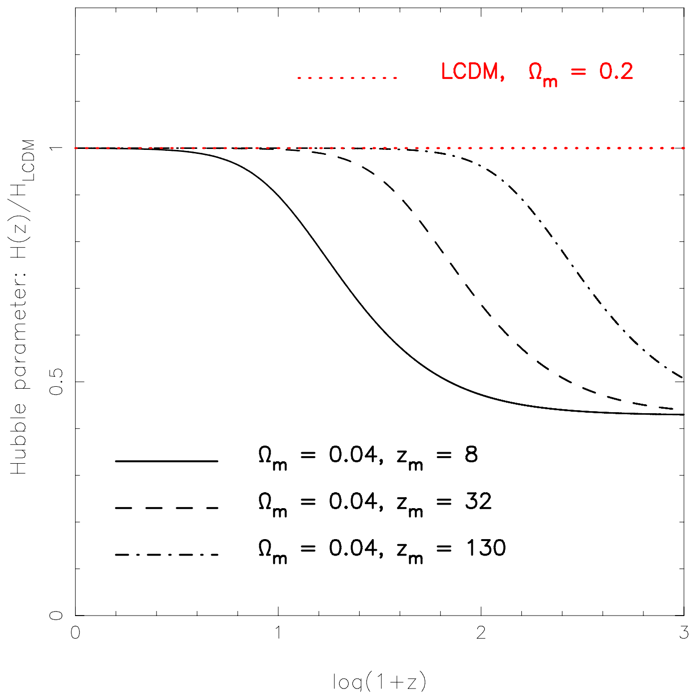

Figure 4: An illustration of cosmic mimicry. The Hubble parameter in three low-density brane models with $\Omega_m = 0.04$ is shown. Also shown is the Hubble parameter in a LCDM model (dotted line) which mimics this braneworld but has a higher mass density $\Omega_m^{\rm LCDM} = 0.2$. The brane matter-density parameter (Ω_m) and the corresponding parameter of the masquerading LCDM model are related in terms of parameters in the higher dimensional Lagrangian. For the model shown $\Omega_m \lesssim \Omega_m^{\rm LCDM}$. The redshift interval during which the braneworld masquerades as LCDM, so that $H_{\rm BRANE2} = H_{\rm LCDM}$ for $z \ll z_m$, is $z_m = 8$, 32, 130 (left to right) for the three braneworld models. Note that a low value of Ω_m has been shown for illustration. Braneworld models with larger values of Ω_m are also straightforward to construct.

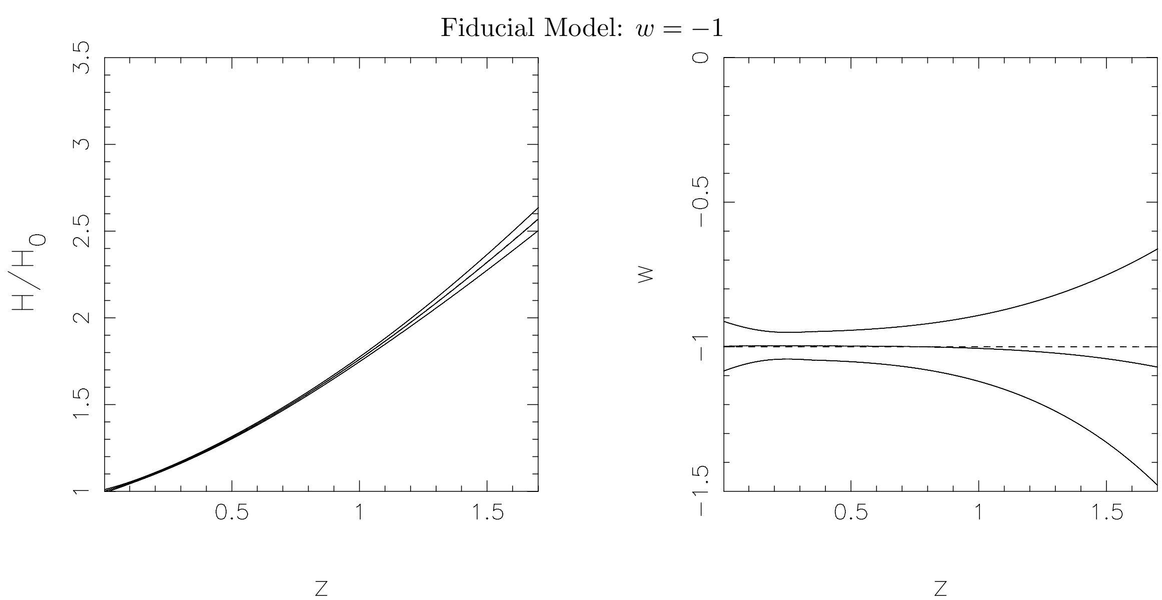

Figure 5: The supernova data have been smoothed to obtain $H(z)$ and $w(z)$ from 1000 realizations of the SNAP dataset. The dashed line in each panel represents the fiducial ΛCDM model with $w = -1$ while the solid lines represent the mean and 1σ limits around it. In the left panel $H(z)$ for the fiducial ΛCDM model matches *exactly* with the mean value obtained from the smoothing scheme.

and other models of dark energy to a high degree of accuracy.

Comprehensive observational constraints on the evolution of dark energy

The dark energy component of the universe is often modeled in terms of a cosmological constant or a scalar field. A generic feature of the scalar field models is that the equation of state parameter $w \equiv P/\rho$ for the dark energy need not satisfy $w = -1$ and, in general, it can be a function of time. Using the Markov chain Monte Carlo method *T. Padmanabhan*, in collaboration with H.K.Jassal and J.S.Bagla, has performed a critical analysis of the cosmological parameter space, allowing for a varying w. They use constraints on $w(z)$ from the observations of high redshift supernovae (SN-Gold), WMAP observations of CMB anisotropies and abundance of rich clusters of galaxies. For models with a constant w, the ΛCDM model is allowed with a probability of about 6% by the SN-Gold observations, while it is allowed with a probability of 98.9% by WMAP observations. The ΛCDM model is allowed even within the context of models with variable w. WMAP observations allow it with a probability of 99.1%, whereas SN data allows it with 23% probability. The SN data, on its own, favours phantom like equation of state ($w < -1$) and high values for Ω_{NR}. The SN-Gold data allows a very wide range for variation of dark energy density, e.g., a variation by a factor of ten in the dark energy density between $z = 0$ and $z = 1$ is allowed at 95% confidence level. WMAP observations provide a better constraint and the corresponding allowed variation is less than a factor of three.

In short, there is significant tension between SN-Gold and WMAP observations; the best fit model for one is often ruled out by the other at a very high confidence limit. Given the divergence in models favoured by individual observations, and the fact that the best fit models are ruled out in the combined analysis, the authors conclude that there is a distinct possibility of the existence of systematic errors in the SN-Gold data which are not understood.

This point of view was vindicated more recently, when the SNLS (SuperNova Legacy Survey) sample has been released. Applying the same analysis, Jassal, Bagla and *Padmanabhan* demonstrate that the SNLS results are in better agreement with CMB observations, unlike the SN-Gold data set, which preferred a different class of models altogether. The SNLS data set favours models similar to the ΛCDM model. They illustrate that WMAP observations are, by far, the strongest constraint on models with a varying equation of state parameter for the dark energy component in a flat universe. Further, the better quality of observations of temperature anisotropies in the CMB are less susceptible to systematic effects and this makes it a more reliable probe of cosmological parameters and dark energy. However, given the ease with which the supernova observations can be compared with a given cosmological model, theoreticians tend to use only the supernova observations for testing models of dark energy. It is, therefore, useful to know that the recent SNLS data prefers models similar to those preferred by WMAP, unlike the previous data sets which had a certain amount of discordance with WMAP.

Alternative cosmology

Work on the quasi-steady state cosmology is continuing and one of the aspects of the mini-creation events predicted by this cosmology has been explored further. This concerns the emission of gravitational waves. In a paper published in the Monthly Notices of the Royal Astronomical Society, it is shown that the LISA detector will be able to detect gravitational waves from explosive creation in the form of double radio sources. The estimated number of events per year will be approximately 1 to 2.

The steady-state theory had used negative energy scalar fields, which have also been subsequently used for the QSSC. There has been a revival of interest in such fields in the form of phantom fields. Using the old formalism of the creation field, work has been going on to see how it affects the gravitational collapse of massive objects. *J. V. Narlikar* has shown that these fields prevent singularity and also reverse the collapse before a black hole is formed.

Cosmic Microwave Background Anisotropy

Cosmic Microwave Background (CMB) anisotropy is a thrust area of astronomy and astrophysics. The transition to precision cosmology has been spearheaded by measurements of CMB anisotropy and, more recently, polarization. Besides precise determination of various parameters of the standard cosmological model, observations have also established some important basic tenets of cosmology and structure formation in the universe – ‘acausally’ correlated initial perturbations, adiabatic nature

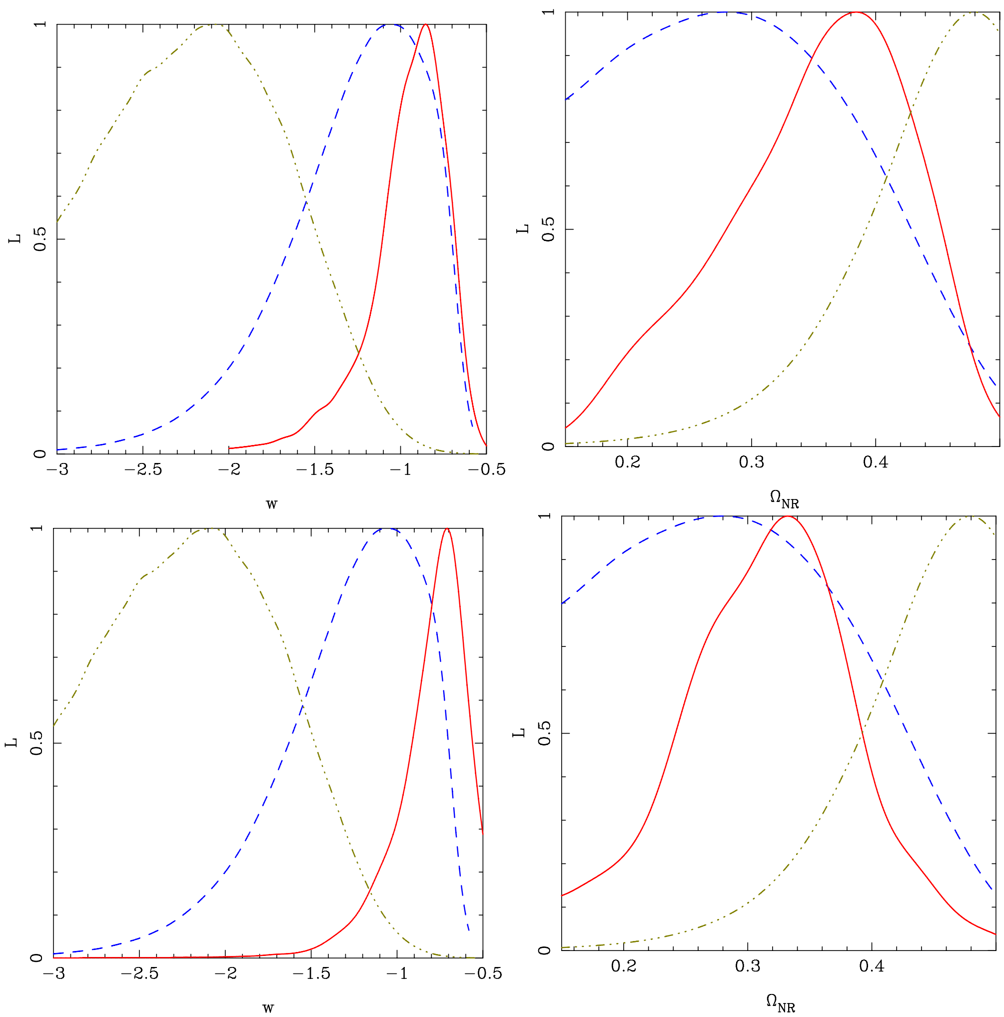

Figure 6: The figure shows likelihoods of w and Ω_{NR} for constant equation of state models. The top panel shows likelihoods when we take dark energy perturbations into account and the lower panel is for homogeneous dark energy component. The solid/red line is likelihood with WMAP data, blue/dashed line shows SNLS data likelihood and the green dot-dashed line is likelihood plot for gold+silver data.

primordial density perturbations, gravitational instability as the mechanism for structure formation.

The exquisite measurements by the Wilkinson Microwave Anisotropy Probe (WMAP) results marked a successful decade of exciting CMB anisotropy measurements and considered a milestone because they combine high angular resolution with full sky coverage allowed by a space mission. *Tarun Souradeep* and his collaborators have worked on a broad range of research problems in CMB anisotropy.

Angular power spectrum of CMB from WMAP

Tarun Souradeep, in collaboration with Pankaj Jain and Rajib Saha has carried out an independent estimation of the angular power spectrum from WMAP. This novel, self contained, analysis of multi-frequency data from WMAP evades the modeling uncertainties involved in using extraneous foreground model. The angular power spectrum computed by their analysis matches that from WMAP. This is also the first demonstration that the CMB angular power spectrum can be reliably estimated with precision from a self contained analysis of the WMAP data, which is a very encouraging news for future CMB experiments. Soon after the second release of WMAP data, the Indian team, in collaboration with five other international research groups, have carried out comprehensive reanalysis of three years of WMAP data that compare the currently important approaches to the estimation of CMB angular power spectrum.

The independent CMB data analysis pipeline developed in IUCAA allows the study of various systematic effects that are important for the next WMAP releases and other future experiments. This method is also being viewed with great promise for near future CMB polarization measurements, like the Planck Surveyor, where very little is known about the polarized foregrounds.

Effects of non-circular beam on WMAP power spectrum estimate

In this era of high precision CMB measurements, systematic effects are beginning to limit the ability to extract more information. The non-circularity of the experimental beam has become progressively important as CMB experiments strive to attain higher angular resolution and sensitivity. Recent CMB experiments such as ARCHEOPS, MAXIMA, WMAP have significantly non-circular beams. Future experiments like Planck are expected to be even more seriously affected by non-circular beams. *Tarun Souradeep, Sanjit Mitra* and Anand Sengupta, had studied the effect of non-circular beams on CMB power spectrum estimation. They showed that a significant correction is expected for an experiment with a beam which is non-circular at a level comparable to the WMAP beam.

Mitra, Sengupta, *Subharthi Ray*, Rajib Saha and *Souradeep* have extended the research work to derive analytic expressions for the effect of non-circular beam for non-uniform sky-coverage. This substantially enhances the results available in the literature and the analytic expressions could provide a considerable computational advantage in data analysis pipelines.

Statistical anisotropy of the CMB maps from WMAP

The statistical expectation values of the temperature fluctuations of cosmic microwave background (CMB) are assumed to be preserved under rotations of the sky. The assumption of statistical isotropy (SI) of the CMB anisotropy should be observationally verified since detection of violation of SI could have profound implications for cosmology. The Bipolar Power Spectrum (BiPS) has been recently proposed as a measure of violation of statistical isotropy in the CMB anisotropy map by *Amir Hajian* and *Tarun Souradeep*. This has been described in detail in the last year's annual report.

The first 'full' sky CMB polarization maps have been recently released in the WMAP-3yr second data release. The statistical isotropy of the CMB polarization maps is an independent probe of the cosmological principle. Since CMB polarization is generated on the surface of last scattering, violations of statistical isotropy are pristine cosmic signatures and difficult to explain as local effects in the universe. In the first study of SI violation in CMB polarization maps, *Soumen Basak*, *Hajian*, *Souradeep* have extended the Bipolar Power Spectrum for CMB polarization maps and demonstrated its use in identifying SI violation in CMB polarization maps.

Besides implementing BiPS on data, some work has been done by *Hajian* and *Souradeep* on the physical effects probed by the BiPS. In collaboration with Pogosyan, Bond and Contaldi, they have computed the BiPS predicted for non-trivial cosmic topology. *Himan Mukhopadhyay*, *Hajian* and *Souradeep* have also worked on the idea of a Bipolar power spectroscopy of cosmic topology based on the interesting, observable, connection between the symmetries of the compact universe models and the measurable BiPS of CMB anisotropy. Tuhin Ghosh, *Hajian* and *Souradeep* have used the BiPS power spectrum to constrain anisotropic

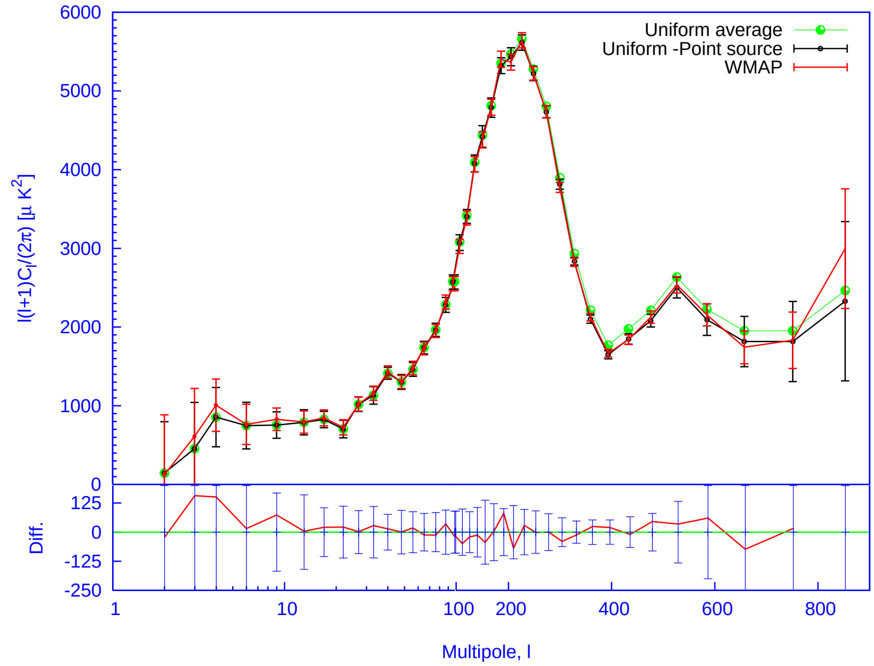

Figure 7: The angular power spectrum estimated from the WMAP multi-frequency using a self-contained model free approach to foreground removal (black curve) is compared to the WMAP team estimate (red) *[Saha, Jain and Souradeep, ApJ. Lett. 2006]*. The method does not rely upon any foreground templates and exploits only basic physical facts such as the achromatic CMB fluctuations and the lack of noise correlation between the independent channels. The published binned WMAP power spectrum plotted in red line with error bars for comparison. The lower panel shows the difference in the estimated power spectra. The method holds great promise for CMB polarization, where modeling uncertainties for foregrounds are much higher.

models of cosmology. Saha, Hajian, Jain and Souradeep have also shown that the BiPS is an excellent diagnostic to check for residual foregrounds in CMB maps.

Constraining early universe scenarios from observations

Cosmological parameters estimated from CMB anisotropy (and related observations) assume a specific form for the spectrum of primordial perturbations believed to have seeded the large scale structure in the universe. Accurate measurements of the angular power spectrum C_l over a wide range of multipoles from the Wilkinson Microwave Anisotropy Probe (WMAP) has opened up the possibility to deconvolve the primordial power spectrum for a given set of cosmological parameters. *Arman Shafieloo* and *Tarun Souradeep* have developed and implemented a direct deconvolution approach to estimate the primordial power spectrum from the angular power spectrum CMB anisotropy measured by WMAP that has cited in the recent second release of WMAP data. *Shafieloo* and *Souradeep* are undertaking a fresh analysis based on the angular power spectra of the CMB anisotropy and polarization. *Rita Sinha* and *Souradeep* have assessed promising inflationary scenarios that incorporate similar infra-red cutoff undertaking a comprehensive cosmological parameter estimation exercise. Yashar Akrami, and *Tarun Souradeep* developed a numerical code for rapidly computing the predicted spectrum of perturbations for a given inflation potential. This will allow joint estimation of the parameters of inflation potential and cosmological parameters from the available cosmological data on CMB anisotropy and large-scale galaxy surveys.

Observational Cosmology

Discovery of an immense ring-like structure of radio emission around galaxy cluster Abell 3376

The origin of ultra-high energy cosmic ray particles (UHECR) with surprisingly large energies of $\sim 10^{18} - 10^{20}$ eV is a long-standing enigma of Physics. In any acceleration scheme, the radiation background induced energy losses and source size/energy constraints put a limit to the attainable maximum energy. Observationally, cosmic ray sources of required parameters are yet unidentified. Some potential UHECR accelerator sources are radio galaxies (lobes, jets), pulsar magnetospheres,

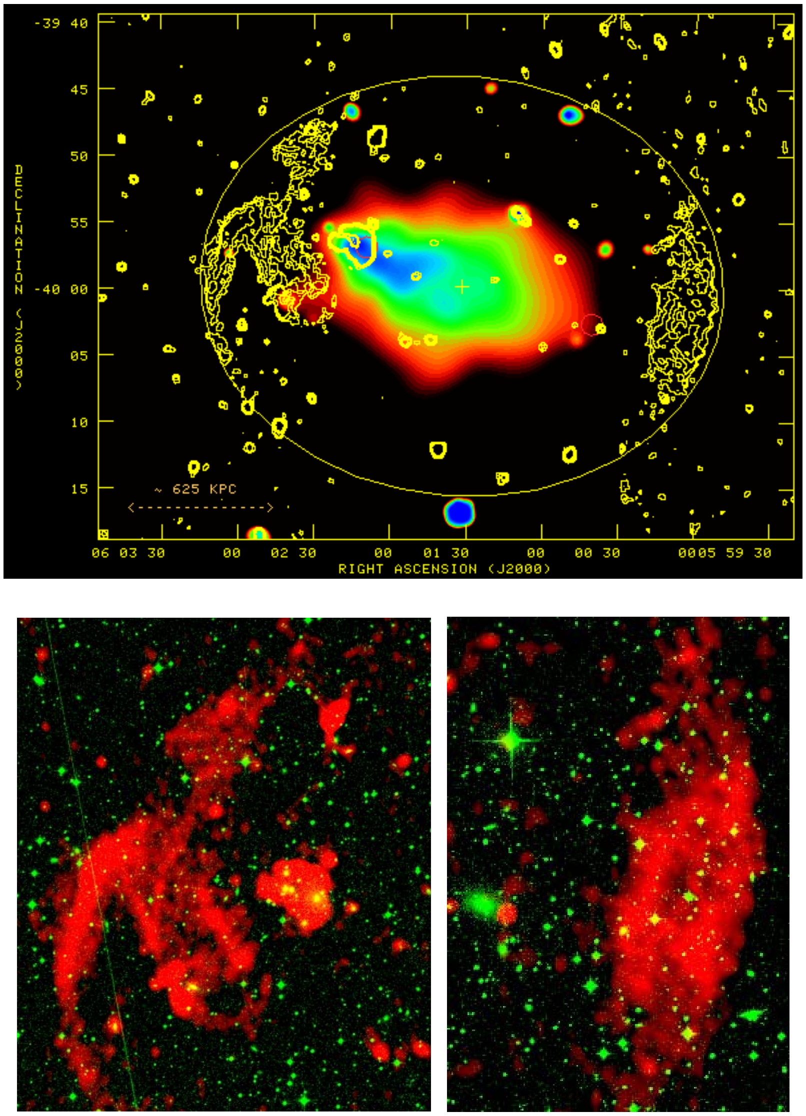

Figure 8: **Top panel:** A composite map of radio and X-ray emission from the galaxy cluster Abell 3376. The radio emission is represented by yellow contours (0.12, 0.24, 0.48 and 1 mJy/beam. Beam width: 20 arcsec FWHM Gaussian) obtained from the VLA 1.4 GHz observations. The yellow ellipse shows an elliptical fit to the peripheral radio structures and the '+' marks the center of the fitted ellipse. The central colour image depicts the thermal bremsstrahlung X-ray emission structure detected by the PSPC detector onboard the ROSAT satellite in ≈12 ks exposure and within 0.14–2.0 keV band. The red circles mark the position of the two brightest cluster galaxies - the brightest cD galaxy on the lower-right and the second brightest galaxy associated with the bent-jet radio source MRC 0600-399 near the X-ray peak. **Bottom panel:** Composite maps obtained from radio and optical images. The VLA 1.4 GHz radio maps (in red colour) for the eastern (left) and the western (right) shock structures are shown overlayed on the red band Digitized Sky Survey image (in yellow-green colour).

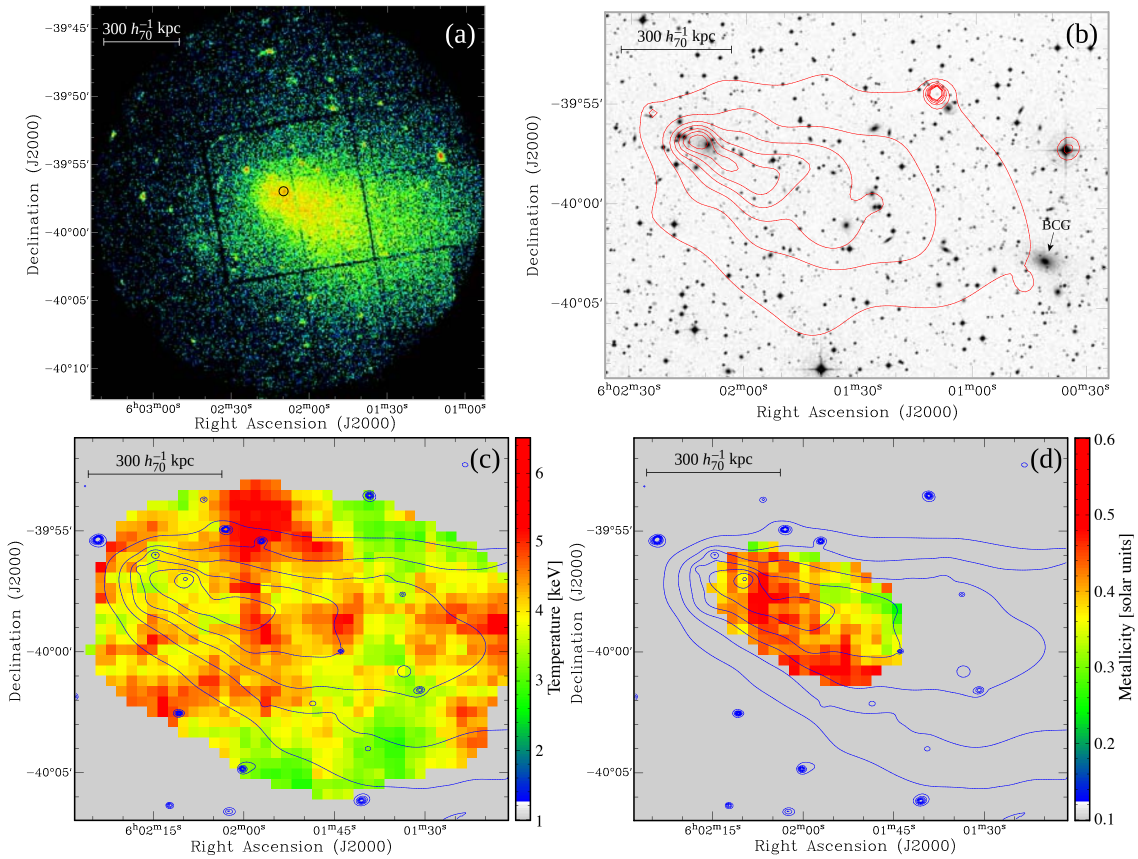

Figure 9: **(a)** XMM-Newton MOS1 and MOS2 composite photon image in the [0.3-8.0] keV band. The black circle shows the position of the second brightest galaxy, which coincides with the X-ray peak. **(b)** Red band Digitized Sky Survey image with ROSAT [0.2-2.0] keV smoothed intensity iso-contours superposed. The brightest cluster galaxy (BCG) is indicated with an arrow. The BCG sits at the edge of the ROSAT field of view but outside of the XMM field of view. **(c)** Temperature map (color scale in keV units) derived from XMM data. Notice the alternating cold and hot regions, their temperature varying from ~ 2 to ~ 6 keV. The superposed X-ray intensity contours are from an adaptively smoothed XMM image. **(d)** Metallicity map (color scale in solar units) derived from XMM data. It shows a strong metallicity gradient along the intensity elongation axis. Contours are the same as in the previous panel. The scale bars are in kpc, assuming $z = 0.046$ and standard ΛCDM cosmology.

gamma-ray bursts, and galaxy clusters. Clusters of galaxies are the largest known virialised structures, which assemble by gravitational infall of smaller mass components. Accretion, mergers and collisions are the dominant processes of 'structure formation'. In these processes, an important role is played by megaparsec scale cosmic shock waves, arising in gravity-driven supersonic flows of intergalactic matter (IGM) onto dark matter dominated collapsing structures such as pancakes, filaments and clusters of galaxies. During cluster mergers, the enormous kinetic energy of colliding subclusters ($\sim 10^{63-64}$ erg) is dissipated in the form of shock-waves, which play a pivotal role in heating of the intra-cluster medium (ICM) to the virial temperatures. Large scale structure-formation shocks in the presence of magnetic fields are capable of accelerating particles upto ultra-relativistic limit by a diffusive shock acceleration process (DSA or Fermi-I), although many details of this process are still hazy due to lack of good observational data.

To understand better what role shock waves in clusters might play as cosmic-ray particle accelerators, *J. Bagchi* and collaborators (Florence Durret, Gastao Lima Neto and Surajit Paul)have made the massive cluster of galaxies Abell 3376 the focus of their study. In Abell 3376, they found several evidences of ongoing energetic structure-formation processes - subcluster mergers, large-scale peripheral shocks etc. They targeted Abell 3376 with deep VLA and GMRT observations at 1.4 GHz ferquency. They have discovered a unique, large-scale ($\sim$ 2 Mpc) ring-like synchrotron radio emission structure, possibly tracing the elusive intergalactic shocks around this galaxy cluster at redshift z = 0.046. This immense ring-like structure [Figure 8] contains mainly a pair of giant, arc shaped diffuse radio emitting sources, each with a linear dimension $\sim 1h^{-1}$ Mpc, located at the outskirts of this cluster at the projected distance of $\sim 1h^{-1}$ Mpc from the cluster centre. In addition, the eastern structure contains several linear filaments and a peculiar loop like feature. The immense physical size of these radio structures places them among the largest shock wave features ever seen.

Both radio structures were found to be oriented such that their concave side faces the cluster center and they fitted quite well on the surface of a large, projected elliptical ring-like formation of dimension $\sim 2 \times 1.6$ Mpc^2 in position angle $\approx 85°$ [Figure 8]. The luminous thermal bremsstrahlung X-ray emission detected by the ROSAT satellite and onboard PSPC detector is also shown in Figure 8. In the cluster central region, it reveals a highly disturbed, non-equilibrium state of the intra-cluster thermal gas, which is obviously extended like a 'comet' or 'bullet-head', its wake running parallel to the major axis of the radio structures described above. Both radio sources are located at the periphery of the ROSAT-observed X-ray emission. From redshift measurements of galaxies in this cluster, a filamentary structure composed of at least three major subclusters, oriented parallel to the ellipse major axis, is reported. Obviously, Abell 3376 is far from being a relaxed cluster.

The X-ray temperature, metal abundance and intensity maps derived from XMM-Newton data are displayed in Fig. 9. Typical errors on temperatures on this map are about 10%. This map reveals an overall temperature of about 5 keV, with several alternating hot and cold regions crossing the cluster, divided by a prominent 'cold-arc' at about 3 keV, which originates at the north edge and curves southwards towards the east. The most plausible scenario is that a large group or a small cluster is falling onto the main body of the cluster from the east-northeast, thus creating hotter regions through a shock. Such a scenario would agree with the second brightest galaxy on the X-ray peak associated with the strong radio source MRC 0600-399, in which both radio-jets are bent backwards suggesting a movement towards the west-southwest along PA$\sim 70°$ (Fig.8). It also agrees with the fact that this cannot be a relaxed cluster, since the two brightest galaxies are not at all close to the cluster center, as defined by the X-ray distribution (Fig.8 9). The highly asymmetrical metal distribution also suggests a violent and recent dynamical event, where the gas is not well mixed and we observe patches of high and low metallicity. All these evidences indicate hydrodynamically unrelaxedd nature of Abell 3376.

Due to relatively short radiative timescale of relativistic electrons, particle transport by diffusion from an AGN like point source upto $\sim$ Mpc dimension will not work and they must be accelerated *in situ*. The lack of any identifiable galaxy progenitor or radio jets/plumes connecting the peripheral radio sources with any central AGN/optical galaxy suggests that these structures can not be the diffuse radio lobes. Hydrodynamical simulations show that only shock waves induced in structure formation processes are sufficiently extended, long-lived, and energetic to overcome the strong radiation losses of the relativistic electrons over a Mpc-scale, rapidly accelerating them to relativistic energies, which could emit synchrotron radio emission at the level observed. These ubiquitous shocks are an inevitable consequence of gravitational collapse and they are pivotal to virialization of diffuse inter-galactic medium (IGM). Two such shockwave inducing events are plausible: the supersonic accretion flows of IGM and their associated virial shocks, and the merger shocks emanating from the centre induced by merger events of subclusters $\sim 10^9$ yr in the past (assuming constant shock speed of $\sim$ 1000 km/s). A pair of outgoing merger shock waves could have created these diffuse radio sources at the outskirts of Abell 3376 by accelerating a preexisting lower energy electron population. Alternatively, their peripheral ring-like geometry at $\sim$ Mpc distance from centre inidicates that these giant radio structures could be the first direct evidence for the accretion shocks near the yet unexplored virial infall region of a massive galaxy cluster, and thus a direct probe of dynamics of warm-hot intergalactic gas (so called WHIM). More work is continued to decide which of the three processes is actually observed here.

The gas dynamics induced in structure formation (large-scale bulk flows, turbulence, collisionless shocks and modified magnetic fields) all create an ideal environment for cosmic ray acceleration via stochastic Fermi-I mechanism, and for amplification of seed magnetic fields. For cosmic ray protons, which suffer negligible radiative losses below 5×10^{18} eV, the highest acceleration energy E^P_{max} is limited only by the finite lifetime of shocks, i.e., $t_{acc} = t_{merger} \sim 10^{9-10}$ y, thus giving $E^P_{max} \sim 10^{18-19}$ eV. For cosmic ray electrons significant radiative losses limit their energy to a maximum $E^e_{max} \sim 10^{14}$ eV. Lower energy electrons of $\sim$ 10 GeV energy would produce the observed 1.4 GHz radio emission. Inverse Compton scatter of the 2.7 K cosmic microwave background photons from both primary electrons accelerated in shocks, and from secondary electrons of hadronic origin (from pion decay and pair production), will give rise to energetic hard X-ray/γ-ray photons of energy $E_\gamma \sim 100\ \gamma^{e\,2}_7$ GeV (where γ^e_7 is the electron Lorentz factor in units of 10^7). The Inverse Compton spectrum could extend upto $\sim$ 10 TeV, limited by higher energy cut-off in the electron energy spectrum. This tell-tale radiation remains undetected, but future identification of hard X-ray (*ASTRO-E2, NEXT*) or 1 MeV - 100 GeV (*GLAST*) to VHE TeV γ-ray (*CANGAROO, MAGIC, VERITAS, HESS*) emission from structure formation shocks in hydrodynamically unrelaxed clusters like Abell 3376 holds a great promise for advancing current knowledge on shock formation in the IGM. It should provide the first direct evidence for such shocks, revealing the underlying large-scale cosmological flows and definitive proof of ultra-high-energy cosmic ray acceleration. When combined with hard X-ray or γ-ray detection, the radio synchrotron signal (*GMRT, SKA, LOFAR*) will probe directly the unknown magnetic fields in the IGM, thus providing a better understanding of processes leading to IGM magnetization and also acceleration and propagation of ultra-high energy cosmic rays.

Magnetic Fields in Astrophysics

Magnetic helicity density and its flux in weakly inhomogeneous turbulence

Magnetic helicity conservation plays a crucial role in constraining the nonlinear evolution of several astrophysical and laboratory plasma systems. It is important for practical applications involving systems with boundaries, to be able to discuss the density of magnetic helicity and its flux. This is difficult when one defines the magnetic helicity using the vector potential, because then the magnetic helicity density or its flux are not gauge invariant concepts.

K. Subramanian and A. Brandenburg have proposed a gauge invariant and hence physically meaningful definition of magnetic helicity density for random fields, using the Gauss linking formula, as the density of correlated field line linkages. This definition was applied to the random small scale field in weakly inhomogeneous turbulence, whose correlation length is small compared with the scale on which the turbulence varies. For inhomogeneous systems, with or without boundaries, our technique then allows one to discuss the local magnetic helicity density evolution, in a gauge independent fashion, which was not possible earlier. This evolution equation is governed by local sources (owing to the mean field) and by the divergence of a magnetic helicity flux density. Such magnetic helicity fluxes can help in alleviating catastrophic quenching of mean field dynamos. Their work, to some extent, lays the conceptual foundation for the many discussions of the effects of helicity fluxes already existing in the literature and future explorations.

Strong mean field dynamos require supercritical helicity fluxes

K. Subramanian and A. Brandenberg have also begun the exploration of the effects of such a helicity flux in solving the catastrophic quenching of dynamos. Several one and two dimensional mean field dynamo models were analyzed, where the effects of helicity fluxes and boundaries are included. Even in the absence of helicity fluxes, the field can reach appreciable strength at the end of a kinematic phase. This is as anticipated in their earlier work, where they had worked out the minimal strength of large-scale magnetic fields, which can be generated, in spite of strict magnetic helicity conservation.

However, due to helicity conservation and nonlinear effects, the field undergoes oscillations, with a fast decay and slow rise, when for long periods, the field can be extremely weak, with its amplitude inversely proportional to the magnetic Reynolds number. Since the magnetic Reynolds number is typically very large in astrophysical systems, this would be disastrous for mean field dynamo theory.

The inclusion of helicity fluxes alters these conclusions. If the helicity flux exceeds a certain critical value then one can circumvent the catastrophic quenching of the dynamo, and the field can saturate at appreciable values. Infact, for supercritical helicity fluxes, the dynamo can operate even without kinetic helicity, i.e., it is based only on shear and helicity fluxes, as first suggested by Vishniac and Cho. The fact that certain turbulence simulations have now shown apparently non-resistively limited mean field saturation amplitudes may be suggestive of the helicity flux having exceeded this critical value.

Galactic dynamo and helicity losses through fountain flow

For the galactic dynamo, simple advection as expected in the galactic fountain flow can lead to the necessary helicity flux. *K. Subramanian*, A. Shukurov, D. Sokoloff, and A. Brandenburg have recently studied the nonlinear behaviour of galactic dynamos, allowing for magnetic helicity removal by the galactic fountain flow. A suitable advection speed is estimated, and an one-dimensional mean-field dynamo model with dynamic α-effect has been explored. The galactic fountain flow is indeed efficient in removing magnetic helicity from galactic discs, and alleviate the constraint on the galactic mean-field dynamo due to magnetic helicity conservation. The mean magnetic field then saturates at a strength comparable to equipartition with the turbulent kinetic energy

Active Galactic Nuclei, Quasars and Intergalactic Medium

Properties of high redshift quasars

In the local universe, the masses of Super-Massive Blackholes (SMBH) appear to correlate with the physical properties of their hosts, including the mass of the dark matter halo. Using these clues as a starting point, many studies have produced models that can explain phenomena like the quasar luminosity function. The shortcoming of this approach is that working models are not unique, and as a result, it is not always clear what input physics is being constrained. Following up on the work reported last year, Stuart Wrythe and *T. Padmanabhan* have analysed some aspects of this issue using a different approach. They identify critical parameters that describe the evolution of SMBHs at high redshift, and constrain the parameter space based on observations of high redshift quasars from the Sloan Digital Sky Survey. They find that the luminosity function taken in isolation is somewhat limited in its ability to constrain SMBH evolution due to some strong degeneracies. This explains the presence in the literature of a range of equally successful models based on different physical hypotheses. Including the constraint of the local SMBH to halo mass ratio breaks some of the degeneracies and their results suggest halo masses at $z \sim 4.5$ of $10^{12.5\pm0.3} M_{\odot}$ (with 90% confidence), with a SMBH to halo mass ratio that decreases with time ($> 99\%$). These features need to be incorporated in all successful models of SMBH evolution. Current data does not permit any conclusions regarding the evolution of quasar life time, or the SMBH occupation fraction in dark matter halos.

Molecular hydrogen in a damped Lyman-alpha system at z_{abs}=4.224

Molecular hydrogen (H_2) is the first neutral molecule to be formed in the universe and is an important coolant for the first generation of stars. In the local universe, H_2 is ubiquitous in star-forming giant molecular clouds, diffuse interstellar medium (ISM) and in the atmospheres of Jovian planets. In the diffuse ISM, H_2 molecules are mainly formed on the grain surface and destroyed by the UV photons with typical energy ~10 eV (called Lyman-Werner band photons). Thus, equilibrium abundance and the population of H_2 in different rotational levels together with excitation of fine-structure states C^0 are used to get a handle on physical conditions such as gas pressure, ambient radiation field and chemical history, etc. These conditions are believed to be driven by the injection of energy and momentum through various dynamical and radiative processes associated with the star formation activity. Thus, detecting H_2 molecule at high z is an important step to understand the evolution of normal galaxies.

R. Srianand and his collaborators Cedric Ledoux and Patrick Petitjean, have reported the direct detection of molecular hydrogen at the highest redshift known today ($z_{abs} = 4.224$) in a Damped Lyman-alpha (DLA) system toward the quasar PSS J1443+2724 (see Fig. 10). This absorber is remarkable for having one of the highest metallicities

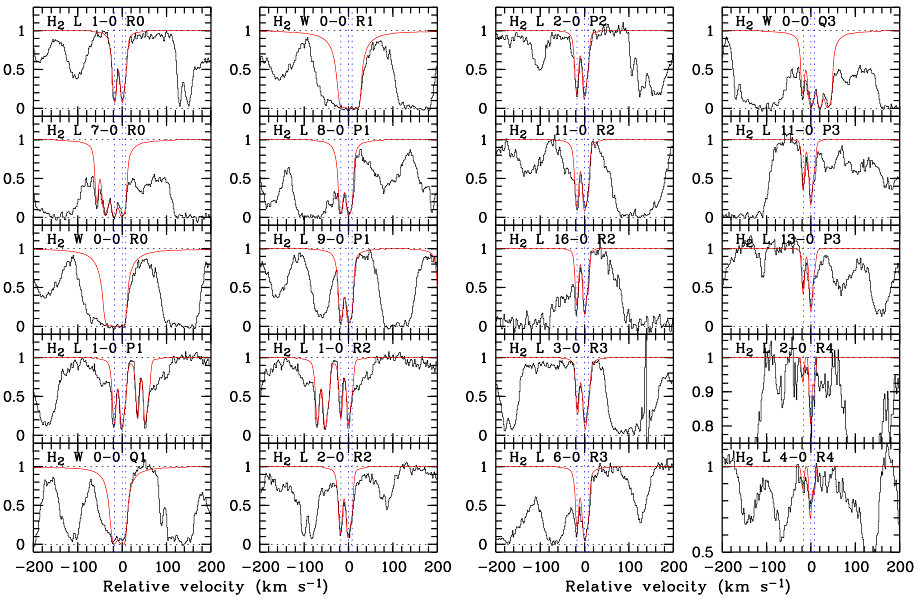

Figure 10: Velocity profiles of selected transition lines from the $J = 0$, 1, 2, 3 and 4 rotational levels of the vibrational ground-state Lyman and Werner bands of H_2 at $z_{abs} = 4.224$ toward PSS J 1443+2724. The best Voigt-profile fitting model is superimposed on the spectra with vertical dotted lines marking the location of the three components of the system.

amongst DLA systems at $z_{abs}>3$, with a measured iron abundance relative to Solar of -1.12 ± 0.10. They provide for the first time in this system accurate measurements of N I, Mg II, S II and Ar I column densities. The sulphur and nitrogen abundances relative to solar, -0.63 ± 0.10 and -1.38 ± 0.10 respectively, correspond exactly to the primary nitrogen production plateau. H_2 absorption lines are detected in four different rotational levels (J = 0, 1, 2 and 3) of the vibrational ground-state in three velocity components with total column densities of log $N(H_2)$=17.67, 17.97, 17.48 and 17.26 respectively. The J=4 level is tentatively detected in the strongest component with log $N(H_2)$= 14. The mean molecular fraction is log f = -2.38 ± 0.13, with f = $2N(H_2)/(2N(H_2)+N(\mathrm{H\ I}))$. They also measure log $N(HD)/N(H_2) < -4.2$. The excitation temperatures T_{01} for the two main components of the system are 96 and 136 K respectively. They argue that the absorbing galaxy, whose star-formation activity must have started at least $2-5\times10^8$ yrs before z=4.224, is in a quiescent state at the time of observation. The density of the gas is small, $n_H \leq 50 cm^{-3}$, and the temperature is of the order of T = 90-180 K. The high excitation of neutral carbon in one of the components can be explained if the temperature of the Cosmic Microwave Background Radiation has the expected value at the absorber redshift, T=14.2 K.

Relative abundance pattern along the profile of high redshift Damped Lyman-alpha systems

Understanding the chemical and ionization inhomogeneities in DLAs is important for our understanding of production and mixing of metals in normal galaxies. *R. Srianand* and his collaborators E. Rodriguez, P. Petitjean, B. Aracil and C. Ledoux have investigated the abundance ratios along the profiles of six high-redshift Damped Lyman-alpha systems, three of them associated with H absorption, and derived optical depths in each velocity pixel. The variations of the pixel abundance ratios were found to be remarkably small and usually smaller than a factor of two within a profile. This result holds even when considering independent sub-clumps in the same system. The depletion factor is significantly enhanced only in those components, where H is detected. They found a strong correlation between [Fe/S] and [Si/S] abundances ratios, showing that the abundance ratio patterns are definitely related to the presence of dust. The depletion pattern is usually close to the one seen in the warm halo gas of our Galaxy. Some of the components that produce H_2 absorption have depletion pattern close to that seen in the cold neutral medium of our galaxy.

Kinematics and star formation activity in the z=2.03954 damped Lyman-α system towards PKS 0458-020

Multiwavelength investigations of DLAs allow us to probe the physical conditions in protogalaxies in detail. Recently *R. Srianand* and his collaborators have conducted UVES observations of the log N(HI) = 21.7 damped Lyman-α system at z = 2.03954 towards the quasar PKS 0458-020. They have detected a H I Lyman-alpha emission in the centre of the damped Lyman-alpha absorption trough. Metallicities are derived for MgII, SiII, PII, CrII, MnII, FeII and ZnII and are found to be -1.21 ± 0.12, -1.28 ± 0.20, -1.54 ± 0.11, -1.66 ± 0.10, -2.05 ± 0.11, -1.87 ± 0.11, and -1.22 ± 0.10, respectively, relative to solar. The depletion factor is, therefore, of the order of [Zn/Fe]=0.65. They observe metal absorption lines to be blueshifted compared to the Lyman-alpha emission up to a maximum of 100 and 200 km/s for low and high-ionization species respectively. This can be interpreted either as the consequence of rotation in a large (~7 kpc) disk or as the imprint of a galactic wind. The star formation rate (SFR) derived from the Lyman-alpha emission, 1.6 solar masses/yr, is compared with that estimated from the observed CII* absorption. No molecular hydrogen is detected in our data, yielding a molecular fraction $f < -6.52$. This absence of H_2 can be explained as the consequence of a high ambient UV flux, which is one order of magnitude larger than the radiation field in the ISM of our Galaxy and originates in the observed emitting region. This work was done in collaboration with Janine Heinmueller, Patrick Petitjean, Cedric Ledoux and Sara Caucci.

On the variation of the fine-structure constant: Very high resolution spectrum of QSO HE 0515-4414

As part of continued effort to measure/constrain the possible time variations of fundamental constants *Hum Chand* and *R. Srianand* with their collaborators have recently presented a detailed analysis of a very high resolution (R ≈112,000) spectrum of the quasar HE 0515−4414 obtained using the High Accuracy Radial velocity Planet Searcher (HARPS) mounted on the ESO 3.6 m telescope at the La Silla observatory. This is the highest resolution spectra ever obtained for the high redshift QSOs. The HARPS spectrum, of very high wavelength calibration accuracy (better than $1mA$), is used to search for possible systematic inaccuracies in the wavelength calibration of the UV Echelle Spectrograph (UVES) mounted on the ESO Very Large Telescope (VLT). They have carried out cross-correlation analysis between the Th-Ar lamp spectra obtained with HARPS and UVES. The shift between the two spectra has a dispersion around zero of $\sigma \simeq 1mA$. This is well within the wavelength calibration accuracy of UVES (i.e., $\sigma \simeq 4mA$). They show that the uncertainties in the wavelength calibration induce an error of about, $\Delta\alpha/\alpha \leq 10^{-6}$, in the determination of the variation of the fine-structure constant. Thus, the results of non-evolving $\Delta\alpha/\alpha$ reported in the literature based on UVES/VLT data should not be heavily influenced by problems related to wavelength calibration uncertainties. Their higher resolution spectrum of the z_{abs}=1.1508 damped Lyman-α system toward HE 0515-4414 reveals more components compared to the UVES spectrum. Using the Voigt profile decomposition that simultaneously fits the high resolution HARPS data and the higher signal-to-noise ratio UVES data, they obtain, $\Delta\alpha/\alpha = (0.05 \pm 0.24) \times 10^{-5}$ at $z_{\rm abs}$=1.1508. This result is consistent with the earlier measurement for this system using the UVES spectrum alone. This work was done in collaboration with Patrick Petitjean, Bastien Aracil, Ralf Quast and Dieter Reimers.

A new constraint on the time dependence of the proton-to-electron mass ratio.

A new limit on the possible cosmological variation of the proton-to-electron mass ratio $\mu = m_p/m_e$ is estimated by measuring wavelengths of H_2 lines of Lyman and Werner bands from two absorption systems at $z_{\rm abs}$= 2.5947 and $z_{\rm abs}$= 3.0249 in the spectra of quasars Q 0405-443 and Q 0347-383, respectively. Data are of the highest spectral resolution (R = 53000) and S/N ratio (30÷70) for this kind of study. *R. Srianand*, *Hum Chand* and their collaborators search for any correlation between z_i, the redshift of observed lines, determined using laboratory wavelengths as references, and K_i, the sensitivity coefficient of the lines to a change of μ, that could be interpreted as a variation of μ over the corresponding cosmological time. They have used two sets of laboratory wavelengths, the first one, (Set A), based on experimental determination of energy levels and the second one, (Set P), based on new laboratory measurements of some individual rest-wavelengths. They find $\Delta\mu/\mu = (3.05 + -0.75)10^{-5}$ for Set A, and $\Delta\mu/\mu = (1.65 + -0.74)10^{-5}$ for Set P. The second determination is the most stringent limit on the variation of μ over the last 12 Gyrs ever obtained. The correlation found using Set A seems to show that some amount of systematic error is hidden in the determination of energy levels of the H_2 molecule. This work was done in collaboration with A. Ivanchik, P. Petitjean, D. Varshalovich, B. Aracil, C. Ledoux and P. Boisse.

Galaxies

Galaxy formation and evolution

Many clues to galaxy formation lay hidden in the fine details of galaxy structure. Active galactic nuclei (AGNs) are intimately related to formation of bulges and black holes. A key question in astrophysics is the nature of the AGN host galaxies. The Great Observatories Origins Deep Survey (GOODS) provides a homogenous sample of deep, multiwavelength observations of galaxies using data from Hubble, Spitzer Space Telescope, Chandra and XMM-Newton. This provides a very unique database of AGNs, starburst galaxies and normal galaxies in wavelengths ranging from infrared to X-ray. The GOODS database can be used to understand the morphology, spectral properties and evolution process of peculiar objects (with some indication of AGN activity) in this sample using indicators like their Xray luminosity, radio flux, etc. *P. Hasan, A. K. Kembhavi, A. Rawat*, F. Hammer and H. Flores have studied the cross correlatation of X-ray source catalogues and the HST/ACS z_{850} catalogues of the GOODS field obtained with Chandra deep field survey with catalogues in the optical. Refined techniques have been used to identify most probable counterparts. Morphological classification is essential to reveal the nature of AGN host galaxies. However, at high redshifts, it becomes difficult to classify galaxy morphology securely, because the images of high redshift galaxies suffer from reduced resolution, band shifting and cosmological surface brightness dimming effects, compared with the local objects. With HST ACS, high resolution imaging in two or more bands with spatially resolved colour distribution can be used to investigate the distribution of the stellar population, which is complementary to single band images. For further reference, they have also carried out decomposition of the luminosity profiles of the galaxies using GALFIT, to derive the bulge to disk ratios and possible features in residual maps. The figure 11 shows an example of a galaxy with its corresponding colour map which clearly shows star forming regions, dusty regions, etc.

High Energy Astrophysics

One of the most enigmatic sources in the universe are black hole systems. Over several decades, a comprehensive understanding of these sources, especially their temporal behaviour, has remained illusive, because of the complexities involved in solving the governing magneto-hydrodynamic equations. *R. Misra*, K. P. Harikrishnan, G. Ambika and *A. K. Kembhavi* have developed a modified version of a standard non-linear time series analysis and have applied the technique on light curves of black hole systems. They find that some systems exhibit low dimensional chaotic behaviour, which implies that the partial differential equations which govern the system, can be simplified into a set of non-linear but ordinary differential ones. Although, their analysis does not reveal the exact nature of these equations, their results indicate that the temporal behaviour of such systems can indeed be understood in a simple framework.

Identification of the radiative processes that occur in black hole systems, is crucial to the understanding of these systems. S. Bhattacharyya, N. Bhatt and *R. Misr*a have improved on their earlier results, to work out the possibility that some of the high energy emission of X-ray binaries is due to proton-proton interactions. Such a scenario is more attractive, since it is difficult to accelerate electrons in such environments.

Ultra-luminous X-ray (ULX) sources are X-ray points sources in nearby galaxies, which are extremely bright ($> 10^{39}$ ergs/sec) and hence, are expected to harbour intermediary size black holes ($10^2 - 10^4 M_\odot$). A. Senorita, *R. Misra*, *V. K. Agrawal* and Y. P. Singh have undertaken a systematic spectral study of these sources. *V. K. Agrawal* and *Misra* have analyzed the spectra of the ULX M822 X-1, and have found it to be different from other low luminosity black hole sources, indicating that it is perhaps emitting on the Eddington limit.

Stars and Interstellar Medium

A multiwavelength investigation of the temperature of the cold neutral medium

Physical state of the local interstellar median can be probed either using 21 cm (H I) absorption or using the rotational distribution of H_2. Recently *R. Srianand* and his collaborators Nirupam Roy and Jayaram Chengalur have presented GMRT measurements of the H I spin temperatures (T_s) of the Cold Neutral Medium (CNM) towards radio sources that are closely aligned with stars for which

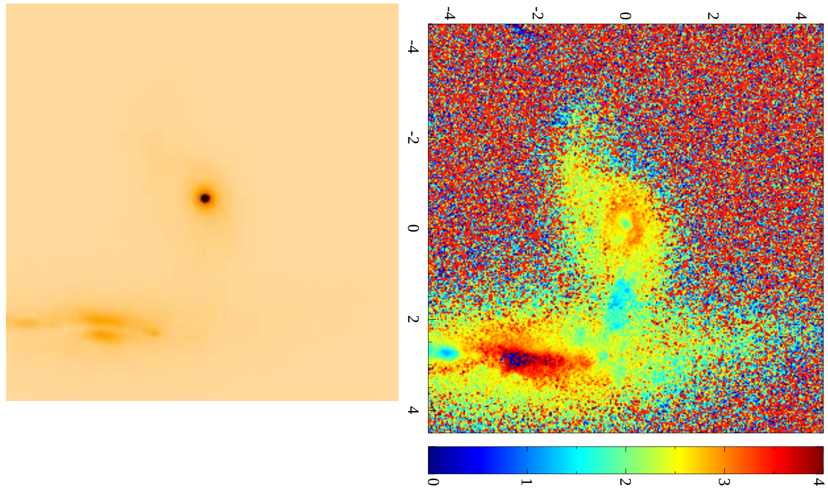

Figure 11: z (F850LP) band image and colourmap made using the B (F435W) and z (F850LP) band filters for a z = 0.27 interacting galaxy.

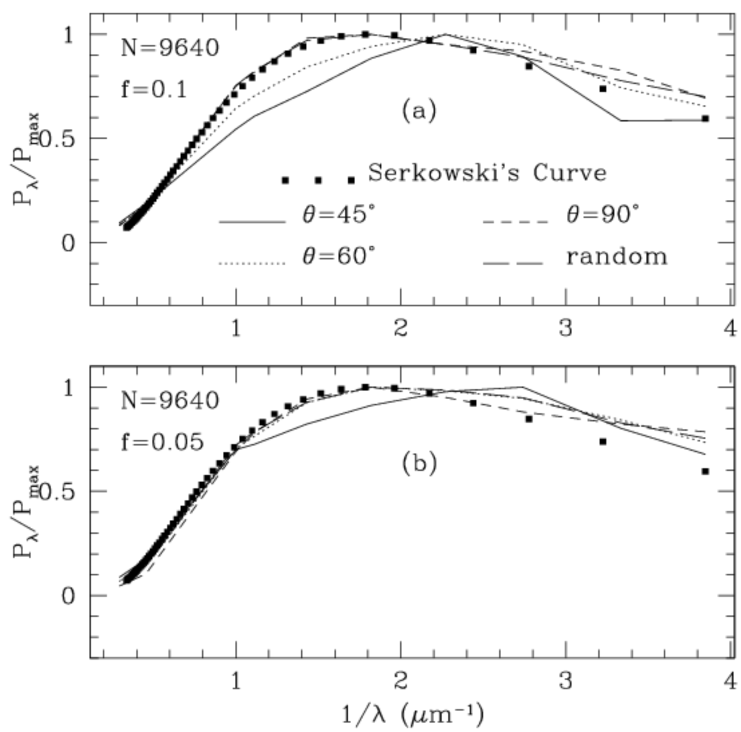

Figure 12: Fitting of interstellar polarization values (in square dots) with the composite grain model polarization.

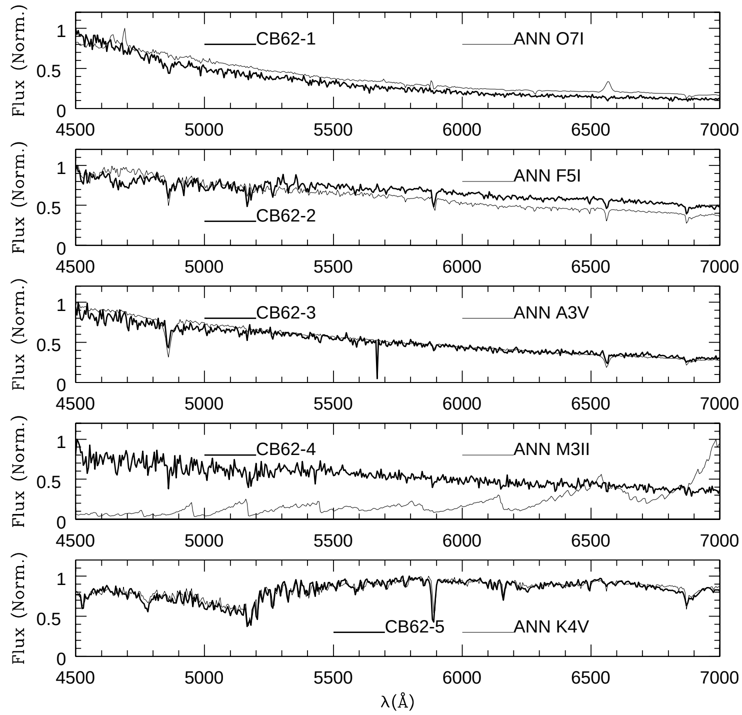

Figure 13: Spectral classification by ANN technique of the peripheral stars around the dark star forming cloud CB62.

published H_2 ortho-para temperatures (T_{01}) are available from UV observations. Their sample consists of 18 radio sources close to 16 nearby stars. The transverse separation of the lines of sight of the UV and radio observations varies from 0.1 to 12.0 pc at the distance of the star. The ultraviolet (UV) measurements do not have velocity information, so they use the velocities of low ionization species (e.g., Na I, K I, C I) observed towards these same stars to make a plausible identification of the CNM corresponding to the H_2 absorption. They find that T_{01} and T_s match within observational uncertainties for lines-of-sight with H_2 column density above $10^{15.8}$ cm^{-2}, but deviate from each other below this threshold. This is consistent with the expectation that in the CNM, T_s tracks the kinetic temperature due to collisions and that T_{01} is driven towards the kinetic temperature by proton exchange reactions.

Physical conditions in the ISM towards HD185418

R. Srianand and his collaborators, Gary Ferland and Gargi Shaw, have developed a complete model of the hydrogen molecule as part of the spectral simulation code Cloudy. Their goal is to apply this to spectra of high-redshift star-forming regions, where H_2 absorption is seen, but where few other details are known, to understand its implication for star formation. The microphysics of H_2 is intricate, and it is important to validate these numerical simulations in better-understood environments. As a first step they studied a well-defined line-of-sight through the galactic interstellar medium (ISM) as a test of the microphysics and methods they use. They have presented a self-consistent calculation of the observed absorption-line spectrum to derive the physical conditions in the ISM towards HD185418, a line-of-sight with many observables. They deduce density, temperature, local radiation field, cosmic ray ionization rate, chemical composition and compare these conclusions with conditions deduced from analytical calculations. They find a higher density, similar abundances, and require a cosmic ray flux enhanced over the galactic background value, consistent with enhancements predicted by MHD simulations.

Modeling of interstellar dust

R. Gupta in collaboration with D.B. Vaidya and T.P. Snow have used the composite dust grain model to reproduce the interstellar polarization and also given better abundance contraints for carbon and silicon in the ISM. Figure 12 shows the composite model polarization and its fitting with Serkowiski's points (square dots).

Spectrophotometric observations of dark clouds

R. Gupta and Asoke K. Sen have carried out spectroscopic observations from Hanle telescope of the peripheral stars in the dark star forming clouds have been reduced and the Figure 13 shows a typical ANN based spectral classification of the spectra of such stars around the cloud CB62. These results along with the B and V band photometry will provide the estimate of colour excess and extinction, which will in turn provide the information whether these stars are in the foreground or at the background of the cloud.

PCA based scheme for filling the gaps in stellar spectral libraries

Recently alongwith H.P. Singh, M. Yuasa and N. Yamamoto, *R. Gupta* has made a preliminary attempt to fill the gaps in the stellar spectral libraries by using the PCA technique. This technique will be used to restore the gaps in all available digital spectral libraries in near future.

Instrumentation

NIPI - Near-Infrared PICNIC Imager

A. Deep,*A. N. Ramaprakash* and others in the instrumentation laboratory are working on building a near-IR camera to be mounted on one of the Cassegrain side ports of the IUCAA Girawali telescope. NIPI will be the first near-IR instrument to be used on this telescope, providing wavelength coverage over 1-2.5 microns with a spatial sampling scale of about 0.8 arcseconds per pixel.

NIPI has a hybrid cryostat, made up of two separate parts - a standard dewar with liquid nitrogen tank, purchased from Infrared Labs, USA and an extension, which houses the lenses, mirrors, filter wheel and the detector. The dewar extension is made using a special aluminium alloy, ingots of which were imported from Germany. By the time the ingots were delivered last year, the design of all the mechanical mounts and support structures were completed. The dewar extension and the mounts for optical components were machined and fabricated with the help of local industry. A radiation shield for providing thermal insulation for the optical components inside the dewar extension was also fabricated and assembled. Currently, tests are being carried out to achieve liquid nitrogen temperatures on the cold block, on which the detector will be mounted. The required temperatures are to be reached by providing thermal paths to the dewar cold face as well as adequate shielding against radiative heat load. On the other hand, damage to the detector by rapid cooling must be avoided by providing adequate thermal mass to the cold block.

The entire assembly consisting of the IR Labs supplied liquid nitrogen dewar as well as the dewar extension were tested for vacuum and cryogenic integrity in the laboratory. An operating vacuum of 10^{-5} mbar was achieved prior to cooling and few times 10^{-6} mbars after cooling. The assembled chamber was found to hold the vacuum very well for more than 20 days during laboratory tests. A feature worthy of special mention about the cryogenic system is that the laboratory developed a vacuum feed through which allows the filter wheel mechanism inside the extension chamber to be rotated using an ordinary stepper motor mounted outside the chamber. This eliminates the need for alternative options like using expensive and fragile cryogenic motors inside the chamber.

The mounts for the lenses and mirrors were coated with Nextel infrared black paint to minimize scattering from their surfaces. The optical components were then carefully mounted on their holders and the holders on the optical bench. The three mirrors which define the optic axis were first alinged using an HeNe laser source and appropriate masks. The lenses were then aligned on the optic axis using the same laser source and employing retro-reflection techniques. In this technique, if light reflected from each surface in the optical path come back to the source, the surfaces are along the optical axis. Once the optics were satisfactorily aligned, the bench was mounted inside the dewar extension chamber and the radiation shield assembled around it. The last component to go in is the filter wheel on its stainless steel shaft. The instrument is currently in its final phase of assembly in the laboratory and is planned to be mounted on the telescope very soon.

Instrument control system

The back-end instruments on the telescope are operated during observations from the control room in the ground floor of the observatory. Although, there are a lot of similarities between the requirements for control of different instruments and accessories, currently many of these have been implemented differently, due to historic development cycles. A project was undertaken last year to develop a unified control system, which will meet the current and immediate future instrument control

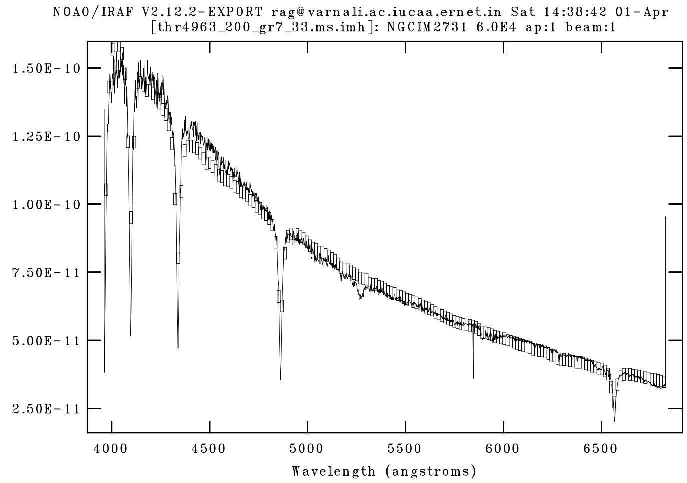

Figure 14: Spectra of IRAF spectroscopic standard star HR4963 taken with the IUCAA Girawali telescope and IFOSC instrument (IFOSC 7 grism) and its fitting with IRAF narrow band fluxes.

requirements at the observatory. In addition to offering a unified command-reponse-recovery interface, this system will also have substantial redundancy in the hardware to meet contingencies. The system is also extendable to meet future increase in demands. It also provides a LAN-based command interface in addition to the traditional serial communication link based ones. The hardware is built around the Atmel make Atmega 128 microcontroller and is designed with a back-plane architecture with configurable plug-play sub-systems. Industry standards have been adopted in the design of the printed circuit cards as well as the enclosure box. *M. Srivastava*, and *A. N. Ramaprakash* have been working with instrumentation laboratory staff on this project.

Observatory science verification

With the hand over of the 2m telescope from Telescope Technologies Ltd, UK, to IUCAA in February 2006, service mode observations were started at the observatory as reported elsewhere in this report. *A. N. Ramaprakash* played a vital role in the activities related to converting the telescope from an engineering product to a working observatory. He was also actively involved in training a core group of observers from IUCAA in the operational and observational usage of the observatory. Apart from carrying out science verification studies, particularly with the polarimetric mode of IFOSC, *Ramaprakash* along with *M. Srivastava* has initiated a spectroscopic campaign of ultraluminous infrared galaxies.

IUCAA Girawali telescope and IFOSC spectral characterization

During the current phase of the characterization of IUCAA Girawali telescope along with the IFOSC instrument, observations were made for IRAF standard stars and Figure 14 shows a fitting of one such spectra from HR4963 with the IRAF narrow band fluxes.

Cryosampler balloon experiment

The cryosampler equipment was flown up from the TIFR Balloon Facility, Hyderabad, to a height of 41 km using a balloon. The cryopump was used successfully to collect samples of air at varying heights upto 41 km. The payload was brought down safely and the samples were sent to the Centre for Cellular and Molecular Biology in Hyderabad and to the National Centre for Cell Science in Pune. S. Shivaji in Hyderabad and Yogesh Shouche in Pune are currently examining the samples to detect microorganisms. Final findings in this experiment are expected to be reported within the next six months and *J. V. Narlikar* is involved in this experiment.

(II) RESEARCH BY VISITING ASSOCIATES AND LONG TERM VISITORS

Gravitational Theory and Gravitational Waves

Banerjee, S. K.

Bhim Prasad Sarmah, in collaboration with S.K. Banerjee, S.V. Dhurandhar and J.V. Narlikar has considered the cosmogony of the creation process that leads to the creation and ejection of matter. They show why the creation phenomenon may have a non-isotropic character, with ejection taking place along preferred directions. To measure its gravitational-wave effect they calculate the gravitational amplitude generated by an MCE (mini -creation event) of mass M at a cosmological distance r, and then compare the signal-to-noise ratio detectable by the ground-based laser interferometric detectors of the LIGO and the advance LIGO type within the frequency range 10 to 1000 Hz with the signal-to-noise ratio detectable by the *Laser interferometric Space Antenna (LISA)* within the frequency range 10^{-4} to 10^{-1} Hz.

The calculations they performed here show that a laser interferometric detector of the LISA type can be used to detect through a window of low-frequency range 10^{-4} Hz to 2 x 10^{-2} Hz for a duration of about 52 min. In this duration, *LISA* will be able to see 'jets' for which, the mass creation rate is at least 200 solar mass per second. Whereas, a laser interferometric detector of the advance LIGO type can be used to detect the MCEs, which opens its window of high-frequency range 10 to 10^3 Hz for a very short duration of the order of 10^{-2} seconds, and in this duration it observes 'jets' for which, the mass creation rate is 2 x 10^4 solar mass per second. It appears from this elementary analysis that the *LISA* detector is well suited to detecting MCEs through their gravitational waves, while the LIGO may have a less sensitive, marginal role to play.

Chakraborthy, Subenoy

Quasi-spherical gravitational collapse both in four and higher dimensional spacetime has been studied by Subenoy Chakraborty and co-workers. S. Chakraborty and U. Debnath have examined the role of anisotropy and inhomogeneity in quasi-spherical gravitational collapse in the form of propositions. They have investigated the role of initial data in characterizing the final state of collapse. Also, they have presented a linear transformation on the initial data set and discussed its impact in the collapsing process. A dynamical symmetry of the quasi-spherical (or spherical) collapse has been studied by S. Chakraborty in collaboration with U. Debnath and Naresh Dadhich. By linear scaling the initial data set (mass and kinetic energy functions), they have shown that the dynamics of quasi-spherical (or spherical) collapse remains invariant for dust or a general (Type-I) matter field, with appropriate scaling of the comoving radius. They have found an equivalence class of data sets, which leads to the same end result as well as its evolution all through the physical parameters, namely, density and shear, remain invariant. The role of pressure in quasi-spherical gravitational collapse has been studied by S. Chakraborty in collaboration with Sanjukta Chakraborty and U. Debnath. Cosmological solutions and their asymptotic behaviour have been examined by them for perfect fluid and matter with tangential stress only. They have presented collapsing scenario for anisotropic pressure and have discussed the role of pressure.

Ibohal, Ng

A class of rotating solutions of Einstein's field equations including Kerr-Newman-Vaidya, Kerr-Newman-Vaidya-de Sitter, Kerr-Newman-monopole describing embedded black holes, have been derived by Ng Ibohal. The physical properties of these solutions observing the nature of energy momentum tensors and Weyl scalars describing gravitational field have been discussed. He has presented the surface gravity, entropy and angular velocity for each of these embedded black holes as they are important parameters. He has studied the Hawking's radiation and has presented various classical spacetime metrics affected by the change in the masses, describing the possible life style of radiating embedded black holes in different stages during evaporation process.

In another paper he has proposed a rotating non-stationary de Sitter solution of Einstein's field equations with a variable cosmological term. It is found that the spacetime of the rotating non-stationary de Sitter model is an algebraically special in the Petrov classification of gravitational field with a null vector, which is geodesic, shear free, expanding as well as non-zero twist. However, spacetime of non-rotating non-stationary model is conformally flat with non-empty space. This work has been done with L. Dorendro.

Jotania, Kanti and Ramesh Tikekar

The conventional approach of obtaining relativistic models of super-dense stars in equilibrium which requires a priori information of the equation of state (EOS) for its fluid content for solving the associated Einstein field equations (EFE) is not applicable for compact objects such as neutron stars, strange stars (SS), hybrid neutron stars etc. Such stars have matter with densities exceeding nuclear matter densities and no reliable information about EOS available. The interest in promoting understanding of such compact objects in the relativistic set up warrants the search for alternative approaches. With this motivation, Ramesh Tikekar and Kanti Jotania have been examining the suitability of Vaidya-Tikekar (VT) ansatz and *ansatz* similar to that, prescribing suitable geometry for the three space of the interior spacetime of a compact star. The geometrical parameters associated with the models obtained in this way have been found linked with mass, mass to size ratio, the density variation and the central matter densities of the configurations. This approach suggests that the geometric considerations would provide deeper insight for the spacetime structure of compact stars and the EOS of their matter content. The study of gravitational collapse of spherical distribution of matter with such compact objects has the final outcome and the collapse of such object to black holes when their equilibrium is lost, will be topic of interesting investigations.

Tikekar and Jotania have studied the models of compact stars like SAX (J1808.4-3658), Her. X-1 etc. obtained by using an *ansatz*, similar to that of VT, prescribing pseudo-spheroidal geometry for their interior spacetimes. The physical viability of the models of this class has been investigated by them using numerical procedures and the EOS of the fluid content of the models studied has been found to admit linear forms under suitable approximate procedures.

Finch and Skea had obtained a two parameter class of relativistic models of relativistic stars, critically examined their physical relevance and discussed their suitability for neutron star interpretation. Tikekar and Jotania observed that the 3-space of the interior spacetimes of Finch-Skea models have the geometry of a 3-paraboloid immersed in 4-dimensional Euclidean space and found that it is possible to choose the two parameters of this family of solutions as the central density of matter and the compactification parameter (mass to size ratio), constituting two physical observables characterizing the models. Their study indicates that the class of models based on the paraboloidal *ansatz* include models representing configurations less massive and smaller in size compared to neutron stars and admitting higher values for compactification factor than those of neutron stars.

It is apparent that the alternative approach is potent to provide criteria to characterize strange matter state, nuclear-density with self-bound hadronic matter at high densities : deconfined quark matter state or di-quark matter state or exotic strange matter state.

Nandi, K. K.

Kamal Kanti Nandi, along with collaborators, has been engaged in studying various aspects of classical and quantum gravity including Brans-Dicke theory. They have shown that the conformal invariance of the vacuum Brans-Dicke action can be used as a tool to rule out many newly proposed solutions. Scalar field contribution to entropy in the background of static and rotating black hole metrics has been studied using the brick wall method. A rather curious example, mainly of pedagogical interest, has also been worked out in which, they have shown how some general relativity equations can be obtained from the Newtonian theory itself.

Patil, K. D.

Vaidya solution represents null dust fluid and has been extensively used to study the formation of naked singularities in spherically symmetric gravitational collapse. Husain solution can be considered as a generalization of Vaidya solution and has been used as the formation of black hole with short hair. K. D. Patil and U. S. Thool have investigated the nature of the singularities arising in the gravitational collapse of Husain spacetime and shown that under certain condition on the mass function, strong curvature naked singularities do form in this collapse. What will be the final outcome of the collapse, which is not spherically symmetric? Must non-spherical collapse produce a black hole? Unlike the spherical symmetric case, very little is known about the cosmic censorship in non-spherical collapse. Patil and Thool have shown that the non-spherical gravitational collapse of asymptotically anti-de-Sitter Husain solution leads to the formation of a naked singularity, while the collapse in a cosmological solution proceeds to form a black hole.

Ray, Saibal

Einstein-Maxwell field equations corresponding to higher dimensional description of static spherically symmetric spacetimes have been solved by Saibal Ray in collaboration with Sumana Bhadra and G. Mohanty. Electromagnetic mass models are proved to exist in higher dimensional theory of general relativity corresponding to charged dust distribution. Along with the general proof, a specific example is also sited as a supporting candidate.

Saibal Ray, in continuation of $(n+2)$ dimensional spacetimes, studied the above problem under two specific set of conditions, viz., (i) $\rho \neq 0$, $\nu' = 0$, and (ii) $\rho = 0$, $\nu' \neq 0$, where ρ and ν represent the mass density and metric potential. The solution sets thus obtained, satisfy the criteria of being electromagnetic mass model such that the gravitational mass vanishes for the vanishing charge density σ and also the spacetime becomes flat. Physical features related to other parameters also have been discussed.

Einstein-Maxwell spacetime also has been considered by Saibal Ray in collaboration with Basanti Das, Subharthi Ray and Farook Rahaman in connection to some of the astrophysical solutions as previously obtained by Tolman (1939) and Bayin (1979). The effect of charge inclusion in these solutions has been investigated thoroughly and also the nature of fluid pressure and mass density throughout the sphere have been discussed. Mass-radius and mass-charge relations have been found out for various cases of the charged matter distribution. Two cases are obtained where, perfect fluid with positive pressures give rise to electromagnetic mass models. The stability conditions have been investigated for all these Tolman-Bayin type static charged perfect fluid solutions in connection to the stellar configurations.

Srivastava, D. C.

D.C. Srivastava is investigating the various methods of getting exact solutions for Plane Symmetric Static Perfect Fluids (PSSPF). The motivation of this work is the remark made in this context by Stephani et al. in their recent book.

"Using (15.51), many static solutions could be obtained from the vast number of known spherically symmetric solutions given in § 16.1, but so far this method has not been exploited."

The key point is the equation (15.51),

$$2GL_{,xx} = LG_{,xx}$$

$$x = \begin{cases} r^2, & k = 1 \\ r, & k = 0 \end{cases}$$

where k is the curvature of orbit S_2; its value 1 represents the spherical symmetry and zero the plane symmetry. This equation represents the pressure isotopy condition. The metric of the space-time is group theoretical approach may be expressed collectively as

$$ds^2 = L^{-2}(r)\big[R^2(r)\{(dx^1)^2 + \sum^2(x^1,k)(dx^2)^2\} + dr^2 - G^2(r)dt^2\big] \quad (1)$$

$\sum(x^1,k) = (Sinx^1, x^1)$ for $k = 1, 0$, respectively.

This equation has been obtained for spherical symmetry by Kustaanheimo and Quist as early as 1948 and needs to be studied in depth. The exact solutions for SSSPF distributions have been studied for more than four decades. Recently, a couple of review articles relating to them have appeared in literature where, the symmetries of the equations to be solved are exploited to provide the general techniques and the classification scheme.

Classical and Quantum Cosmology

Banerjee, Narayan

Narayan Banerjee has studied various possibilities for explaining the present acceleration of the universe. He has investigated scalar field cosmologies with a trigonometric potential, a complex scalar field and also a scalar field with a possible transfer of energy with matter. He has also studied the role of curvature in driving the acceleration of the universe.

Chakraborty, Subenoy

Cosmological solutions in the background of Randall-Sundrum brane-world-type-scenario have been evaluated by S. Chakraborty, B. C. Santra and N. Chakravarty. They have studied the Bianchi V spacetime model in the background of a 5D bulk having non-vanishing Weyl tensor with a viscous fluid as matter content and have investigated the physical properties of these solutions.

Chandra, Deepak

Deepak Chandra has continued his study on the dark energy problem in cosmology. It is believed that the scalar field models play an important role in describing the current observations, which indicate that our universe is accelerating due to the presence of a matter component with negative pressure like the cosmological constant. Deepak Chandra has been exploring the different dark energy models and their equations of state. Also, he has been investigating the cosmological evolution of different fields and potentials like scalar fields, phantom fields, Chaplagyn gases, etc. and exploring their impact on the future evolution of our universe.

Debnath, U.

U. Debnath, in collaboration with S. Bhanja and S. Chakraborthy has considered a decaying cosmological constant, and particle production in an adiabatic process have been considered as the sources for the entropy for anisotropic model of the universe with constant energy per particle. The model with non-flat universe and can describe the evolution of the universe from radiation era to ΛCDM model, but beyond radiation in the past is not describable by the model - probably some quantum theory is necessary to describe the evolution of the early era.

It is well known that when a fermion propagates in curved spacetime, its spin couples to the curvature of background spacetime. This interaction for neutrinos propagating in early curved universe could give rise to a new set of dispersion relations and then neutrino asymmetry at equilibrium. They demonstrate this with the Bianchi models, which describe the homogeneous but anisotropic and axially symmetric universe. If the lepton number violating processes freeze out at 10¯37 second when temperature GeV, neutrino asymmetry of the order of 10¯10 can be generated. A net baryon asymmetry of the same magnitude can, thus, be generated from this lepton asymmetry either by a GUT B - L symmetry or by the electro-weak sphaleron processes, which have B + L symmetry.

Jain, Deepak

Over the last years, a considerable number of high-quality observational data have transformed radically the field of cosmology. Results from distance measurements Type Ia supernovae combined with CMB observations and with dynamical estimates of the quantity of matter in the universe suggest that the universe is spatially flat and undergoing a phase of acceleration. An energy component with negative pressure, widely referred as dark energy, was invoked to explain the apparent acceleration of the universe. However, it is also well known that effects arising from new physics can mimic the gravitational effects of dark energy through modification of the Friedmann equation. Deepak Jain along with Abha Dev, and Jailson S. Alcaniz have investigated the observational consequences of a flat matter dominated and accelerating/decelerating scenario, in which this modification is given by $H^2 = g(\rho_m, n, q)$. The $g(\rho_m, n, q)$ is a new function of energy density ρ_m, the so called Cardassian models. They mainly focus attention on the constraints from the CLASS lensing sample on the parameters n and q that fully characterize the models.

They also considered the possibility of discriminating between the various evolving dark energy models and ΛCDM models using the joint analysis of CLASS statistical sample and Sne gold sample.

Deepak Jain and Abha Dev have also discussed the observational constraints on various parameterizations of dark energy from age measurements of old high redshift objects.

Assuming general time dependence of the scale factor, $R \propto t^{\alpha}$, Deepak Jain, Abha Dev and G. Sethi have investigated observational constraints on the dimensionless parameter, α. The model is consistent with the latest Sne Ia "gold" sample and accommodates a very high old high-redshift quasar, which the standard cold-dark matter model fails to do.

John, Moncy V.

Using an improved version of the model-independent, cosmographic approach, Moncy V. John has addressed an important question relevant to cosmology: Was there a decelerating past for the universe? To answer this, the Bayes's probability theory was employed, which is the most appropriate tool for quantifying our knowledge when it changes through the acquisition of new data. The cosmographic approach helps to sort out the models, in which the universe was always accelerating from those in which it decelerated for at least some time in the period of interest. Bayesian model comparison technique is used to discriminate these rival hypotheses with the aid of recent releases of supernova data. It was also attempted to provide and improve another example of Bayesian model comparison, performed between some Friedmann models, using the same data. The conclusion, which is consistent with the earlier results, is that the apparent magnitude-redshift data alone cannot discriminate these competing hypotheses.

Pandey, Sanjay K.

It is widely accepted that the large scale structures (of the universe) originated from initially small density fluctuations were a Gaussian random field. Non-Gaussian features arise as the fluctuation growth through the process of gravitational instability. Quantifying these at the various stages of the growth is expected to yield a significant amount of information. The three-point correlation function and its Fourier transform, and the bispectrum, are the lowest order statistics sensitive to non-Gaussian features. Sanjay Pandey, in collaboration with S. K. Saiyad Ali and Somnath Bharadwaj, has investigated the possibility of using the fluctuations in the redshifted 21 cm radiation from the neutral hydrogen (HI) to detect the bispectrum arising from nonlinear gravitational clustering and from nonlinear bias. They have calculated the expected signal for GMRT and have found that the magnitude of the signals from the bispectrum is comparable to that from the power-spectrum, allowing a detection of both in roughly the same integration time. They have also considered the possibility of using observations of the bispectrum to determine the linear and quadratic bias parameters of the HI at high redshifts, this having possible implications for the theories of the galaxy formation.

Paul, B. C.

B. C. Paul has studied the evolution of a flat Friedmann- Robertson-Walker universe in a higher derivative theory in the presence of a variable cosmological constant considering a varying Newton's gravitational constant. He obtains new cosmological solutions, which are important for model building. A cosmological model is permitted in which gravitational constant varies initially, which, however, attains a constant value at a later epoch.

Following Bousso and Hawking, the probability for quantum creation of a universe with a pair of primordial black holes (PBH) in a modified theory of gravity with higher order terms in addition to an inverse power of scalar curvature $(dR - 1)$ introduced by Carroll, et al. has been evaluated by B. C. Paul. He obtains a class of instanton solutions, which permit quantum creation of an inflationary universe. He notes that the probability of a pair of primordial black holes suppressed with a positive cosmological constant when $0 < d < L2$. It is also found that unlike Bousso and Hawking, de Sitter instantons without PBH and with PBH are permitted even in the absence of a cosmological constant (L) in the modified gravity.

Pradhan, A.

A. Pradhan, together with G. S. Khadekar and M. R. Molaei has studied the multi dimensional cosmological implications of a decay law for cosmological term Λ. It is widely believed that a consistent unification of all fundamental forces in nature is possible within the spacetime with an extra dimension beyond those four observed so far. The absence of any signature of extra dimensions in current experiments is usually explained for compactness of extra dimensions. It has been observed that such models are compatible with the results of observations, and cosmological term Λ gradually reduces as the universe expands. Kaluza-Klein type R-W cosmological models with dynamical cosmological term $\Lambda(t)$ have been studied by A. Pradhan, Saeed Otarod and co-authors. The proper distance, the luminosity distance-redshift, the angular diameter distance-redshift, and look back time-redshift for the models are presented in the frame work of higher dimensional spacetime.

Models with dynamic cosmological term $\Lambda(t)$ becoming popular as they solve the cosmological constant problem in a natural way. Generation of Bianchi type V cosmological models with varying cosmological term Λ are studied by A. Pradhan, together with A. K. Yadav and L. Yadav. They have also studied spatially flat bulk viscous LRS Bianchi type I cosmological models with a time dependent displacement field within the frame work of Lyra's geometry. These type of studies may be relevant for inflationary models. A. Pradhan, G. P. Singh and co-authors have studied causal bulk viscous LRS Bianchi type I models with variable gravitational and cosmological "constant".

The occurrence of magnetic fields on galactic scale is a well-established fact today and their importance for a variety of astrophysical phenomena is generally acknowledged. E. R. Horrison has suggested that magnetic field could have a cosmological origin. As a natural consequences, we shall include magnetic fields in the energy momentum tensor of the early universe. Anisotropic magnetic field models have significant contribution in the evolution of galaxies and stellar objects. In this context, a detailed study of relevant theories has been undertaken by A. Pradhan, Purnima Pandey and K. K. Rai by considering plane-symmetric and Bianchi type I metric.

Ray, Saibal

Saibal Ray and Utpal Mukhopadhyay are continuing the investigations on dynamical models of the cosmological term Λ in connection to the dark energy theory.

Choosing a phenomenological model of Λ, viz., $\Lambda \sim \dot{H}$, it has been shown by Ray and Mukhopadhyay that this model of Λ is equivalent to other three types of Λ, $\Lambda \sim (\dot{a}/a)^2$, $\Lambda \sim \ddot{a}/a$, and $\Lambda \sim \rho$. Through an indirect approach, it has also been possible to put a limit on the deceleration parameter q. It has been shown that if q becomes less than -1, then this model can predict about the presence of phantom energy.

Two phenomenological models of Λ, viz., $\Lambda \sim (\dot{a}/a)^2$ and $\Lambda \sim \ddot{a}/a$ are also studied by them under the assumption that G is a time-variable parameter. Both models show that G is inversely proportional to time as suggested earlier by others, including Dirac. The models considered here can be matched with observational results by properly tuning the parameters of the models. Our analysis shows that $\Lambda \sim \ddot{a}/a$ model corresponds to a repulsive situation and hence, correlates with the present status of the accelerating universe. The other model $\Lambda \sim (\dot{a}/a)^2$ is, in general, attractive in nature. Moreover, it is seen that due to the combined effect of time-variable Λ and G the Universe evolved with acceleration as well as deceleration. This later one indicates a Big Crunch.

Seshadri, T. R

T. R. Seshadri has studied a model of scalar-tensor theory of gravitation, in which the scalar field, ϕ determines the gravitational coupling G and has a Lagrangian of the form, $\mathcal{L}_\phi = -V(\phi)\sqrt{1 - \partial_\mu\phi\partial^\mu\phi}$. This work has been done in collaboration with Sanil Unnikrishnan. It has been shown that there is a transition from an initial decelerated expansion (in the matter dominated era) to an accelerated expansion phase at the present epoch. Using observational constraints, it has been shown that the effective equation of state today for the scalar field turns out to be $p_\phi = w_\phi\rho_\phi$, with $w_\phi = -0.88$ and that the transition to an accelerated phase happenned at a redshift of about 0.3.

Singh, G. P.

Exact solutions of general theory of relativity for spatially homogeneous spacetimes belongs either to the Bianchi types or to Kantowski-Sachs spacetimes. The isotropic Friedmann-Robertson-Walker (FRW) models are special cases in the Bianchi classification. The Bianchi models can be coupled to any gravitational theory. A number of authors have investigated the nature of cosmological solutions for homogeneous Bianchi type models. As dissipative effects, including bulk and shear viscosities play a very important role in expansion of the universe, cosmological models with dissipative process have been extensively investigated in an attempts to explain the formation and evolution of the early universe. Recent observations provide us an evidence that the expansion of the universe is accelerating at the present epoch. This apparent acceleration is attributed to dark energy residing in space. The literature suggests that dark energy represent approximately 70 % of the total energy density of the universe. The most straightforward source of dark energy is a cosmological constant, but a level of fine tuning necessary to make it a variable candidate is disconcerting. To explain this dark energy, another alternative Q-matter or quintessence has been introduced. This energy propose a scalar field that slowly rolls down it's potential with the key property of having a negative pressure. G. P. Singh and his coworkers have studied some Bianchi type I cosmological models with bulk viscous cosmic fluid in the presence of quintessence, cosmological and gravitational constants.

Due to the possibility of the large extra-dimensions in the brane-world models, the cosmological models of the early universe must be studied with careful consideration of the effect of the higher dimensional geometry. It has been suggested that brane-world models satisfy both recently released Supernova data sets: the Gold data and the data from the Supernova Legacy Survey (SNLS). A number of authors have studied multi dimensional cosmological models in different context. G. P. Singh and his collaborators have presented a new class of higher dimensional cosmological models . The new models obtained in these investigations generate several known models and results are well within the range of observational limits.

Galaxies and Quasars

Jog, Chanda

N-body simulations of mergers of spiral galaxies with an emphasis on the case of unequal-mass galaxies, covering the mass ratios 1:1- 10:1 was carried out by C. J. Jog. The study uses a powerful FFT code and a million particles per galaxy and includes the effects of gas, thus, the study treats realistic galaxies. It is shown that the mass ratios 1:1-3:1 give rise to elliptical-like remnants, while the ratios 4.5:1-10:1 result in peculiar, mixed systems with spiral-like mass profiles and elliptical-like kinematics. The transition between these two cases occurs over a surprisingly narrow range of mass ratios- this is important in understanding the dynamical evolution of elliptical galaxies (see Bournaud, Jog, and Combes 2005 for details).

Near-IR data for a large sample of 149 galaxies from the OSU catalogue have been Fourier-analyzed to obtain the lopsided density distribution and the potential in the disks. A large fraction (30 %) of these galaxies show significant lopsidedness. N-body simulations were carried out to identify the physical mechanism for its origin. These show that galaxy interactions can generate high amplitude of lopsidedness, however in addition asymmetric gas accretion onto a galaxy is required to explain all the statistical results observed, see (Bournaud, Combes, Jog and Puerari 2005) for details.

Warps are a common feature of spiral galaxies, and a large fraction of these are now known to be asymmetric. C. J. Jog and K. Saha propose and work out the mechanism for the origin of the asymmetric warps as arising due to a dynamic superposition of m = 1 modes (s-shaped warps) and m =

0 modes (bowl-shaped distribution). The results, naturally, explain the wide variety of asymmetry in warps that is observed, including the extreme cases of U-shaped and L-shaped warps, see Saha and Jog (2006) for details.

Khare, Pushpa

Pushpa Khare along with her collaborators studied a large sample of strong Mg II absorbers in the spectra of QSOs, from the Data Release 1 of the Sloan Digital Sky Survey. They constructed absorber rest frame composite spectra of various sub-samples of their sample of 809 QSOs, to determine the average abundances and average dust extinction in the QSO absorbers. Their study produced definite evidence for the presence of dust in the intervening absorbers; QSOs with absorbers in their spectra are at least three times more likely to be highly reddened as compared to QSOs without any absorbers in their spectra. No evidence was found for the 2175. $\dot{A}$ bump in the average extinction curves. The abundances in the absorbers were found to decrease with increasing reddening in the sub-samples. Close to solar abundance was found in the sub-sample of 698 absorbers with average H I column density of 10^{20} cm $^{-2}$.

She along with her collaborators observed several low redshift Damped Lyman Alpha systems (DLAs) in the spectra of QSOs, with the Very Large Telescope and an equal number of DLAs with the Magellan telescope (both in Chili) with the aim of determining the metal abundances in these systems.

Pandey, S. K.

As a part of ongoing programme on multiwavelength surface photometric studies of early-type galaxies in collaboration with A. K. Kembhavi and others, deep CCD images of several early-type galaxies were obtained in BVRI broad bands and H-alpha using the 2m Himalaya Chandra Telescope (HCT) of IIA during 2005-06. Preliminary reduction of the data has been completed, and detailed analysis of properties of dust in the sample galaxies is in progress. Samridhi Kulkarni, a research student at Raipur, is also involved in this programme. Huge amount of data from a variety of sky surveys are available for further investigation. It is planned to make use of multiwavelength data on galaxies from LFC fields as apart of the collaboration. The LFC survey has been done using the Large Format Camera on 200-inch Hale telescope at Mount Palomar Observatory. The field diameter of detector is 25 arcmin with pixel scale of 0.36ṕer pixel after rebinning. Twelve fields, each of area 0.25 square degree is observed to cover 3 square degree area of the sky. The data of LFC survey is not public, but it has been made available to the group at IUCAA by one of the original observers, namely, Ashish Mahabal to make use of the data for further detailed study on galaxies in individual frames. Preliminary study of LFC fields shows that all the images of these fields have excellent signal to noise ratio. It is possible to reach up to 0.3% of the sky level to study the fainter parts of the galaxy and still have significant signal-to-noise ratio. The multi-wavelength study of statistically significant sample of detected objects from this survey can address wide variety of issues in Astronomy and Astrophysics, including galaxy formation and evolution, AGN structure and demographics, etc. After preliminary data reduction, Sextractor(software for source extraction) has been used for the detection, classification of sources and final preparation of the catalogue of galaxies. Detailed analysis of individual galaxies from the catalogue of galaxies, thus, made is in progress. Laxmikant Chaware, a research student at Raipur, is involved in this programme.

Pandey, U. S.

U. S Pandey has worked on properties of self-gravitating gaseous disks which are presumed to be the precursor of massive dark objects (MDOs) as the energy source at the centres of active galactic nuclei (AGNs) and quasars. They obtain mass-density ρ and surface mass-density σ in terms of particular solution of a linear differential equation of third order. Gravitational potential W and rotational velocity V_c profiles are also obtained. They have calculated and plotted the variation of ρ, σ, W and V_c with distance from the centre. They have discussed the perturbation of self-gravitating gaseous disk to test their stability. An instability criterion has been derived for a stratified plane disk with uniform σ and Ω. This is found in agreement with Toomre instability criterion under short wave radial gravitational perturbation. For a typical Jeans disk, they have shown that critical Toomre wavelength is larger than the radius of the disk implying unstable radial perturbation for practically all wavelengths. Surface mass-densities are shown to be crucial to the evolution of gaseous disks. They have established inter-relationship between various σ. It is shown that degeneracy near the mid-plane, turbulent velocity and surface temperature are effective parameters to determine the nuclear burning phase of the disk.

Patil, M. K.

Recent imaging surveys using ground-based as well as space telescopes across the electromagnetic spectrum have amply demonstrated that early-type galaxies, ellipticals (E) and lenticulars (S0), harbour multi-phase ISM. In particular, deep CCD imaging and their careful analysis have revealed that a large fraction ($\sim$ 80%) of E-S0 population contain dust features in a variety of morphological forms. Study of physical properties of dust in extragalactic environment provides useful clues, not only for understanding origin and fate of the dust in external galaxies but also for the subsequent evolution of the host galaxies. M. K. Patil, along with S. K. Pandey, A. K. Kembhavi, U. C. Joshi, and D. K. Sahu, has carried out multicolour (optical as well as near-IR) surface photometric analysis of a large sample of early-type galaxies with an objective of studying dust extinction properties in extragalactic environment. Extinction curves derived for the sample galaxies run parallel to the galactic extinction curve implying that properties of dust in extragalactic environment are quite similar to those of the Milky Way, and are characterized by a parameter Rv, ratio of total extinction in V band to the selective extinction in B and V bands. However, the Rv values are found to be function of the dust morphology as well as environment of the host galaxy, in the sense that galaxies with well defined dust morphologies exhibit smaller Rv values. Dust masses derived from optical extinction are found to be an order of magnitude smaller than those derived from the IRAS flux densities, indicating that a significant fraction of dust intermixed with stars remains undetected by the optical method. As regard to the issues of origin of dust in early-type galaxies, they have determined the injection rate of dust into the ISM by mass-losing evolved stars and have observed that the dust mass quantified through optical extinction exceeds the total dust accumulated by a galaxy over its lifetime. This in turn implies that at least a part of dust have been acquired by the galaxies through a merger like event. They are also involved in studying morphological and spectral properties of the hot gas heated to temperatures $\sim 10^6$ - 10^7 K in the early-type galaxies selected from different environments. This involves analysis of the high resolution X-ray images from Chandra and XMM-Newton space missions. From this analysis, they have derived diffuse emission maps and spectra of the hot gas alone, excluding resolved point sources. Fits to the surface brightness profiles and spectra yielded in determination of the surface density, length scale and temperature of the hot gas. This study has also resulted in to the detection of a number of point sources in the E/S0 galaxies, majority of which are LMXBs with X-ray luminosities spanning a wide range from 10^{37} erg/s to over 10^{39} erg/s.

Compact Objects and X-ray Binaries

Ambika, G.

In collaboration with R Misra, A K Kembhavi and K. P. Harikrishnan, the various types of long term variability exhibited by the blackhole system GRS 1915+105, have been explained by G. Ambika in terms of deterministic nonlinear behaviour in the presence of inherent stochasticity. The results of the study indicate that the equations governing the magneto-hydrodynamic flow of the inner accretion disk can be approximated by a small number of nonlinear differential equations.

Chattopadhyay, Tanuka

Tanuka Chattopadhyay, in collaboration with Rajeev Misra and Asis Kumar Chattopadhyay has applied a new clustering technique to the BATSE current GRB catalogue data to obtain the optimum number of coherent groups of GRB and have found three classes as found by Balastegui, et al. (2001) and Mukherjee, et al. (1998). The longest duration class has mean duration 63.1 sec and intermediate duration class has mean duration 15.85 sec, which is longer than found by Mukherjee, et al. (1998). The longest duration class is most inhomogeneous with $< V/Vmax > \sim 0.15$, being the deepest population with $z_{max} \sim 10$. They have also carried out discriminant analysis to verify the level of efficiency of the above clustering and the value of the proportion constant (at 95% confidence) is found to be 0.954. They have used the HETE2 GRB with known red shifts and have carried out clustering of the BATSE data with respect to two parameters logT90 and logFt into three classes and calculated the probabilities of HETE 2 GRB's with known red shifts in falling these three classes and tried to calculate their luminosities and original distances. They are developing a Dirichlet Process of Mixture Modelling for a second way of classification of the GRB's of BATSE data to verify whether the "three class classification" is compatible with the present classification scheme.

Dey, Jishnu and Mira Dey

In the past, the Equation of State (EOS) was derived for strange quark matter using the phenomenological Richardson potential which contained one single scale parameter for asymptotic freedom (AF) and confinement. It is important to use different AF and confinement scales and with these baryon masses and magnetic moments are rechecked. With self consistent Debye screening length a refined EOS is derived at different temperatures and the Mass - Radius of the compact object calculated. Density dependent quark masses lead to decoupling of $f_p i$.

The compact stars showing broad absorption band and the gravitational red shift lines are strange star candidates. We have noted that in one star both are simultaneously observed.

Surface tension in a body is due to the inward force experienced by particles at the surface and usually gravitation does not play an important role in this force. But in compact stars the gravitational force on the particles is very large and the surface tension is found to depend not only on the interactions in the strange quark matter, but also on the structure of the star, i.e. on its mass and radius. Indeed, it has been claimed recently that 511 keV photons observed by the space probe INTEGRAL from the galactic bulge may be due to e+ e annihilation, and their source may be the position cloud outside of an antiquark star. Existence of stars may explain the antibaryon deficit of the universe. So, the surface tension for such stars must be high enough to allow for survival of quark/antiquark stars born in early stages of the formation of the universe. We studied the surface tension of strange stars and the Newtonian and general relativistic contributions to the same.

It appears that there is a genuine shortage of radio pulsars with surface magnetic fields significantly smaller than $\sim 10^8$ Gauss. It has been proposed that pulsars with very low magnetic fields are actually strange stars. It is shown that superconducting super fluid of ud, ss quark pairs in a rotating strange star will permit a low magnetic field.

Work is done in collaboration with Siddhartha Bhowmick, Subharthi Ray, Sushan Konar, Monika Sinha and Raka Dona Ray Mandal, Manjari Bagchi and Ashik Iqubal.

Singh, K. Y.

Three distinct categories of blackhole systems have been identified as of today : X-ray binaries, Active Galactic Nuclei (AGNs), Ultra-luminous X-ray sources (ULXs). X-ray binaries are black holes and neutron star systems which are accreting matter from a regular star. They constitute the brightest class of X-ray sources in the sky. AGNs are also strong sources of high energy photons generated by viscous dissipative processes in the accretion disk of a super massive blackhole. The most salient properties of AGNs are high luminosity (10^{40} - 10^{46} ergs/s) and strong optical emission lines with large line widths (upto 10^4 km/s). X-ray binaries and AGNs have been well studied in the last few decades and their exact nature, to a large extent, are well understood. On the other hand, ULXs, the third black hole system, which are basically non-nuclear, very bright, point like sources with intrinsic luminosity ($> 10^{39}$ ergs/s) have been discovered recently (by the Einstein satellite in 1989). Due to lack of combination of a very good angular resolution and moderate spectral resolution of detectors in the past X-ray missions, the ULXs were poorly studied in the last 10-15 years. With X-ray missions like ROSAT, ASCA, XMM and most importantly with the advent of CHANDRA, the ULXs have become much more revealed and their properties are being studied more rigorously. However, the study of the ULX may be said to be still in the infant stage as their physical properties are not yet clearly confirmed and still in controversy. They neither belong to the stellar mass ($< 20 solarmass$) X-ray binaries nor they belong to super massive black hole systems (10^6-10^{10} solar mass) AGNs. The ULXs are associated with 'intermediate mass black holes' (IMBHs) (10^2-10^5 solar mass) which represent the missing component of the above BH mass spectrum. Therefore, it is expected that a detailed study of the properties of the ULXs and also a comparative study of the spectral properties of the ULXs, X-ray binaries and AGNs will enhance our understanding of these BH-systems as a whole. K. Y. Singh and some of his Ph.D. students are presently studying some ULXs using the Chandra ACIS galaxy data available in the CXC archive. The data reduction and analysis are being carried out using CIAO3.2 and LHEASOFT5.3.1 tools. The spectral fitting package XSPEC11.3.1 has been used for spectral analysis of events.

Besides working on data analysis and interpretations of ULXs archive data, K. Y. Singh is presently engaged in an ongoing DST project entitled "Development of Stellar Photometric Observation Facility at Manipur University". With the assistance of a JRF of the project L. Dharendra Singh, Singh has successfully established an astronomical observational facility at Manipur University equipped with a Celestron CGE 9.25" telescope and a SBIG ST-7XME Camera Delux Package. Using this observational facility, Singh has carried out three outreach programmes for school and college students. Singh and his JRF of the project are also presently taking observations on some variable stars. Two Ph.D. students A. Senorita Devi and I. Ablu Singh working under the supervision of Dr. Singh have already passed the IUCAA-NCRA one year graduate Pre-Ph.D. programmes held at IUCAA, Pune.

Stars, Stellar Systems and Interstellar Medium

Chandra, Suresh

Suresh Chandra and his research group is actively involved in radiative transfer calculations in asymmetric top molecules. They want to use the anomalous absorption - absorption against the cosmic microwave background, as a technique for identification of molecules in cool cosmic objects. The kinetic temperature in cool cosmic objects may not be sufficiently high to generate the emission spectrum of the molecules present there. However, these molecules may be identified in absorption, as their lower energy levels are always populated. Some transitions in asymmetric top molecules, may show anomalous absorption. In the case of the anomalous absorption, the brightness temperature of radiation is smaller than that of the cosmic microwave background, 2.73 K. The idea behind identification of as many molecules as possible, is to have better understanding about the physical conditions prevailing in the cool cosmic objects and to know more about the chemical reactions going on there. The group has investigated a number of molecules and further work is in progress.

Chattopadhyay, Asis Kumar

Asis Kumar Chattopadhyay has carried out an objective classification for the globular clusters in our Galaxy, LMC and M31 by a new method of cluster analysis (CA) and the set of parameters for this method has been selected through an objective process, Principal Component Analysis (PCA). The clusters exhibit multimodality, unlike bimodality found in many spirals and giant ellipticals with respect to only one parameter colour/metallicity. This work was done in collaboration with Tanuka Chattopadhyay.

Pandey, S. K.

A detailed analysis of photometric data on five suspected active stars, namely, HD85945, HD20277, HD39286, HD88639, and HD191179 selected on the basis of their intense X-ray emission, were carried out. Low-resolution spectroscopic observations in H-alpha and CaII Infrared triplet(IRT) of these stars carried out using HCT 2m telescope at Hanle during 2004-2005 for seven nights were also analyzed. All stars except HD85945 are found to exhibit significant photometrc variation typical of spotted stars. All except HD85945 are also found to show variable absorption/emission in H-alpha and CaII IRT region. This together with the observed photometric variation seen in the four of the five stars suggest that these are variable stars possibly belonging to the class of chromospherically active stars. This work formed a part of Ph. D. thesis of Sudhanshu Barway, who has submitted his thesis in December 2005 to the University.

Rastogi, Shantanu

The mid IR emission features at 3050, 1610, 1310, 1165 and 885 cm^{-1} (3.28, 6.2, 7.7, 8.6 and 11.2 μm) are ubiquitous in a variety of interstellar regions viz., Planetary Nebulae, proto-Planetary Nebulae, reflection Nebulae, H II regions and even in extra galactic sources. The IR features are a result of emissions from a family of Polycyclic Aromatic Hydrocarbon (PAH) molecules consisting of neutrals, cations, anions and hydrogenated/de-hydrogenated species. These Aromatic Infrared Bands (AIBs) show source to source variations in the IR bands related to the type of PAHs present in the surrounding medium. Spectral variations with shape, size and ionization state of PAHs have been studied by Amit Pathak and Shantanu Rastogi to get a better understanding of the interstellar spectra. A systematic study of several PAHs and their cations has been done using ab-initio density functional method. The variation in intensity of IR bands upon ionization is related to the change in charge distribution within the molecules. The C-H stretch intensity increases as the partial charge on the Hydrogen atoms in the PAH decreases. Theoretical IR spectra for catacondensed and pericondensed PAHs in both neutral and ionic forms show that large compact PAH cations are preferred in the ISM. Study of very large PAHs (having > 30 C atoms) has been done using the High Performance Computing facility at IUCAA. Co-added spectra of different groups of PAHs have been used to model the observed composite AIB features. More neutrals and medium sized pericondensed PAHs seem to be within the benign atmospheres around AGB stars and proto-Planetary Nebulae, while large PAH cations are probable in the harsh environments of star forming regions.

Sen, Asoke Kumar

The polarization observed for stars background to dark clouds (Bok Globules) is often used as diagnostic to study the ongoing star formation processes in these clouds. Such polarization maps in the optical were reported for eight nearby clouds

CB3, CB25, CB39, CB52, CB54, CB58, CB62 and CB246 in an earlier work (Sen et al. 2000, A&AS, 141, p175). In a recent work (Sen, Mukai, Gupta and Das 2005 MNRAS, 361, p177), the relations between this observed polarization and other physical parameters in the cloud (like temperature, turbulence, etc.) have been studied. The observed polarization does not seem to be clearly related to the dust and gas temperatures ($TdandTg$) in the cloud as expected from Davis-Greenstein grain alignment mechanism. However, the average observed polarization (pav) appears to be related to the gas turbulence V (measured by ^{12} CO line width) by the mathematical relation pav =2.95exp $(-0.24 * V)$ as derived in the present work. The possible relation between the direction of polarization vector and other physical parameters have been also studied. In order to study the spatial distribution of the degree of polarization and position angles across the different parts of the cloud, a simple model was proposed, where the cloud has been assumed to be a simple dichroic polarizing sphere and the light from the background star first passes through the IS medium and then through the cloud, before reaching the observer. The polarizing sphere contains several layers of dichoric sheets having same polarizing properties as that of IS medium. This model could successfully explain the observed polarization for the above star forming clouds.

Singh, H. P.

The Indo-US coudé feed stellar spectral library (CFLIB) made available to the astronomical community recently by Valdes, et al. (2004) contains spectra of 1273 stars in the spectral region 3460 to 9464 Å at a high resolution of 1 Å FWHM and a wide range of spectral types. Cross-checking the reliability of this database is an important and desirable exercise since a number of stars in this database have no known spectral types, and a considerable fraction of stars has not so complete coverage in the full wavelength region of 3460-9464 Å resulting in gaps ranging from a few Å to several tens of Å . Harinder P. Singh in collaboration with Ranjan Gupta and their counterparts Manabu Yuasa and N. Yamamoto, used an automated classification scheme based on Artificial Neural Networks (ANN) to classify all 1273 stars in the database. In addition, principal component analysis (PCA) was carried out to reduce the dimensionality of the data set before the spectra are classified by the ANN. Most importantly, they successfully demonstrated employment of a variation of the PCA technique to restore the missing data in a sample of 300 stars out of the CFLIB.

Sun and the Solar System

Badruddin

Badruddin and coworkers have examined galactic cosmic ray (GCR) intensity from ground-based and space-borne experiments and identified a number of transient depressions lasting several days. After classifying them into different categories, they utilized solar data, and analyzed interplanetary plasma/field data, to search for the solar and interplanetary causes of the observed depressions in GCR intensity. By examining and analyzing simultaneous variations in solar wind plasma speed, density and temperature, along with the interplanetary magnetic field, its magnitude and fluctuations in it, they have identified possible structures such as manifestations of coronal mass ejections in interplanetary space, shock/sheath regions formed due to compression of ambient magnetic field by high speed mass ejections, interaction regions formed by interaction between slow and high speed solar wind, compression region formed due to interaction of high speed streams from coronal holes with slow moving coronal mass ejections. They have studied the relationship between GCR intensity and various solar wind parameters during the passage of these structures of distant plasma and field characteristics. From their analysis they could suggest possible physical mechanisms playing major role in producing different types of depressions in GCR intensity.

Kumar, Nagendra

The heating of the solar corona by MHD waves has been investigated by Nagendra Kumar, in collaboration with P. Kumar and S. Singh. Taking into account dissipation mechanisms viscosity and thermal conduction, a general dispersion relation of fifth order for MHD waves has been derived and solved numerically. It is found that the dispersion relation results three modes namely slow, fast, and thermal. The damping of both slow and fast-mode waves depends upon the plasma density, the temperature, the magnetic field strength, and the angle of propagation relative to the background magnetic field. Slow-mode waves contribute to the heating of the solar corona, if one considers that they are generated in the corona by turbulent motions at magnetic reconnection sites. Calculations of wave damping rates determined from the dispersion relation indicate that slow mode waves with periods of less than 60 seconds damp sufficiently rapidly and dissipate enough energy to balance radiative losses, whereas the fast mode waves with periods less than 3 seconds may damp at rates great enough to balance the radiative losses in active regions. In the case of magnetic coronal loops, it is observed that slow mode waves with frequencies greater than 0.003 Hz and fast mode waves with frequencies greater than 0.28 Hz (high frequency) are needed for coronal heating and to balance the radiative losses in active regions. Nagendra Kumar along with Pradeep Kumar has studied the damping of MHD waves in solar coronal magnetic field, taking into account thermal conduction and compressive viscosity as dissipative mechanisms. The dispersion relation results into three wave modes: slow, fast, and thermal modes. Damping time and damping per periods for slow and fast mode waves determined from dispersion relation show that the slow mode waves are heavily damped in comparison with fast mode waves in prominences, prominence-corona transition regions, and corona. In prominence-corona transition regions and coronal active regions, wave instabilities appear for considered heating mechanisms. For same heating mechanisms in different prominences the behaviour of damping time and damping per period changes significantly from small to large wave numbers. In all prominence-corona transition regions and corona, damping time always decreases linearly with increase in wave number indicate sharp damping of slow and fast mode waves.

Narain, Udit

Udit Narain and his group have been carrying on research on heating of solar and stellar coronae. The latest work concerns heating of solar corona by nano- and microflares, which are explosive events of magnetic reconnection. Each event releases energy in the range 10^{22} to 1026 ergs.

They have started work on environmental effects of coronal mass ejections (CMEs) in which billions of tonnes of solar material is thrown away into the interplanetary space from the solar surface. These CMEs travel at a speed of about 300 to 2000 km/s towards earth. On reaching earth's magnetosphere they disturb the distribution of magnetic field in the earth's atmosphere. The energetic CMEs can cause power break-down in terrestrial power stations. They can damage satellites and are hazardous to humans, animals and vegetation. Thus, their study is quite important.

Prasad, Lalan

Lalan Prasad has reinvestigated the work of Narain and Kumar (1995) and overcome the inconsistencies present in it. The variation of total electrodynamic coupling efficiency E and its non-resonant component with loop length l for four different dissipation times are discussed. He also discusses the variation of resonant heating efficiency E with dissipated time for four different loop lengths. He found that there was decrease in the heating efficiency for large values of l. The variations are not so steep and large, as shown by Narain and Kumar (1995) in their figures. There is one peak in each graph however, Narain and Kumar (1995) have found two peaks. Thus, the AC component of heating plays important role for loops of lengths $l > 10^{9.25} cm$. The AC component for m = 1 is the most effective for the loop lengths $\sim 10^{9.7}$cm and the component for m = 2, 3 and 4 show peak for large value of l. The AC component of heating efficiency plays significant role for long coronal loops.

Sahijpal, Sandeep

The planetary differentiation of terrestrial planets into iron-core with silicate-mantle and silicate-crust occurred within the initial 30 million years in the early solar system. The differentiation processes initiated prior to the accretion of the terrestrial planets, while they were still in the (10-100 km sized) planetesimal stage. Based on the detailed analyses of iron and stony-iron meteorites, there is a substantial evidence to support the early differentiation of planetesimals. Heat generated due the decay energy of the two short-lived nuclides, ^{26}Al and ^{60}Fe, in the early solar system is considered to be responsible for the planetary differentiation. S. Sahijpal has performed comprehensive numerical simulations of the planetary differentiation of planetesimals undergoing a linear accretion growth. The two short-lived nuclides were considered as the heat sources. The gradual growth of the iron-core during the segregation of iron from the melting planetesimal was numerically modeled for the first time according to the thermal evolution of the accreting planetesimal. The extrusion of the basaltic melts to form a crust has been also parametrically modeled for the first time to understand the most primitive volcanic activities in the solar system. In order to have significant melting for planetary differentiation, the accretion of the planetesimal should commence within the initial couple of million years in the early solar system. Depending upon the accretion scenario and the planetary differentiation criteria, the growth of the iron-core and the silicate melting in a planetesimal can prolong for the initial 10 million years.

Sen, Asoke Kumar

In collaboration with Institute for Planetary Research, German Aerospace Centre (DLR), Berlin, some photometric observations (November 2005) were carried out with the Himalayan Chandra Telescope (HCT) under the IUCAA's guest observing programme to study the Karin cluster of asteroids. The Karin cluster is by far the youngest known family of main-belt asteroids, dating back to a collisional event only 5.8 Myr ago. The main aim of the observations include a study of trends in thermal inertia and albedo with size. This in turn will help to answer questions like : Are the distributions of sizes and albedos compatible with the Karin cluster being the result of a single catastrophic collision 5.8 Myr ago? The data are now being analysed.

Shrivastava, Pankaj K.

Pankaj K. Shrivatava and his coworkers have studied the latitudinal and longitudinal distribution of solar flare events of high importance around the sun and their effects on cosmic ray modulation. A large number of solar flares in the western hemisphere are found to be associated with Forbush decreases of cosmic rays intensity. Forbush decrease events are identified in hourly plots of neutron monitor data. Forbush decreases are transient decreases of cosmic rays. Such decreases are followed by a slow recovery typically lasting for several days. They have utilized the Coronal Mass Ejections (CMEs) data to derive their impact on cosmic ray modulation. Adopting the chree analysis of superposed epoch method, they have also studied the effects of CMEs and solar flares on geomagnetic activity for the period of solar cycles 22 and 23. The average characteristics of the diurnal and semi-diurnal anisotropy of cosmic ray intensity at realistic energies have been obtained by using data from world wide grid of neutron monitor for the period 1989 to 2003. The complex behaviour of diurnal amplitudes and time of maxima (phase) and its association with Ap index on a long-term and day to day basis have been studied. On a long-term basis, the correlation of diurnal variation with Ap index have been found to vary during the solar cycle. On a short-term basis, it has been observed that the high Ap days are usually associated with higher amplitudes with phase shifted to early hours. It is well known that one of the most dynamical feature in interplanetary space is high speed solar wind streams (HSSWS). Shrivastava has derived a significant effects of these streams on geomagnetic field variation as well as on transient decreases in cosmic rays. Relationship between cosmic ray intensity and tilt of the heliospheric current sheet has been carried out for $A > 0$ and $A < 0$ epochs of solar magnetic field for the period 1980 to 1999.

Plasma Physics

Khan, Manoranjan

Pure pair-ion plasma composed of positive and negative ions with an equal charge to mass ratio has been recently created in the laboratory. The ion thermal waves in a pair-ion plasma with equal ion-to-charge mass ratio can be modulated due to their coupling with quasistationary density perturbation. Modulated ion thermal waves in such a plasma can be localized and trapped in a self created ion density hole. This work has been done in collaboration with P.K. Shukla during the visit of M. Khan under INSA-Deritsche For Schungsgemeinschaft (Germany) exchange programme to the Ruhr Universitat (Germany).

In a dusty plasma (or complex plasma), secondary electron emission leading to the enhancement of the electron number density is an important phenomenon in astrophysical bodies, ionospheric layers, etc. The existence of the steady state for the dusty plasma is possible through compensation of ambient electron and ion density variation due to their attachment to the dust grains. On the other hand, in a dusty plasma containing neutral atoms, replenishment of such losses are likely to occur through ionization-recombination phenomena.

The effects of all these processes on dust ion acoustic wave propagation are investigated in collaboration with M.R. Gupta, S. Sarkar, B. Roy and A. Karmakar.

The role of negative ions is also an important phenomenon in a complex plasma (or dusty plasma). The dust acoustic wave propagation has been studied in a complex plasma consisting of Boltzmann distributed electrons, positive and negative ions and negatively charged dust grains when grain charge fluctuations are taken into account. The presence of negative ions is found to be an additional component, which may occur naturally or may be injected from external sources in space or laboratory plasma. The grain charge fluctuation effect is responsible for damping of dust acoustic wave in absence of negative ions. It has been observed that the negative ions significantly reduces the damping effect as well as the real frequency. The low temperature negative ions are also responsible for this reduction process. Presence of negative ions in a complex plasma also contribute to negative ion current to the grain charging mechanism. This work has been done in collaboration with M. R. Gupta, S. Sarkar, B. Roy and with the scientists of the Institute of Plasma Research, Gandhinagar.

Dynamics

Ambika, G.

G. Ambika, in collaboration with K. P. Harikrishnan, has conducted extensive studies on stochastic resonance (SR) and its characteristic features in three model systems viz., Josephson junction, bimodal cubic map and coupled map lattice. It is found that a model Josephson system can function both as bistable and threshold systems and can detect effectively subthreshold signals and composite signals with multiple frequencies under suitable tuning of input or inherent noise. That stochastic resonance can be used as a filter for multi signal inputs, which is established in the case of cubic maps also. A fundamental difference between the SR in bistable and threshold systems is that while the former transmits the constituent frequencies alone, the latter permits detection of the difference frequency also.

The different types of resonance phenomena that can occur in a coupled map lattice (CML) in the presence of noise and a sub threshold signal are analysed with an onset bisatble dynamics. In addition to the conventional SR observed in the temporal iterates, the possibility of a spatial or lattice stochastic resonance (LSR) is established in the spatial sequences along the lattice. The characterizing features in both are analysed in detail under different types of spatially varying signals, traveling waves, etc. The work is suggestive of practical applications possible in signal detection, image processing and communication networks.

Harikrishnan, K. P.

Harikrishnan, K. P., along with G. Ambika, R. Misra and A. K. Kembhavi, has done a detailed nonlinear time series analysis of the light curve from the black hole system GRS 1915+105. Using surrogate analysis and singular value decomposition (SVD) technique, they have given evidence for nonlinearity in the temporal behaviour of the black hole system.

Harikrishnan K. P. has also done some work related to the phenomenon of stochastic resonance in coupled map lattice. Along with G. Ambika and Kamala Menon, he has introduced the novel concept of "Lattice Stochastic Resonance" in coupled map lattice.

Kuriakose, V. C.

Studies on propagation of electromagnetic waves through optic fibres find very wide applications. In many situations ideal fibres are considered. P.A. Subha and V. C. Kuriakose have studied wave propagation through realistic fibres. We have considered an inhomogeneous optic fibre with frequency chirping. The wave propagation through such a fibre is studied using variational analysis and numerical methods and found that adiabatic compression of solitons can be achieved in such systems. Recently, the study of formation solitons in bulk media is gaining interests. We have also studied the case of solitons in bulk media with varying diffraction and nonliearity management using variational and numerical methods and found the conditions under which such a system can support spatial solitons. C. P. Jisha and V.C. Kuriakose have shown the existence of light bullets in a medium with cubic-quintic nonlinearity and self defocusing effect of free electrons due to plasma polymerisation using analytic and numerical methods, and light bullets find application in optical communication. The study of dynamics of Josephson junctions is a topic of interests to both theoretical as well as experimental physicists. The interaction of Josephson junctions with external fields has played important role in the development of Josephson junction and its chaotic dynamics. Chitra R. Nayak and V. C. Kuriakose have studied the effect of phase difference of the applied fields on mutually coupled Josephson junctions and found that by applying a phase difference in the driving fields, we can control chaos in Josephson junctions and also obtained the junction parameter values to achieve the same.

Mittal, A. K.

A. K. Mittal, S. Dwivedi and R. S. Yadav applied an invariant manifold technique, to obtain the return map for the maximum value of the variable x of the Lorenz model. They used this return map to derive the regime transition rules discovered empirically by them earlier. They applied the Perron-Frobenius algorithm over this return map to estimate the probability distribution for number of cycles between successive regime transitions. They also obtained this probability distribution for a forced Lorenz model that was introduced by Palmer as a conceptual model to explore the effects of sea surface temperature on seasonal rainfall.

The regime transition rules obtained by them for the Lorenz model and some other two-regime attractors had earlier led them to conjecture positive correlation between magnitudes of maximum anomaly during active rainfall spell and duration of subsequent break spells. S. Dwivedi, A. K. Mittal and B. N. Goswami analyzed several data-sets pertaining to Intra-Seasonal Oscillations and found significant positive correlation between these two variables. They also proposed a method of making extended range prediction of duration of Indian summer monsoon breaks. They further showed that a stochastically forced Lorenz model exhibits some of the salient features of Indian summer monsoon intra-seasonal oscillations.

Vishwakarma, J. P.

The study of converging shocks in a non-uniform medium is applicable to the motion of shock waves in outer layer of a star, where the density goes to zero. J. P. Vishwakarma, in collaboration with S. Vishwakarma has obtained the self-similar solution of the gas dynamic equations of strong converging cylindrical and spherical shock waves moving through an ideal gas with initial density obeying a power law. The flow behind the shock is assumed to be adiabatic. A study of singular points of the differential equations leads to an analytic description of the flow and a simple determination of the similarity exponent, which is in excellent agreement with the earlier values obtained by sophisticated analytic or numerical methods.

The problem of shock wave propagation in a dusty gas is of importance in the study of a collision flow pattern of a coma with a planet. J. P. Vishwakarma, in collaboration with A. S. Rai obtained the shock velocity and effective shock Mach number for a shock wave propagating in a dusty gas by using Whitham's rule. The initial density and temperature of the medium are assumed to be decreasing exponentially. The results are discussed for different values of mass concentration of solid particles in the dusty gas, the ratio of density of solid particles and that of initial gas at the origin, and the index of variation of initial temperature.

Theoretical Physics

Gangal, Anil

Anil Gangal together with Seema Satin and Abhay Parvate has obtained a diffusion equation on fractal curves. An equivalent of Chapmann-Kolmogorov equation was proposed, which was expanded using fractal Taylor series. It results in an equivalent of Kramers-Moyal expansion, from which Fokker-Plank equation for such curves follows. For a suitable transition probability on fractal curves, the diffusion and drift coefficients can be calculated and lead to the fractal diffusion equation. Such equations provide a framework for dealing with diffusion on fractal paths.

Gaur, Naveen

Naveen Gaur has studied the signatures of new physics in various semi-leptonic decays of B-meson. A study of purely dileptonic and radiative decay mode was carried out within the context of two Higgs doublet (2HDM) model and Supersymmetric (SUSY) model. In another work, the study of sensitivity of the position of zero of the Forward Backward (FB) asymmetries in $B \to K^* \ell^+ \ell^-$ in a model independent framework was done. Continuing the study in semileptonic B-decays, the study of CP violating signatures in $B \to K \ell^+ \ell^-$ was also carried out in a model independent fashion. In another work, he tried to constrain the possibility of lepton number violation in Little Higgs (LH) model. For this, he considered the experimental results on $(g-2)_\mu$ and $\mu^- \to e^- e^+ e^-$. The work was done in collaboration with S. Rai Choudhary, A. S. Cornell and G. C. Joshi.

Goyal, Ashok

Ashok Goyal, with S.R. Choudhury, Naveen Gaur and Sukanta Dutta has been investigating phenomena and processes likely to point towards new physics beyond the standard model. K^0-K^0 bar mass difference, lepton number violation and neutrino Majarona mass generation in Little Higgs model. Bounds on lepton number violation from neutrinoless double beta decay, meson and lepton decays, trimuon production in neutrino factory, anamolous magnetic moment of muons. In addition they have been studying the signals of LH model in gamma- gamma scattering. Triple vector-boson anamolous coupling are some other phenomenon under consideration.

Kaushal, R. S.

In the development of theoretical sciences, the use of harmonic oscillator potential (a manifestation of simple pendulum) or its variants has often become an important tool for the purposes of testing the formulated underlying theories in different fields. R. S. Kaushal has made a survey of such applications of the oscillator potential in the context of mathematical, conceptual, conventional and engineering disciplines, besides the one in mathematical physics. From the point of view of putting the available knowledge in a nut-shell, such analogous applications of the pendulum are brought together and discussed by Kaushal as an example of *structural analogy.* With a view to classifying the analogies in a philosophical domain, the concept of structural analogy is introduced by Kaushal in his earlier publications. In conclusion, Kaushal has suggested a new dimension of thinking for theoretical physicists by way of analyzing and subsequently generalizing the Chevreul's hand-held pendulum.

In another ongoing project, Kaushal, in collaboration with D. Parashar, A. K. Sisodiya and V. S. Bhasin, has also pursued his studies on nonstrange and strange diquark (dq) stars within the framework of an effective phi-4 field theory. Two-diquark interaction energies in the quark-gluon plasma are explicitly calculated within the framework of the constituent quark model and a generalized Pauli principle. Equations of state for the diquark matter for a variety of dq-dq couplings are derived and subsequently the Tolman-Oppenheimer-Volkoff equations for the masses and radii of diquark stars are solved.

Kuriakose, V. C.

The discovery made by Hawking that small black holes can radiate energy implies that black holes can exist in thermal equilibrium with a heat bath composed of quantum fields interacting with the black hole geometry. P. I. Kuriakose and V. C. Kuriakose have studied the back reaction at the cosmic horizon of Schwarzschild - de Sitter black hole in thermal equilibrium with conformal massless quantum field. They have determined the effect of back reaction by solving Einstein's field equation. They have also studied the problem by evaluating the perturbed potential in the presence of a quantum field using the Hamilton-Jacobi method and obtained stable and unstable orbits for massive and massles particles. Sini and Kuriakose have studied scattering of scalar particles by a Schwarzschild - de Sitter black hole by considering reflection of waves at the black hole horizon. Reflection of waves at the horizon may not be possible classically, but it can take place quantum mechanically.

Mukherjee, Pradip

Reparametrization invariant theories occupy a very spatial space in theoretical physics for their occurrence in string theory, general relativity and quantum gravity. From the point of view of constrained systems, such theories are categorized as already parameterized. There exists a deep connection between gauge symmetries of such theories with reparametrization invariance. This connection can be conveniently explored by an interpolating action technique introduced in recent past.

P. Mukherjee, along with R. Banerjee and A. Saha has studied a bosonic p-brane in the interpolating Lagrangean scenario. Specifically, they have demonstrated the transition to Polyakov type action from the Nambu-Goto one and investigated the connection between the gauge symmetries and reparametrization symmetries of the model. The cosmological term follows naturally in their scheme. Also, the dynamics of the structure lead to a natural emergence of the A-D-M like split of the world volume.

The main problem of present day theoretical physics is physics at the Plank scale. At such high energy, spacetime may exhibits fuzziness leading to noncommutative behaviour. P. Mukherjee with A. Saha have studied a noncommutative Chern-Simons theory using a recently proposed closed form Seiberg-Witten map. The various forms of the energy-momentum tensor have been presented. It has been demonstrated that no BPS soliton exists in the model. This analysis compliments the operator approach results for the model.

Pandita, P. N.

Supersymmetry is the only known framework, in which the Higgs sector of the Standard Model, so crucial for its internal consistency, is natural. A much favoured implementation of the idea of supersymmetry at low energies is the minimal supersymemtric standard model$\sim$ $(MSSM)$, which is obtained by doubling the number of states of SM, and introducing a second Higgs doublet to generate masses for all the SM fermions and to cancel the triangle gauge anomalies. However, the MSSM suffers from the so-called μ problem associated with the bilinear term connecting the two Higgs doublet superfields H_u and H_d in the superpotential. An elegant solution to this problem is to postulate the existence of a chiral electroweak gauge singlet superfield S, and couple it to the two Higgs doublet superfields H_u and H_d via a dimensionless trilinear term $\lambda H_u H_d S$ in the superpotential. This model, the so called nonminimal supersymmetric standard model $\sim (NMSSM)$ contains a lepton number violating trilinear superpotential coupling, which has no analogue in the MSSM with lepton number violation.

P. N. Pandita has studied nonminimal supersymmetric standard model with lepton number violation, together with M. Chemtob. This model, through a unique trilinear lepton number violating term in the superpotential, can give rise to neutrino masses. Discrete symmetries of the Z_N-type, which can allow such a lepton number violating term in the superpotential, and which satisfy the constraints of the anomaly cancellation, have been investigated. The implications of such a trilinear lepton number violating term in the superpotential for the phenomenology of the light neutrino masses and mixings have been studied in detail. Tree and one-loop contributions to the neutrino masses in this model have been evaluated. A search for possible suppression mechanism which could explain neutral leptons of large mass hierarchies with maximal mixing angles has been carried out.

Rao, Nagalakshmi

Nagalakshmi A. Rao has studied the relativistic generalization of the well-known Virial Theorem (VT) of classical mechanics, which applies to a wide variety of systems ranging from an assembly of ideal gas to a cluster of galaxies. In the outer space, often a bunch of particles collapse to form a gravitationally bound system. Using this theorem, the masses of the bound systems can be found. Infact, global properties are the very essence of Virial Theorem. Interestingly, Virial Theorem is known to have a quantum analogue. More importantly, the relativistic generalization of this theorem is interesting in itself, as it would establish a correspondence between classical physics, thermodynamics, stellar astrophysics, non-relativistic and relativistic quantum mechanics. Starting from the relativistic Hamiltonian, Virial Theorem in the standard form is accomplished, which serves as a novel and elegant approach to address bound systems.

Usmani, A. A.

The role of the strangeness degree of freedom may play a significant role in the physics of a neutron star or a hyperon star, specially in the early evolution of the star and its cooling scenario. The possible Kaon condensation has been a frontier of research due to this reason. A realistic study of an infinite-body system like a dense neutron star in the framework of many-body theories requires precise information about the baryon-baryon forces as its basic ingredients. We know that strangeness can be experimentally injected in a few- and many-body bound nuclear system through the (K^-,π^-) reaction, for example. Hypernuclei are, thus, the unique laboratory to extract precise informations about these forces. This year, a complete realistic study of the ${}^5_\Lambda$He hypernucleus has been performed using a realistic Hamiltonian and a fully correlated wave function that involves all dynamical corrrelations and the ΛN space exchange correlation. In this study, the behaviour of baryon-baryon and three-baryon forces have been thoroughly investigated. Quantum Monte Carlo methods have been implemented to study all the s-shell single- and double- hypernuclei. This would help in pinning down the strengths of the potentials, which will then be used in a microscopic study of infinite-body neutron stars.

E-Content Development

Philip, Sajeeth

Recent advances in communication opens many new avenues for modernising the conventional educational system. Modernisation does not mean replacement of existing teaching and learning methodologies. It only supplement and compliment them. While the chalk and blackboard teaching has its own merits, a lot more can be done with an additional power-point or video presentation. Recognising these possibilities, the Consortium for Educational Communication (CEC) in collaboration with HP Labs and the Inter-University Centre for Astronomy and Astrophysics (IUCAA), launched the Educentre project in 2005. The goal of the project is to develop necessary infrastructure to implement digital libraries in colleges and universities with value added electronic content. The content could be in video, audio, pdf or power-point formats.

The first installation of the Educentre was carried out on February 1, 2006 at St. Thomas College, Kozhencheri, Kerala. The installation includes a video capturing hardware that captures video telecast by the educational satellite channels on a 24 by 7 basis. Two different tools were developed for this purpose. The first one was developed by HP Labs and the second one, called Media Pipeline, was developed by Ninan Sajeeth Philip, who is also the regional coordinator for the Educentre project in the state.

Video on demand is a feature that allows different viewers to watch different video programmes on their machines simultaneously from a common server. This makes it possible for students to watch programmes of their choice without having to wait for the exact times at which they are aired by the satellite channels.

Media Pipeline is a public domain software based on ffmepeg tools. It uses a temporary ring buffer to capture and store video channels for a predefined period of time. This could be from one day to ten days. The ring buffer is called a pipeline in analogy to the water pipeline, where water entering through one end remains trapped inside the pipeline until it exit through the other end. Media Pipeline captures video from a preset channel continuously and traps it in its buffer for the predefined time. A user may view the programme or record it into his local system at any time in this predefined period by specifying the date and time of the programme he/she wants to view. Multiple users can simultaneously make demands and watch programmes of their choice on their machines simultaneously. Since the programmes aired by the satellite channels cover different subjects, this feature makes it possible for teachers and students to save time in sorting out and permanently storing programmes of their choice in parallel.

Three student projects are being carried out under the guidance of Ninan Sajeeth Philip to add more features to the Media Pipeline. They have already built a video library of about 30 hrs of video material on "Basic Mathematics", that offers a foundation course in Calculus, Algebra and similar topics for BSc students who did not study Mathematics in their plus two classes. The students projects mainly create interfaces for the data that they may be easily accessed by students without any computer knowledge. For example, one of the projects creates a web interface in PHP that interact with a MySQL database to help the student to search for video content of his/her choice in the digital library. In addition to playing the video, the database provides related text material including references to further reading.

In addition to Video content, interactive pdf documents are also developed here. A continued evaluation model is followed to monitor the usefulness of the tools. The interactive pdf document conducts evaluation by asking multiple choice questions and finally grading the student on the basis of his/her performance. It has the facility to give explanations to the wrong answers in addition to references and video content. The whole project is picking up effectively and CEC is planning to organise a state wide training program on e-content development during June 2006.

Instrumentation

Dodia, Umesh

Umesh Dodia has built low cost previewer, a unique attachment to the IUCAA CCD camera/Photometer with multi filters slider. It has a front coated flip mirror with adjustable inclination of mirror. The mirror can be locked with a button magnet. It is very robust, since it is made up of AL casting with standard brass ring threading. Observation will be carried out in near future.

Radio Astrophysics

Kumbharkhane, A. C.

A. C. Kumbharkhane is actively engaged in the field of radio astronomy. He has developed radio astronomical image processing facility in the School of Physical Sciences at Swami Ramanand Teerth Marathwada University, Nanded, with financial support from the Indian Space Research Organisation (ISRO) under the RESPOND programme. He, along with Nimisha Kantharia of NCRA, Pune, is working on the radio recombination lines (RRLs) of galactic ionized regions. As a part of this programme they have taken observation with GMRT and data analysis work is being carried out at S.R.T.M. University, Nanded. He, is collaborating with J. Bagchi (IUCAA) for investigation of Radio Halo cluster A523. They have presented the results based on this study at the 29th International Cosmic Ray Conference held at NCRA, Pune.

Srivastava, P. K.

In the neighbourhoods of young bright stars, the interstellar gas, and in particular the hydrogen, becomes ionized and gives rise to diffuse nebula or an HII region. Compact HII regions are seen to be embedded in more extended, less dense regions of ionized hydrogen and are mostly not visible in the optical region. In the radio frequency domain, thermal radiation from these compact HII regions is observed in free-free continuum. Low frequency radio astronomy, therefore, provides information about several physical properties of these HII regions such as kinetic electron temperature and emission measure. P. K. Srivasatva, in collaboration with Pramesh Rao of NCRA, has been using GMRT for observing and studying galactic HII regions. In their first detailed study of giant HII complex W51, they have found that electron temperatures in all the 11 compact components were much lower ($\leq 5000K$) than that reported by RRL studies ($\sim 10000K$). Moreover, they also inferred that 9 out of these 11 sources in W51 consist of two components, a dense core embedded into an independent hotter ionized envelope (astro-ph/0406644). In order to look into the issue of electron temperatures derived from low frequency continuum study and RRL observations, they have observed another set of 6 compact HII regions, in continuum at 235, 610, and 1420 MHz, using GMRT during summers 2005. These include 5 compact sources (G10.15-0.34, G10.30-0.15, G12.21-0.10, G23.46-0.20, G29.96-0.02) and S53 complex. All these sources are seen to have extended regions, from low resolution studies done before. The high resolution data from GMRT is under analysis and will provide useful information about the electron temperatures and the structure of these compact HII regions, i.e., whether the extended ionized regions are directly connected to respective compact sources or not.

(III) IUCAA-NCRA GRADUATE SCHOOL

Three IUCAA Research Scholars, Sunu Engineer (Guide: T. Padmanabhan), Anand Sengupta (Guide: S.V. Dhurandhar) and *late* Jatush Sheth (Guide: Varun Sahni) have defended their theses submitted to the University of Pune during the year of this Report. The abstracts of the same are given below :

(i) Phenomena in Nonlinear Gravitational Clustering

Sunu Engineer

We can lick gravity but sometimes the paperwork is overwhelming – Werner von Braun

The problem of large scale structure formation in the universe is one of the core problems of cosmology today. This thesis discusses some of the issues involved in explaining how the observed large scale structure in the universe came to be.

This thesis has two distinct parts. The first part (Chapters 1–5) discusses the issues of structure formation from the view point of standard model of structure formation. Chapter 6 discusses alternate cosmologies and structure formation scenarios in them.

In the standard approach, we will explore the problem of structure formation through gravitational clustering in the universe. The sizes of numbers involved renders a microscopic viewpoint cumbersome. We have to adopt a statistical procedure, which essentially averages over many particles and their individual behaviour to give us some entities which we shall call “particles” whose behaviour we can describe more easily. Alternatively, we can replace the discrete structure of particles by a continuum approximation, thinking of the system of particles as a continuous fluid and apply the theoretical models of fluid mechanics to describe cosmological systems. In either of the approaches, we run into a similar problem. When we frame the equations that describe the system, we find that the equation has terms, which are highly nonlinear, leading to an analytically intractable system of equations. An analytical solution to the relevant equations can be obtained only if one assumes that the system is linear, *i.e.,* one drops all the terms that are nonlinear in the parameter of interest. But the degree of nonlinearity associated with observed structures in the universe like galaxies is of the order of 10^3. Thus, we need to deal with the nonlinear terms in the equations to establish correspondence with observational results. The nonlinear terms elude a simple description, in that a general solution is not yet found. But since we have to study the behaviour of this equation at highly nonlinear regions, we try to model the behavior in a variety of ways.

1. Various approximation schemes such as Zeldovich approximation, frozen potential approximation, frozen flow approximation and adhesion approximation attempt to take us a little beyond linear theory.

2. Numerical simulation techniques attempt to integrate the equations either in terms of a particle based approach or a field based approach (or a combination of the two). N-Body simulations form the mainstay of this approach.

3. An alternate technique treats evolution in time and space as a mapping problem and tries to find an appropriate map that takes us from one point in the history of the universe to another in a global sense. Scaling laws and other ansatzes fall under this category.

In this thesis, we will be concerned with all the three approaches, but with a preferential leaning towards the second and third approaches. Herein, we explore the utility of the third method in various aspects of the study of structure formation and the insights it provides into dynamics of gravity in shaping the observed structures.

The first Chapter gives a concise overview of the background.

The Chapter titled "Nonlinear gravitational clustering: dream of a paradigm", of this thesis uses the third approach to generate nonlinear quantities from their linear theory counterparts and applies it to the question of “universal” profiles in gravitational clustering. We addressed the problem by asking the following question: Is it possible to populate the nonlinear universe with structures, such that the two point correlation function evolves as per linear theory in all regimes? We find that it is not possible to have strict linear evolution but it is possible to find functional forms such that approximate linear evolution to any desired order is possible. The earlier investigations had indicated that the evolution of density contrast can be separated into three regimes, namely, linear, quasilinear and nonlinear. We have found a functional form which evolves approximately linearly in quasilinear and nonlinear ends of the two point correlation function. It is also conjectured in this chapter that it should be possible to find basis functions which may be based on such approximately invariant forms such that the nonlinear density fields can be decoupled to a large extent if expanded in terms of these functions. We suggest that the functions that we have derived, which evolve approximately linearly in all regimes might be a good candidate for the role of "units of nonlinear universe". Another aspect of the analysis tries to discover universal aspects of the structures formed via gravitational clustering such as density profiles.

The Chapter "A formal analysis of two dimensional gravity", critically examines the theoretical framework underlying two dimensional N-body simulations. If one has to get requisite amount of dynamical range in force and mass, one requires large grids and large number of particles, which is not possible given the computing resources available. One attempts to get around this problem by trying to do the simulations in two dimensions which brings the computational requirements down by a considerable amount. So, if it is possible to extract fundamental principles which may be generalized to the case of three dimensional gravity from such simulations then they are a good way of exploring the fundamental features of gravity.

There are three ways in which we can define a two dimensional gravitational clustering scenario: (i) A set of point particles interacting by $1/r^2$ force but with a special set of initial conditions such that they are confined to a plane and have no velocity components orthogonal to the plane,(ii) A set of infinite parallel "needles" in which each particle interacts with $1/r^2$ force, but the "needles" interact with a $1/r$ force, and (iii) A description derived from Einstein's equations in two dimensions.

Approach (i) is highly contrived and we will not discuss it. The second approach based on infinite "needles" suffers from the problem of manifest anisotropy, because the universe is considered to be expanding in three dimensions, while the clustering takes place only in two dimensions. In order to explore the third approach, we developed the formal theory of gravity in $D+1$ dimensions and considered $D=2$ as a special case. The formal analysis of $D+1$ dimensional gravity led us to the general expressions for scale factor and background density in the $D+1$ dimensional universe.

Taking the usual Newtonian limit of the metric and writing down the equation describing the growth of density perturbations in the universe via a fluid approach made it possible to obtain the $D+1$ dimensional analogue of the equation describing growth of density contrast. A corresponding formula for spherical collapse model is also derived in this work. We then specialize to the case of $D=2$ and make the following observations. The linearized form of the density contrast equations only yield a constant or decaying solution.This is consistent with the result that perturbed gravitational potential does not couple to density contrast δ. The spherical collapse model solution yields a similar result in the sense that it is not possible to have a gravitational clustering model that grows in time. It is possible to obtain clustering by an *ad hoc* approach by making some assumptions but they also lead to inconsistent results in that they give rise to singular solutions for the scale factor of the universe. Thus, we conclude that the infinite "needle" based approach is the only viable way of simulating two dimensional gravity.

In Chapter "Scaling relations in two dimensions", some of the issues involved in two dimensional gravitational simulations are discussed. Nonlinear scaling relations, which have been identified in three dimensional simulations, define a mapping from initial linear theory values of two point correlation function to the final nonlinear values at a different length scale. This allows us to immediately compute the nonlinear parameter at a specific length scale, knowing the value of the linear one at some other length scale. We wish to check the theoretical prediction that similar nonlinear scaling relations hold in two dimensions. Another aspect of universal behaviour of gravitational clustering that is conjectured is called "stable clustering". This is the conjecture that at late times structures have their gravitational infall balanced by background expansion leading to a fixed profile. By applying this conjecture to the theoretical model for the NSR (nonlinear scaling relations) it is possible to derive the theoretical dependence of the NSR in two dimensions if it exists. Our conclusions regarding two dimensional gravitational clustering based on the simulations are as follows. (i) The prediction is verified and a form of nonlinear scaling relation exists for the two point correlation function in two dimensions as well. This NSR is independent of the spectrum for the spectra (power laws) considered in this study. (ii) In the quasilinear regime, the theoretical model based on infall onto peaks predicts a dependence that is confirmed by the numerical experiments. (iii) In the highly nonlinear regime, the results diverge from that predicted by the "stable clustering" hypothesis. The "stable clustering" hypothesis demands that the ratio between infall velocity and expansion velocity go to unity but we find that it is driven towards 3/4. Thus, we find that stable clustering is not a valid hypothesis in two dimensions.

The Chapter "An improved spherical collapse model", addresses the question: What happens at the late stages of clustering? The hypothesis of stable clustering asserts that at some point, the system 'virialises'. We examine this process of virialisation and stabilization in more detail by analyzing what happens to a single spherically symmetric object as it goes through the cycle of expansion and collapse. By including a term that describes the asymmetries that are generated and enhanced during collapse, we examine the final state of the system. We begin by writing a modified equation for the spherical collapse of a system,including a term, which takes into account the asymmetries that are generated during the process of collapse and we derive a functional form for this "asymmetry" term by an ansatz that this term depends only on density contrast δ. Since we have a relation connecting density contrast with the pairwise velocity function h, it is now possible to close the system of equations. We require the form of the h function before we can integrate this system of equations. By using the fact that the system must reach a constant value for h we obtain a functional form for the "asymmetry" term, which allows us to integrate the equation and analyze the collapse of a single object. This leads us to conclude that the system reaches a constant value of 0.65 times the maximum radius, which is not widely off the value of 0.5 that is usually stipulated. Thus, we demonstrate that the growth of asymmetries can be used to stabilize the collapse.

In Chapter "Structure formation in QSSC", the question of approaching the problem of structure formation from other alternate cosmological scenarios is discussed. To address this question, Quasi Steady state cosmology (QSSC) is the theme of the work discussed here. An algorithm was devised which mimicked the basic physical content of QSSC model by the following geometrical method. We generate N random points and require that in the next cycle the volume becomes eight times the initial volume (due to the expansion) and the particles generate new mass particles in their vicinity. Then we select the central volume equal to the initial volume and repeat this scale and shrink process. To apply this algorithm in the context of QSSC model, we use the fact that only a fraction of the particles given by $f = 3Q/P$, where Q and P are parameters of the QSSC model create new masses in the next generation. Consequently the scaling used is $\exp(f)$. We have succeeded in showing that this model reproduces the observed two point correlation function with a slope of -1.8. Visual analysis shows clear indication of the clustering growing and the initial smooth distribution separating into voids and clumps. This approach is characterized by the fact that clustering in this model takes place without the help of gravity, *i.e.,* gravity plays no role in inducing clustering.

The final chapter of the thesis presents the conclusions and integrated discussion based on the previous chapters.

Publication:

1. T. Padmanabhan, **S. Engineer**, *Nonlinear gravitational clustering: dreams of a paradigm*, Ap.J **493**,(1998).
2. J. S. Bagla, **S. Engineer**,T. Padmanabhan, *Scaling Relations for gravitational clustering in two dimensions*, Ap.J **498**,(1998).
3. **S. Engineer**, K. Srinivasan, T. Padmanabhan, *A formal analysis of (2+1)-dimensional gravity*, Ap.J **512**,(1999).
4. Ali Nayeri, **S. Engineer**, Jayant Narlikar and F. Hoyle, *Structure formation in Quasi Steady State Cosmology: A toy model*, Ap.J **525**,(1999).
5. **S. Engineer**, Nissim Kanekar and T. Padmanabhan, *Nonlinear density evolution from an improved spherical collapse model*, MNRAS **314**,(2000).

(ii) Efficient Data Analysis Techniques for the Extraction of Inspiraling Binary Signals

Anand Sengupta

According to Einstein's theory of general relativity, spacetime is strongly warped around compact masses. It predicts that any non-spherical dynamics associated with this mass will travel through the spacetime as tiny 'ripples' in spacetime. Although small, these ripples or gravitational waves carry information about the source and its macroscopic dynamics. Over the last 20 years or so, this theory of gravitation has been subject to and passed many tests in its weak field limit. However, the discovery of gravitational waves in flesh will be the first direct verification of its predictions in the strong field limit.

Pulsar timing experiments by Hulse and Taylor led to accurate measurement of periastron time shifts in the PSR1913+16 binary pulsar system. These matched the prediction from the theory of general relativity for energy losses due to gravitational waves (GW) to better than a fraction of a percent accuracy. This was the first strong indirect evidence for the existence of GWs. Over the last decade or so, several laser interferometric detectors such as the two Laser Interferometric Gravitational Wave Observatory LIGO detectors in the United States, GEO600 in Germany, the TAMA 300 in Japan, and VIRGO in Italy and France are being built to catch these waves in the flesh and unravel the physics of the universe encoded in them. Inspiraling compact binaries are one of the most important sources for gravitational waves in these detectors. These systems consist of two compact objects like neutron stars or black holes that inspiral into each other as they lose energy and angular momentum in the form of GW. Current observations indicate that many such systems exist in the universe with a lifetime that is significantly less than the age of our universe. This is very encouraging, because it implies that one can expect to see many such objects just before their final merger using the state of the art detectors.

An important component in the effort towards detecting gravitational waves is signal processing. This involves efficient data analysis algorithms and filter design that enable us to look for signatures of gravitational waves in the data stream of detectors. GW signals are very weak compared to the detector noise in the current generation or near future GW detectors. In this thesis, we address the problem of an efficient hierarchical search algorithm and its implementation for the detection of gravitational waves from the inspiral phase of compact binary systems. The standard strategy of signal processing for such sources is matched filtering, where one cross correlates a template waveform with the detector output. However, the template waveform is usually spanned by many parameters and one needs to discretely span the parameter space by building a template bank. The brute force implementation of matched filtering, involves hundreds of thousands of template, which can become prohibitively expensive even on modern clusters of computers and one usually ends up sacrificing some of the parameters, such as the spin, in order to carry out the search. A computationally efficient implementation of matched filtering is needed in order to free up the computational resources so that the full set of astrophysically relevant parameters of the search can be included and that the overwhelmingly large data sets generated by the detectors can be analsysed in real time.

Our method of implementing the matched filtering idea is summarized briefly: we consider two hierarchical layers of template banks. The first layer samples the parameter space more coarsely than the other, and is treated as a trigger generation layer. The key new idea over an earlier proposal of hierarchical search (Mohanty and Dhurandhar, 1996) is the introduction of coarse time-sampling of the data in the trigger stage.

The goals of this thesis are as follows:

1. The main goal of the thesis is to reduce the computational cost of the online search for the GW from non-spinning inspiral compact binaries by using an efficient search strategy. This is achieved by extending the hierarchical templated search to three parameters: the two masses and the time of arrival. We call this the Extended Hierarchical Search (EHS).

2. In order to achieve (1), two template banks are constructed on the parameter space. One that coarsely samples the parameter space (trigger bank) has a low threshold on signal to noise ration. Candidate events from this bank are followed up with a second template bank that has a higher template density in its local neighbourhood. The formulation of this problem as well as the anlaysis is the main thrust of the thesis.

3. To implement the EHS as a stand-alone code and establish its validity against synthetic chirp signals injected in Gaussian noise.

4. To implement the code as a parallel data analysis pipeline on the LIGO Data Analysis System (LDAS) and establish its validity against real data from LIGO detectors.

The overall structure of the thesis is as follows:

In Chapter 1, we briefly review the status of gravitational wave astronomy from a historical perspective. We start by noting that traditionally, the pursuit of astronomy has been through images of the universe in electromagnetic radiation at different frequencies. Since gravitational waves are generated by an altogether different mechanism, they carry a completely different (and complementary) set of information about the sources that emit them. We enlist the differences between these two different approaches of astronomy. We review the theory of gravity a la Einstein in the linearised domain that leads to the standard wave equation for the propagation of small metric perturbations in a flat Minkowski spacetime. We review the effect of such waves on test particles. We also build up a case for the strongest sources of gravitational waves to be of astrophysical origin and then on to enumerate a host of such cosmological scenarios that can generate gravitational waves. We summarise the various experimental efforts towards gravitational wave detection by briefly summarizing the construction details of bar and interferometic detectors, and the latest status of their experiments and results. Gravitational waves interact very weakly with matter and their detection requires special data analysis techniques, and we review a variety of signal processing methods used for different kinds of sources.

In Chapter 2, we examine in detail the model of coalescing compact binary objects, that is believed to be one of the most important sources for laser interferomettic detectors. Two neutron stars/black holes spiral-in together as they lose energy through gravitational radiation culminating in their coalescence. Although, it is hard to mathematically predict the exact form of the waves just prior to the coalescence, it is possible to work out the time evolution of phase of the gravitational waves emitted from such systems in the inspiral phase as a perturbation series, within the framework of general relativity to sufficiently good accuracy. The total energy in the inspiral phase is significant, because the stars release a lot of their potential energy over a few minutes before the final plunge. The last few minutes of the inspiral lie within the sensitive band of the the detector and due to its accurate modeling, matched filtering techniques can be used to optimally extract the signal.

Chapter 3 is an overview of the statistical theory of signal detection. We start by glossing over some of the basics of random processes and their statistical properties. We review linear filtering techniques for signal detection, their construction of linear filters, the maximum likelihood method, and the Neyman Pearson criteria for constructing decision surfaces. The standard results are derived from Gaussian noise. In this context, we discuss the noise features of LIGO detectors and qualitatively remark about its non-stationary and its non-Gaussian features. We review the calculation of the construction of an optimal linear filter, that maximizes the signal to noise ration. For Gaussian stationary noise, the form of the matched filter resembles the signal and its Fourier transform is equal to that of the signal weighted by the power spectral density of the detector noise.

In Chapter 4, we formulate the problem of the Extended Hierarchical Search (EHS). The usual (flat) search involves cross correlating the detector output with hundreds of thousands of templates spanning a multi-dimensional parameter space, which is very expensive computationally. A faster implementation algorithm devised by Mohanty and Dhurandhar, prescribes a hierarchy of templates over the mass parameters, which speed up the procedure by about 25-30 times. It should be noted that this factor does not take into account the boundary effects of the parameter space of the curvarture of the signal manifold and is obtained by assuming Gaussian noise in the data stream. We describe the Mohanty-Dhurandhar scheme here and argue that a further reduction in computational cost is possible if we extend the hierarchy paradigm to an extra parametrer, namely, the time of arrival of the signal. In the first stage, the chirp waveform is cut-off at a relatively low frequency, allowing the data to be coarsely sampled leading to cost saving in performing the FFTs. This is possible, because most of the signal power is at low frequencies, and therefore, the advantage due to hierarchy over masses is not compromised. Results are obtained for spinless templates up to the second post-Newtonian (2PN) order for a single detector with LIGO I noise power spectral density. We estimate that the gain in computational cost over a flat search is about 100, which is about a factor of four over the previous less sophisticated hierarchical scheme.

In Chapter 5, we report the feasibility of the EHS by examining various implementation aspects in detail. We investigate the performance of the new two step hierarchical search algorithm for detection of gravitational waves from compact inspiraling binarie. Here the first stage is coarsely sampled in time, while retaining the earlier advantage of hierarchy of templates over the mass parameters. The noise power spectral density used is that for initial LIGO. We give a detailed scheme for template placement in the trigger state of the hierarchical search. This takes into account the boundary effects and the rotation of the templates. Because of these effects, i.e., templates flowing out of the deemed parameter space and marginal oversampling to account for rotation, the gain factor is reduced to 60. We also clearly outline methods to set up thresholds at the two levels based on probability arguments. The calculations of false alarm probabilities and detection probabilities follow from a basic assumption of Gaussianity and wide sense stationarity of the noise in the gravitational wave detectors. We perform Monte Carlo simulations to validate our results. We present a clustering tool based on the time of arrival (impulse time) of the candidate events. We also describe the implementation of a spatial clustering method in order to cluster putative events in mass parameters at the intermediate level of the hierarchical search and detail its use in the pipeline. The two clustering tools are often used in conjunction in the EHS pipeline.

In Chapter 6, we give the details of the construction of the EHS parallel data analysis pipeline with the LIGO Data Analysis System (LDAS) framework. We start with a review of LDAS and its capabilities. We discuss the design from the general consideration of (a) the requirements of our parallel pipeline and (b) the design constraints from LDAS baseline itself. We give the details of the construction of data conditioning, construction of filter banks, matched filter, clustering events, identifying triggers and communicating them to a database system. The flowchart of the pipeline is presented. We have adopted and improved upon several existing module in the LIGO Algorithm Library (LAL) codebase such as template placement, finding trigger events, etc. We present timing results for the actual implementation of the EHS pipeline and find that the computational gain factor in carrying out the EHS search is a factor x 4-5 over the flat search. This is however not optimal but here, we do not pursue this point further. The reduction in the gain factor is due to the non-Gaussianity of the noise that nearly nullifies the advantage due to the hierarchy on mass parameters. Optimising the code over mass hierarchy should lead to higher gain factors. The advantage due to down-sampling is independent of the noise statistics and is, thus, likely to be retained at the end of the pipeline. Over time, as the detectors become better behaved, one expects to regain the advantage due to mass hierarchy as well.

In Chapter 7, we describe the performance of the EHS pipeline on gravitational wave data. We consider, (a) mock data that consists of synthetically generated Gaussian noise coloured by the expected power spectral density in LIGO interferometers, and (b) the real LIGO playground data from the second science (S2) run. We test our pipeline against hardware injection S2 data. We also present the performance of the pipeline on a subset of the LIGO second science run data to validate the code, and discuss issues related to tuning the various parameters of the pipeline for optimal performance such as SNR (p) and x2 cut. We also present the results of a Monte Carlo chirp injection assuming uniform distribution of sources on this data set, in order to test the efficiency of the pipeline.

Chapter 8 is a summary of the main results of the thesis.

(iii) Issues in Gravitational Clustering and Cosmology

Late Jatush Sheth

The present era marks a remarkable milestone in the history of cosmology. While values of the cosmological parameters have been obtained to a great precision through measurement of microwave background anisotropies (e.g., COBE, BOOMERANG, WMAP) and type Ia supernovae, dedicated telescopes have been yielding information about the distribution of galaxies going back in time to when the universe was only a fraction of its current age. These observations allow us to understand the history of the universe. We have recently witnessed the culmination of one of the two most ambitious surveys - the 2 degree Field Galaxy Redshift Survey (2dFGRS). It maps out the 3 - dimensional distribution of galaxies over 1500 steradians of the sky going as deep as 600 Mpc*. As a result we know the 3 - dimensional locations of a quarter of a million galaxies. Another even more ambitious survey, the Sloan Digital Sky Survey (SDSS) is underway, and when completed in a few more years, it would have covered a quarter of the sky and would give us positions of a million galaxies.

Thus, the time is ripe enough to confront predictions for large-scale structure (LSS) arising from theoretical models, with observations. This thesis reports the development of a unique methodology, which will help the cosmology community in comparing theoretical predictions of LSS with observations in a detailed and reliable manner.

The LSS data from either numerical experiments or observations consist of a large number of galaxies distributed over a cosmic volume, with mean inter-galactic separation of $\tilde{5}$ Mpc. Before comparing theory with observations, we first need to quantify the basic facts concerning LSS. The traditional way of doing this has been to utilize the two-point correlation function and its Fourier-space counterpart, the power spectrum. It turns out, however, that quantifying LSS using the 2-point correlation function alone can result in a considerable information loss. For example, the correlation length-scale for galaxies is estimated to be $\tilde{5}$ Mpc, signifying that the galaxy-distribution is highly clustered compared to one that is random. But this information is of little help in understanding the existence of large-scale superclusters 50-100 Mpc in length as well as large voids, which exist in the universe which reflect the fact that the underlying density field is quite non-Gaussian. It is now widely believed that the non-Gaussian features in the LSS formed as a result of the gravitational clustering of a density field, which was initially distributed in the manner of a Gaussian random field (GRF). Evidence of Gaussian initial conditions come primarily from observations of cosmic microwave background (CMB). Gravitational clustering is characterised by the transfer of power from larger to smaller scales, which leads to phase-coupling between different Fourier wavemodes. Although, the two-point correlation function is sufficient do describe the properties of a GRF, the density field which we see in the universe today is significantly non-Gaussian. To fully specify its statistical properties, one in principle requires to know the entire hierarchy of correlation functions. However, the task of estimating n-point correlation functions is highly cumbersome and offers limited physical insight into the gravitational clustering process. Hence, the need for alternative statistics, which would be more effective in quantifying LSS, is highly essential.

Minkowski Functionals (MFs) provide us with the needed alternative to traditional approach of utilising correlation functions. This is chiefly due to two reasons:

MFs have been shown to depend on the entire hierarchy of correlation functions of a system of N points.

MFs give us physically relevant interpretation involving geometry and topology of the LSS. Thus, for example, in 3-dimensions, there are 4 MFs namely, (1) Volume V, (2) surface area S, (3) integrated extrinsic curvature C, and (4) genus G.

The first three MFs tell us about the geometry of the surface (such as an isodensity contour), and the fourth MF conveys information about the connectivity (topology) of the density field.

An added advantage of utilising MFs is in their ability to quantify the morphology of LSS. As first evidenced by the famous CfA-slice and later confirmed by slices of LSS from deeper redshift surveys (2dFGRS and SDSS) and N-body simulations, the LSS is rich in texture. Its visual impression is that of filaments and sheet-like structures running through space, separated by large, empty and quasi-spherical regions-voids. The LSS often reminds us of the web of cosmic spider, a reason why it is dubbed as the Cosmic Web of Cosmic Froth. The problem of quantifying our visual impression of LSS has been pursued for a long time, and pattern-specific statistics have been found to be preferable over the traditional n-point correlation functions. In this regard, Shapefinders, a set of morphological statistics derived from MFs, provide us with an excellent probe of the shapes and sizes of coherent large-scale superclusters and voids. Thus, by using MFs in conjunction with Shapefinders, we can systematically compare cosmic web due to two or more theoretical models and can point out the relevant differences between models. Thus, the MF-based approach of quantifying LSS provides us with an efficient way to compare the theoretical models with the observations.

This thesis is chiefly devoted to the accurate estimation of MFs for cosmic density fields. The power and promise of this method is illustrated by applying it to a class of N-body simulations and to mock galaxy catalogues.

The last part of the thesis concerns the analysis of the distribution of galaxies in the Las Campanas Redshift Survey (LCRS). The survey consists of 6 quasi 3-dimensional slices containing about 25,000 galaxies with a depth similar to that of 2dFGRS. The issue of the scale of homogeneity of the universe has been addressed using data from these slices. In addition, the size of the longest coherent superclusters has also been derived. These results are reported in the thesis.

The overall structure of the thesis is as follows:

Chapter 1 briefly summarises the observational evidence for LSS and the properties of the supercluster-void network in the universe. We discuss the importance of various statistics including the n-point correlation functions in quantifying the LSS and the role these play in interpretation of cosmic data sets. This is motivated by summarising the current status of our knowledge about bias between baryonic and dark matter. Minkowski Functionals are be introduced and their expected utility in quantifying the LSS is stressed. MFs can also be used to independently study the morphology of the large-scale superclusters and voids. The related morphological measures, the Shapefinders, are introduced. Finally, an overall layout of how the MFs can be used to confront various models with each other are presented.

Chapter 2 is devoted to the techniques developed in this thesis for determining the

MFs. Minkowski Functionals are geometric and topological measures, and for a scalar field (for example, the cosmic density field) in 3-dimensional space, the four MFs are defined on a 2-dimensional surface which could represent, say an isodensity contour. Thus, in order to estimate MFs, one first needs to have a mathematically robust prescription with which to define an isodensity contour for a chosen threshold of density. Further, this prescription is to be complemented by an algorithm which enables us to compute MFs for the resulting surface defined at this threshold.

This thesis reports a unique method, which unites both the above aspects into a software called SURFGEN (short for "surface generator"). SURFGEN accepts at its input a density field defined on a cubic grid, and builds a surface for an overdense (underdense) region with respect to a user-specified threshold of density. SURFGEN simultaneously computes MFs for that surface. Such a surface could refer to overdense regions including clusters and superclusters of galaxies and to underdense regions (voids). Thus, SURFGEN enables us to study superclusters and voids individually as well as the entire supercluster-void network.

This chapter describes in detail the methodology and algorithms, which form the foundation of SURFGEN. This is followed by test of SURFGEN, which serve to illustrate its accuracy.

Chapter 3 is devoted to a comprehensive morphological study of LSS resulting from three rival cosmological models. An important test for statistical diagnostics of LSS is that they should be capable to discriminate between rival theoretical models of structure formation. This chapter is devoted to MF-based comparison of three rival cosmological models, and SCDM, γCDM and ΛCDM. It is shown that MF's for the three models are considerably different and hence, their MFs can distinguish between rival structure-formation models. Further, the MFs are used to glean information about relative shapes and sizes of superclsuters occurring in the density fields corresponding to the three cosmological models. Thus, this chapter provides valuable insight into the morphology of LSS. Earlier in this chapter we have given deeper insights into the morphology of the cosmic web resulting from the ΛCDM model. Properties of both superclusters and voids are quantified using MFs. This analysis provides precious information, the first of its kind, about the shapes and sizes of voids which may conceivably refer to the real universe.

There is ample observation evidence to suggest that the dark matter is almost 10 times as abundant as the baryonic or visible component of the universe. Furthermore, dark matter is believed to be collisionless and to interact only through gravity. For this reason, the clustering of dark matter is very well understood theoretically, and gravitational clustering in dark matter has been simulated to great precision using cosmological N-body simulations. However, galaxies are composed of baryons and it is still a subject of some debate as to how galaxies form and evolve together with the evolving dark matter. Most theoretical studies assume that baryons follow dark matter on large scales, i.e., on the scales of superclusters. However, on smaller scales, it is not clear how the galaxies may be distributed relative to the dominant dark matter component. In the absence of a complete understanding of baryonic physics, one can try and derive the *galaxy distribution* from the (simulated) dark matter distribution using a well-motivated ansatz. Such an ansatz is expected to provide the observed bias between the dark matter and galaxies, and to satisfy observational constraints on the galaxy-distribution such as the two-point correlation function and the power spectrum.

Chapter 4 reports the analysis of mock SDSS *galaxy catalogues* constructed from two rival cosmological models, γCDM and ΛCDM. For both models, *galaxies* are selected as biased tracers of the underlying dark matter mass in such a way that the resulting galaxy distributions reproduce the observed two-point correlation function and the power spectrum of galaxies derived from the APM galaxy-catalogue.

Because mock catalogues of both γCDM and ΛCDM have identical 2-point correlation functions and power spectra, discrimination between these models is an excellent challenge for new statistical diagnostics like MFs.

In this chapter, we compare 10 realizations of γCDM mock SDSS catalogues with a given realization of its ΛCDM counterpart. We show that MFs are very well constrained statistics and are remarkably different for the two models. We further note an interesting effect of bias. A scale-dependent bias is found to lead to different clustering properties for the galaxies compared to the underlying dark matter-distribution. The effect is such that the dark matter distribution due to γCDM is less clustered compared to its ΛCDM counterpart, whereas the galaxy-distributions show a completely reverse trend, i.e., γCDM galaxy distribution is found to be more clustered compared to the ΛCDM galaxy distribution. Thus, MFs help us to gain deeper insight into clustering properties of the galaxies, an effect which would have been otherwise missed because the galaxy-catalogues share the same 2-point correlation functions. We do however stress that a relatively simple treatment of having a scale-independent uniform bias should be complemented by more thorough treatment, which incorporates complex physics of galaxy formation in preparing galaxy catalogues before confronting our theoretical models with observations.

A general impression of the large-scale structure is that of a percolating web of galaxies. Are the superclusters of galaxies *actually* so long as they percolate the entire available volume of the universe? Or is it that the cosmic web arises because of a chance alignment of superclusters of much smaller size?

The two-point correlation function of galaxies fluctuates around zero beyond about 20 Mpc. But we do see structures spanning across much longer length scales. Clearly, detection of the longer structures can be attributed to non-zero higher order correlation functions and correlations among phases. Much like in the case of 2-point correlation function, we can assign an effective length to all the correlation functions, beyond which their contribution is negligible. A situation may be envisaged wherein, there is a maximum length-scale in the cosmic density field beyond which the phase correlations are negligibly small. Naturally this length-scale refers to the largest coherent structures in the universe. Further, the universe can be interpreted as composed of representative volume elements of this size. Thus, this scale is also a scale of homogeneity.

In Chapter 5, we report measurement of the scale of homogeneity, and of the size of the longest superclusters using 6 slices of the Las Campanas Redshift Survey. Here, we have adopted an MF-based morphological shapefinder, *filamentarity* to measure the shapes and sizes of structures. Further, we have employed a statistical method of *Cosmic Shuffle* to establish the scale of homogeneity. This chapter discusses the method employed in our analysis and presents the main results of this exercise.

Finally, Chapter 6 presents the conclusions of the thesis and offers an integrated discussion based on the previous chapters.

(IV) PUBLICATIONS

By IUCAA Academic Staff

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

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(c) Books

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(d) Supervision of Thesis

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Vishwakarma, J. P. (2005) A study of shock and detonation waves in non-ideal gases, D. D. U. Gorakhpur University, Ph.D. thesis of *Vinai Chaube*.

Vishwakarma, J. P. (2005) A study of shock propagation in conducting and non-conducting gases, D. D. U.Gorakhpur University, Ph.D. thesis of *Anil Kumar Maurya.*

(e) Research Projects

Chandra, Suresh, Radiative transition probabilities and anomalous absorption by molecules in cool cosmic objects' from the Department of Science and Technology, New Delhi

Chandra, Suresh, Anomalous phenomena in C3H and C3D cyclic molecules' from the Indian Space Research Organisation, Bangalore.

(f) Talk

Goyal, Ashok (2004) Astroparticle Physics, Plenary talk given at XVI DAE High energy Symposium held at Saha Institute of Nuclear Physics, Kolkata.

(V) PEDAGOGICAL ACTIVITIES

(a) IUCAA-NCRA Graduate School

Sanjeev Dhurandhar
Methods of Mathematical Physics I

Ajit Kembhavi
Electrodynamics and Radiative Processes I

Ranjeev Misra
Electrodynamics and Radiative Processes II

T. Padmanabhan
Extragalactic Astronomy I

A. N. Ramaprakash
Astronomical Techniques I

R. Srianand
Galaxies : Structure, Dynamics and Evolution

Tarun Souradeep
Methods of Mathematical Physics II

(b) University of Pune

M.Sc. (Physics)

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 and K. Subramanian
Astronomy and Astrophysics I

M.Sc. (Space Sciences)

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

(c) Supervision of Projects

Joydeep Bagchi

Viral J. Parekh, M.Sc., Fergusson College, Pune
The study of nonlinear dynamics and chaos through electronic circuits

Nikhil Pawar, B.Sc., Fergusson College, Pune
The nature of Jovian decametric radio emissions and their corelation with Io.

Siddharth Hegde, B.Sc., Fergusson College, Pune
The invisible Sun: Observation and analysis of solar radiation at radio region.

Nikhil Pawar, B.Sc., Fergusson college, Pune
(Joint IUCAA/NCRA VSP/VSRP Project)
The study of 21 cm hydrogen line spectrum from Milky Way galaxy.

Jaydeep Belapure, B.Sc., Fergusson College, Pune
(KVPY Project)
Study of meteor showers through scater of FM radio station signals from ionization trails

Satyajit Chavan, SRTM University, Nanded
Training in GMRT observations and data analysis
(Long term collaborative project)

Sanjeev Dhurandhar

K. Thorat, VSP 2005
General relativity and gravitational waves

S. Das, M.Sc. Univ. of Pune
Gravitational Waves

For a batch of four school students
Trigonometry: applications to astronomy

Ajit Kembhavi

Anushyam Mohan, JNCASR, Bangalore
Photometry and galaxy luminosity functions

Pratamesh Shenai, VSO 2005, COEP, Pune
Shapes of the Galaxies.

Vinu V., M.G. University, Kottayam
Cluster of galaxies.

Harsha Naik, B.V. Bhoomaraddi College of Engg. and Tech., Hubli
VOPlot.

Abdul Rauf, B.V. Bhoomaraddi College of Engg. and Tech., Hubli,
VOPlot.

Anjali Chordia, IUCAA, Pune
Pulsar catalogue.

Abhilash Mishra, Fergusson College, Pune
Planets.

Tarun Souradeep

Himan Mukhopadhyay, IUCAA graduate school project
Cosmic spectroscopy of CMB correlation patterns.

Sharanya Sur, IUCAA graduate school project
Cosmological inflation and generation of perturbation.

Yashar Akrami, M.Sc. thesis, Sharif University of Technology, Iran
Primordial perturbations as an observational probe of inflation.

Ehsan Khourchi, M.Sc. thesis, Sharif University of Technology, Iran
CMB anisotropy in multiply connected universes.

Tuhin Ghosh, VSP student, MSc. Indian Institute of Technology, Kharagpur
Unveiling the hidden patterns in the cosmic microwave background anisotropies.

Tuhin Ghosh, MSc. thesis, Indian Institute of Technology, Kharagpur.
Cosmic microwave background anisotropies in a Bianchi universe.

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Detecting symmetries in CMB maps.

Ranjeev Misra

D. Aarthi, VSP 2005
Galactic center electron-positron annihilation.

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Models of universe in Newtonian cosmology.

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A. N. Ramaprakash

A. Shukla (Pune University)
Wavefront aberration from defocussed images.

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

V. S. Shaiju, Mahatma Gandhi University, Kerala
Cryogenic stepper motors.

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

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

Varun Sahni

Maqsuda Afroze, MSc project
Basics of dark energy.

R. Srianand

Mudit Srivastava ,
IUCAA-NCRA graduate school project
Time variability of associated absorption lines.

K. Subramanian

J. Sunil Kumar, VSP 2005
Galactic dynamo.

(d) Supervision of Thesis

T. Padmanabhan (Guide)
Sunu Engineer
Phenomena in Nonlinear Gravitational Clustering.

Sanjeev Dhurandhar (Guide)
Anand Sengupta
Efficient Data Analysis Techniques for the Extraction of Inspiraling Binary Signals.

Varun Sahni (Guide)
(Late) Jatush Sheth
Issues in Gravitational Clustering and Cosmology.

(VI) COLLOQUIA, SEMINARS, ETC.

(a) Colloquia

Atish Dabholkar: *Going beyond Bekenstein and Hawking (black hole entropy in string theory),* April 13.

Anvar Shukurov: *Prehistoric demography and the spread of the neolithic: Models based on radiocarbon dates,* April 19.

Sumit R. Das: *Gravity, holograms and matrices,* June 27.

Somak Raychaudhury: *The largest structures in the universe and their dynamical effect on us,* July 7.

Tom Gehrels: *Our natural inheritance and global responsibility,* October 19.

Kameshwar Wali: *Bose and Einstein, and the discovery of their statistics,* November 28.

Reza Tavakol: I*nflation, oscillating universes and loop quantum cosmology,* March 13.

(b) Seminars

Anvar Shukurov: *Measuring interstellar current helicity in supernova remnants,* April 7.

T. Padmanabhan: *Subtle is the malice of the Lord - A new perspective on gravity,* April 20.

Vikram Soni: *Neutron stars (perhaps magnetars) from a single field theory,* April 28.

Prasad Subramanian: *Combining visibilities from the GMRT and the NRH: High dynamic range snapshot images of the solar corona at 327 MHz,* April 28.

Sandeep Sahijpal: *Magnetic flaring and the production of short-lived nuclei in the early solar system,* May 12.

Chanda J. Jog: Vertical scale height distribution of stars and gas in a galactic disk, May 18.

Arif Babul: *The evolution of the intracluster medium within the hierarchical model for structure formation,* June 22.

Mohammad Sami: *Accelerated expansion and cosmological relevance of scaling solutions: Brane worlds, tachyons, phantoms, cosmic doomsday and all that,* July 1.

Saeed Otarod: *A discussion on the devised new method for solving nonlinear partial differential equations,* July 22.

S. Mukherjee: *The emerging universe in Starobinsky model,* July 27.

Sudipta Sarkar: *Quantum field theory in collapsing spacetime,* July 29.

Sharanya Sur: *Cosmological inflation and generation of primordial perturbations,* July 29.

Mudit Kumar Srivastava: O*utflows from quasars: The za = 2.082 absorption system towards quasar TOL 1037 – 2703,* July 29.

Himan Mukhopadhyay: *Cosmic spectroscopy on CMB correlation patterns,* August 4.

Maulik Parikh: *A matter of Inertia: Mach 2,* August 8.

Rosanne di Stefano: *Mesolensing: Studying nearby dark and dim stars with gravitational lensing,* August 9.

Urjit A. Yajnik: *Magnetic domain walls of relic fermions as dark energy,* August 25.

Prathamesh M. Shenai: *Shapes of the galaxies,* September 5.

Sanjit Mitra: *CM/GW Beams,* September 26.

Andrea Tartari: *The cosmic microwave background frequency spectrum:Open questions and experimental problems,* October 3.

Andrea Tartain: *Coherent radiometers:A physical perspective,* October 6.

Abhishek Rawat: *Morphological analysis of intermediate redshift luminous compact galaxies using the HST/ACS GOODS survey,* October 10.

Divakara Mayya: *M82:A spiral galaxy in formation,* October 14.

Alain Kerdraon: *The Nancay radioheliograph: Recent results and future developments,* November 3.

Arnab Kumar Ray: *A time-dependent perturbative study of the shallow water hydraulic jump,* November 8.

Dmitry Sokoloff: *The maunder minimum and the solar dynamo,* December 8.

Amir Hajian Forushani: *Cosmology through CMB anisotropy,* December 9.

Rita Sinha: Parameter constraints using WMAP data, December 10.

Juergen Ehlers: *The Einstein Hilbert debate,* January 2.

Rob Crittenden: *Probing dark energy with CMB anisotropy,* January 13.

Badri Krishnan: *The trapped region of a blackhole spacetime*, January 17.

Amrit Lal Ahuja: *A novel technique of pulsar DM estimation using the GMRT,* January 26.

Emmanuel Rollinde: *Lithium between big bang nucleosynthesis POP III and VMPHS,* January 27.

Jishnu Dey: *Strange star hypothesis and its implication for nuclear particle phenomenology,* February 3.

Francois Hammer: *Evolution of the Tully-Fisher relation and scenarios of galaxy evolution,* February 8.

J.E. Pringle: *Spinning black holes- Which way do they point?*, February 10.

Y.P. Viyogi: *Experimental search for quark gluon plasma and Indian contribution,* February 14.

Jayanti Prasad: *Gravitational collapse in an expanding background and the role of substructure*, February 16.

Uma P. Vijh: *(i) Photoluminescence by interstellar dust, and (ii) A look at the dust characteristics in the LMC using the Spitzer Space Telescope*, March 2.

K. Nakamura: *Second order gauge invariant perturbation theory,* March 13.

H. Maeda: *Final fate of the gravitational collapse in Einstein-Gauss-Bonnet gravity, March 16.*

U. Miyamoto: New stable state of inhomogeneous black string, March 16.

(VII) TALKS AT IUCAA WORKSHOPS OR AT OTHER INSTITUTIONS

(a) Seminars, Colloquia and Lectures

Naresh Dadhich

Detecting extra dimensions with gravity wave spectroscopy: The black string brane-world, Informal Discussions Group Meeting, NCRA, Pune, April 29.

Why Einstein?, Garware College, Pune, May 23.

General relativity, VSP, Pune, IUCAA, May 24, (2 lectures).

Science and society, Tata Research Development and Design Centre, Pune, May 28.

Why Einstein [Had I been born in 1844!]?, Master's Resource Training Programme organized by Rashtriya Vigyan Evam Prodyogiki Sanchar Parishad, Masobra, Shimla, June 1.

Why Einstein [Had I been born in 1844!]?, Master's Resource Training Programme organized by Rashtriya Vigyan Evam Prodyogiki Sanchar Parishad, Guwahati, June 15.

Science and society, Master's Resource Training Programme organized by Rashtriya Vigyan Evam Prodyogiki Sanchar Parishad, Guwahati, June 16.

Why Einstein [Had I been born in 1844!]?, Saha Institute of Nuclear Physics, Kolkata, June 17.

From Newton to Einstein, Refresher Course, Smt. Kashibai Navale College of Engineering, Pune, June 28.

Why Einstein? Master's Resource Training Programme organized by Rashtriya Vigyan Evam Prodyogiki Sanchar Parishad, Mumbai, June 29.

Why Einstein?, Second Saturday School Students Programme at IUCAA, Pune, July 9.

Why Einstein?, [in Hindi] Second Saturday School Students Programme, IUCAA, Pune, July 9).

Why Einstein [Had I been born in 1844!]?, Master's Resource Training Programme organized by Rashtriya Vigyan Evam Prodyogiki Sanchar Parishad, Bangalore, July 13.

IUCAA : An Experiment in propagation of astronomy in Indian universities, The 9th Asian-Pacific Regional IAU Meeting [APRIM 2005], Indonesia, July 29.

Why Einstein?, (One-day seminar on Astrophysics for teachers and students, Christ College, Irinjalakuda, Kerala, August 6.

Why Einstein? (IUCAA sponsored workshop on "Exciting Astronomy : From Stars to the Universe", University of Calicut, Calicut, Kerala, August 7.

Had things been right?, Colloquium organized by Tata Institute of Fundamental Research, Mumbai in memory of the Late Professor A.K. Raychaudhuri, Mumbai, August 10.

Why Einstein? Jadavpur University, Calcutta, August 16.

Gauss-Bonnet gravity, S.N. Bose Centre for Basic Sciences, Calcutta, August 17.

Why Einstein?, International Year of Physics, Fergusson College, Pune, September 8.

Challenges of a knowledge society, Crompton Greaves Management Development Centre, Mulshi, September 17.

Why are there only four basic forces in nature?, University of Cape Town, South Africa, September 22.

On the Gauss-Bonnet gravity, Physics Department, University of Cape Town, South Africa, September 23.

Curvature driven acceleration of the universe, Physics Department, University of Cape Town, South Africa, September 23.

Science and society, iThemba Laboratory, Somerset West, South Africa, September 24.

Why Einstein [Had I Been Born in 1844!]?, A plenary talk delivered at the Einstein Centennial Meeting at the University of Kwazulu-Natal, Durban, South Africa, September 25.

Why Einstein [Had I Been Born in 1844!]?, University of Kwazulu-Natal, Durban, South Africa, September 30.

Why Einstein [Had I Been Born in 1844!]?, University of Witwatersrand, South Africa, October 3.

Why Einstein [Had I been born in 1844!]?, University of South Africa, October 4.

Why Einstein [Had I Been Born in 1844!]?, Young Astronomers' Meet 2005, IUCAA, November 29.

Why Einstein [Had I Been Born in 1844!]?, Department of Physics, University of Mumbai, December 1.

Why Einstein [Had I Been Born in 1844!]?, National Conference on "Exciting Physics of this Decade", Department of Theoretical Physics, University of Madras, Chennai, December 2.

Why Einstein [Had I Been Born in 1844!]?, Consortium for Educational Communication, New Delhi, EDUSAT Network Programme, December 5.

Why Einstein [Had I Been Born in 1844!]? First Annual Convocation of the Indian Association of Physics Teachers, Kolhapur, December 11.

Raychaudhuri and his equations, International Conference on "Einstein's Legacy in the New Millennium", Puri, December 19.

Tribute to Professor A.K. Raychaudhuri, School on Cosmology and the Very Early Universe, IUCAA, December 26.

Why Einstein [Had I Been Born in 1844!]? Indian Institute of Astrophysics, Bangalore , February 1.

Principle of universality in science, Workshop on "Foundations of Science", National Institute of Advanced Studies, Bangalore, February 2.

Why Einstein [Had I Been Born in 1844!]?, Nehru Planetarium, Mumbai, February 4.

Topics in gravity, (2 talks) Workshop on "Geometry, Gravity and Cosmology" at Sardar Patel University, Vallabh Vidyanagar, Gujarat, February 16.

Science and society, National Conference on "Rational Thinking and Development of Scientific Temperament in Indian Masses", Bharatiya Jain Sanghatana College, Wagholi, Pune, February 25.

On Gauss-Bonnet gravity, Workshop and Discussion Meeting on Black Holes, Spacetime Singularities and Cosmic Censorship, Tata Institute of Fundamental Research, Mumbai, March 5.

On Gauss-Bonnet geometry, 12th Regional Conference on Mathematical Physics, National Centre for Physics, Islamabad, March 31.

Sanjeev Dhurandhar

Gravitational waves, (two talks), IUCAA Refresher Course and VSP, May-June .

Mapping the gravitational wave sky with LIGO, LIGO Science Collaboration Meeting, M. I. T., Boston, U. S., November 20.

The quest for gravitational waves, XIV th National Space Science Symposium, Vishakapatnam, February 9.

LISA data analysis, Osaka National University, Osaka, Japan, February 22.

Ranjan Gupta

Dust in astrophysical environments, Department on Astronomy, Osmania University, Hyderabad, August 4.

Spectroscopy, Workshop on Observing Projects with Small Telescopes, IUCAA, Pune August 30.

Telescopes and back-end instruments, at the National Level one-day Seminar on Observational Astrophysics, Department of Physics, University of Kalyani, Kalyani, September 27.

Earth's atmosphere, telescopes and effects , Introductory Workshop: Sun and Stars, St. Xavier's College, Kolkata, November 22.

Astronomical spectroscopy, Introductory Workshop: Sun and Stars, St. Xavier's College, Kolkata , November 23.

Interstellar and other dust models, SNBNCBS, Kolkata, November 24.

Cosmic dust and modeling, Department of Physics, Patna University, Patna, November 26.

Dark molecular clouds, Science with HCT workshop, IIA, Bangalore, January 21-22.

Commissioning of IUCAA 2 meter telescope and future opportunities for universities, NSSS-2006 workshop, Waltair University, Vishakhapatnam February 11.

Effects of Earth's atmosphere on astronomical observations and new generation telescopes, Workshop on Astronomy and Astrophysics, Department of Physics, Assam University, Silchar, February 21.

Earth's atmosphere and new generation telescopes and dust models and interstellar medium, S.N. College, Purulia, February 23.

Earth's atmosphere and its effects on astronomical observations and modern telescope technologies and new era, Space Meteorology workshop for IAF officers, Department of Atmospheric and Space Sciences, University of Pune, Mar 1-14.

Application of artificial neural network to stellar spectra and TAUVEX data, TAUVEX Science Meeting, IIA, Bangalore, March 21-23.

Dust and its role in astrophysics, IPR, Ahmedabad , Mar 27.

Priya Hasan

Computers and Astronomy, Refresher Course in Astronomy and Astrophysics, IUCAA, Pune, May 16.

Archival data and its potential, Refresher Course in Astronomy and Astrophysics, IUCAA, Pune, May 17.

AGN host galaxies: Observations and simulations, European Association for Research in Astronomy Workshop, IAP, Paris, December .

Lives and death of stars, Introductory Workshop on Astronomy and Astrophysics, Osmania University, Hyderabad, February.

Ajit Kembhavi

Library consortia and UGC infonet, UGC Infonet Programme, Government Medical College, Aurangabad, April 20.

Introduction to networks and astronomy research facilities in India and France, Workshop on Indo-French Astronomy Network : Prospects and Programmes, IUCAA, Pune, June 30.

Galaxy formation : The AGN-spheroid connection, Workshop on Indo-French Astronomy Network : Prospects and Programmes, IUCAA, Pune, July 1.

Einstein's gravity, Master Resource Persons Training Programme on Year of Physics - 2005, Institute of Physics, Bhubaneswar, July 27.

Einstein's gravity and black holes, National Seminar on Astronomy and Astrophysics, Christ College, Irinjalakuda, Kerala, August 6.

Einstein's gravity and black holes, Workshop on Exciting Astronomy : From Stars to the Universe, Calicut University, Kerala, August 8.

Noise, sky brightness and observing limits, Workshop on Observing Projects and Small Telescopes, IUCAA, Pune, August 31.

From the special theory of relativity to the general theory, Fergusson College, Pune, September 8.

Supermassive black holes, Einstein Centennial Meeting, University of KwaZulu-Natal, Durban, September 26.

Gravity without gravity : Newton, Einstein and black Holes, Students Physics Society, University of KwaZulu-Natal, Durban, September 29.

The black hole in our galaxy, Witts University, Johannesburg, October 3.

Supermassive black holes, UNISA, Pretoria, October 4.

Promotion of e-information resources, Seminar on the Usage Promotion of E-Information Resources, Le Meridian, Pune, November14.

Virtual Observatories, YAM 2005, IUCAA, Pune, November 29.

Galaxies - I, Introductory Workshop : Instruments and Observations, Karnatak University, Dharwad, December 5.

Galaxies - II, Introductory Workshop : Instruments and Observations, Karnatak University, Dharwad, December 5.

Virtual Observatories, B.V. Bhoomaraddi College of Engg. and Tech., Hubli, December 5.

Black holes : From Newton to Einstein, UGC-DAE Consortium for Scientific Research, Indore, December 14.

Human r esource development for planetary exploration programme, ISRO HQ, Bangalore, December 16.

The sky is the limit, Workshop on Astrostatistics, Department of Statistics, Calcutta University, December 21.

Virtual Observatory : Status and future, Scientific Advisory Committee Meeting, IUCAA, Pune, January 3.

Virtual Observatories : A new data paradigm, IISc., Bangalore, January 17.

Gravitational lenses (Two talks), *Seminar on Gravity and Light*, CUSAT, Kochi, January 30.

Stars (Two talks), Workshop on Introductory Astronomy and Astrophysics, Purulia, February 24.

Virtual Observatories, IIT, Kharagpur, February 25.

Virtual Observatories, Invited talk at International Conference, LCWS Bangalore, T/DAQ Session, IISc., Bangalore, March 11.

Ranjeev Misra

Time series Analysis of Astronomical Data, Workshop on Astrostatistics, Department of Statistics, Science College, Kolkata, December 21.

Observational evidence for black holes, Utkal University, Bhubhaneswar, February.

Observational evidence for black holes, Dalmia College, Rajgangpur, Orissa, February.

Radiative processes, (two lectures), VSP and Refresher Course, IUCAA, Pune, June.

The non-linear time series analysis of GRS 1915+105, UofA, Amsterdam,August 9.

Radiative processes in astrophysics, Dinabhandhu College, Kolkata, May.

Observational evidence for black holes, St. Xavier's College, Kolkata, May.

Sanjit Mitra

Non-circular beam correction to the CMB power spectrum Poster presentation in the Conference on Open Questions in Cosmology: the First Billion Years, MPA Garching, August 22-26.

Surfing on gravitational waves , Plenary talk at the Young Astronomers' Meet, IUCAA-NCRA, Pune, November 30.

J. V. Narlikar

Science centres as tools for science education, a keynote address delivered at the 4th Science World Congress, Rio de Janeiro, Brazil, April 12.

Scientific temper and cultural systems , 4th Science World Congress, Rio de Janeiro, Brazil, April 12.

Cosmology (2 lectures) VSP, IUCAA, Pune, May 26.

Einstein and our understanding of the universe, Mid-year meeting of the Indian Academy of Sciences, Bangalore, July 7.

A case for alternative cosmology, 9th Asian-Pacific Regional Meeting of the International Astronomical Union, Bali, Indonesia, July 28.

Einstein and cosmology, 29th International Cosmic Ray Conference, (organized by the Tata Institute of Fundamental Research, Mumbai), Y.B. Chavan Auditorium, Pune, August 5.

Cosmology in the post-Einstein era, Physical Research Laboratory, Ahmedabad, August 10.

What is special relativity?, Sir Parshurambhau College, Pune, August 12.

Theory of relativity Department of Physics, University of Pune, Pune, August 19.

Cosmology, Fergusson College, Pune, September 12,

Gravitational collapse with negative energy fields (a technical talk) SARS Einstein Centennial Meeting at the University of Kwazulu-Natal, Durban, South Africa, September 25.

Theory of relativity (a general talk), SARS Einstein Centennial Meeting at the University of Kwazulu-Natal, Durban, South Africa, September 26.

Theory of relativity - I and II (two lectures) Conference on Albert Einstein Theories and Present Scenario, Thane, November 18.

Facts and speculations in cosmology, Sikkim-Manipal Institute of Technology, Sikkim, March 22.

Gravitational collapse with negative energy fields, Physics Department, North-Bengal University, Siliguri, March 24.

Gravitational collapse with negative energy fields, 12th Regional Conference on Mathematical Physics, The National Centre for Physics, Islamabad, March 27.

T. Padmanabhan

Holographic aspects of Einstein gravity, UCT Cosmology Meeting, Capetown, South Africa, July 7.

Dark energy and the cosmological constant,UCT Cosmology Meeting, Capetown, South Africa, July 8.

Nonlinear gravitational clustering in expanding universe,UCT Cosmology Meeting, Capetown, South Africa, July 9.

Dark energy- Mystery of the millenium, Einstein Conference, Paris, July 20.

Observations and interpretation of dark energy in the universe, International Cosmic Ray Conference, Pune, August 5.

Challenges in the study of nonlinear gravitational clustering, Workshop on Statistical Mechanics of Non-Extensive Systems, Paris, October 24.

A new perspective on gravity, Einstein's Legacy in the New Millennium, Puri, December 18.

Atoms of spacetime, (Abdus Salam Memorial lecture), Jamia Millia Islamia, New Delhi, February 28.

Dark energy, IISc, Bangalore, August 9.

Dark energy in the universe, KSCSTE, Trivandrum, August 17.

A holographic perspective of gravity, (Highlight Colloquium), SISSA, Italy, November 8.

Horizons and/of Gravity, [TIFR Colloquium, Mumbai], November 22.

A new perspective on gravity, Harishchandra Research Institute, Allahabad, April 26.

Origin of structure in the universe, School on Cosmology and Very Early Universe, IUCAA, Pune, December 26.

A. N. Ramaprakash

Atmospheric effects in astronomy: Training school for International Astronomy Olympiad, Nehru Science Centre, Mumbai, May 17.

The world of large and small telescopes: Inaugural meeting on Calicut University Observatory, Calicut University, Kerala, August 8.

Laboratory and sky experiments training : Refresher Course on Astronomy and Astrophysics, IUCAA, Pune, May 22.

Varun Sahni

Braneworld cosmology (Invited review), Dark Energy Meeting, Ringberg Castle, Germany, February 26 - March 1.

Dark energy (Invited review), School on Cosmology and the Very Early Universe, IUCAA, Pune, December 26-30.

The cosmological constant and dark energy (Plenary talk), Physics in the trails of Einstein, Saha Institute of Nuclear Physics, Kolkata, November 21-22.

The cosmological constant — Einstein's Enduring legacy (Plenary talk) Physics 2005, 100 years after Einstein's Revolution, IIT Kanpur, November 3-6.

Dark energy (Plenary talk), Third 21COE Symposium : Astrophysics as Inter-disciplinary Science,Waseda University, Tokyo, Japan, September 1-3.

The cosmological constant and the accelerating universe, (Plenary talk) International Year of Physics celebrations Bhabha Atomic Research Centre, Mumbai, India, July 22.

Tarun Souradeep

Statistical isotropy of CMB anisotropy, Planck Group Meeting at JPL (Caltech), Pasadena, March 29.

Measuring statistical isotropy of CMB anisotropy, Fundamental Physics With Cosmic Microwavem Background Radiation, The Center for Cosmology, University of California, Irvine March 23-25.

Cosmology with CMB anisotropy, Plenary talk at the WHEPP-9, Bhubaneshwar, Januaary.

Status of CMB observations, A.K. Raychaudhuri Memorial School on Cosmology and the Very Early Universe, IUCAA, PunDecember.

Statistics of CMB anisotropy, International workshop on 'Astrostatistics', Kolkata, India, December 23.

Cosmological quests in the CMB sky, plenary talk at the International meeting on Einstein's Legacy in the new Millennium, Puri, December 15.

Two lectures on Introductory Cosmology, IUCAA sponsored Introductory Astronomy school, Dharwad, December 7.

CMB anisotropy at the frontiers of cosmology Colloquium at ARIES, Nainital, November 7.

Frontiers of cosmology with the CMB anisotropy Colloquium at the Institute of Mathematical Science, Chennai, September 30.

Mining the CMB anisotropy for early universe physics Seminar at the Institute of Mathematical Science, Chennai, September 29.

Observable test of cosmological principle, Physics Colloquium at the Indian Institute of Technology, Chennai, September 28.

Testing the statistical isotropy of CMB maps, MPA/ ESO/ MPE/ USM Joint Astronomy Conference on 'Open Questions in Cosmology', Garching, Germany, August 24.

Statistical isotropy of CMB anisotropy, COSMO 05: 9th International Workshop on Particle Physics and the Early Universe, Bonn, Germany, August 28 - September 1.

Cosmological principle and the Cosmic microwave Background , Physics Colloquium at the Indian Institute of Technology, Kanpur, April 4.

R. Srianand

Search for molecules with ELTs, Captown IAU Symposium on Science with Extremely Large Telescopes, September.

A review of IGM, IAU Symposium, South Africa, Capetown, Septmber.

K. Subramanian

The origin and evolution of cosmic magnetism, Review talk, Cosmic Ray Propagation Meeting, Institute of Astrophysics, Paris, France, November.

Magnetic fields and CMB anisotropies and Polarization, (Plenary review), International Conference on The Origin and Evolution of Cosmic Magnetism, Bologna, Italy, August.

CMBR anisotropies: Theory, School on Cosmology and very Early Universe, IUCAA, Pune, December.

Structure formation (2 lectures), *Cosmic magnetic fields* IUCAA Refresher Course in Astronomy and Astrophysics and VSP, IUCAA, Pune, May-June.

Lecture Courses

Naresh Dadhich

General relativity, University of Kashmir, Srinagar, October 2005 (8 lectures).

Sanjeev Dhurandhar

Special and general relativity and their applications, Einstein Centenary Conference, S. P. College, Pune, December 8 - 10 (4 lectures).

Ranjan Gupta

Spectroscopy; *Spectroscopy Instrumentatio*n and *Applications based on neural networks*, Introductory Workshop: Instruments and Observations, Department of Physics, Karnataka University, Dharwad during December 5-7 (3 talks).

Earth's Atmosphere; New generation telescopes; Artificial neural networks and applications to stellar spectroscopy; Interstellar dust models at Department of Physics, Kumaon University, Nainital February 28 to March 2 (6 talks).

Ajit Kembhavi

The physics of stars, Refresher Course, Department of Physics, Utkal University, Bhubaneswar, November 7 - 9 (4 talks).

Galaxies in the universe, Certificate Course in Astronomy and Astrophysics, University of Mumbai, February 26 (3 talks).

J. V. Narlikar

Cosmology from the sidelines , Junior Research Scholars, IUCAA, Pune, May 10, 11, 12 (3 lectures).

T. Padmanabhan

Aspects of gravitation, Cochin University, August 11 - 14 (8 letures).

Making sense out of the universe, X Special Courses at Observatorio Nacional/Brazil National Observatory at Rio de Janeiro, September 26-30 (5 lectures).

Introductory Astronomy and Astrophysics ,Order of magnitude, IUCAA, Pune, May 16-19 (3 lectures).

R. Srianand

UV spectroscopy of AGNs, Udaipur University, Physics Department, Astrosat workshop on AGNs (3 lectures).

Diffuse matter in space, VSP, IUCAA, Pune, May-June (5 lectures).

(VIII) SCIENTIFIC MEETINGS AND OTHER EVENTS

Vacation Students' Programme

Participants and Lecturers 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 16 - July 1, 2005. Eleven 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 NCRA and IUCAA. They also did a project with one of the faculty members of IUCAA during this period. K. Subramanian was the faculty coordinator of this programme.

School Students' Summer Programme - 2005

Students in various activities during the School Students' Summer Programme

The annual IUCAA School Students' Summer Programme was held from April 18 to May 27, 2005. This programme at IUCAA was started in 1993 for the school students of Pune. It gives a glimpse of the pursuit of scientific research to the young minds and has been conducted for six weeks. Each week, starting on Monday, a fresh batch of 26 students of class VIII and IX were invited to work on a project at IUCAA. Groups of four to six students were attached to a scientist at IUCAA, who guide them on scientific projects. In the spirit of true research, the students and guides work together unfettered by a set syllabus or course guidelines, time schedules. The students are given access to the IUCAA library. On the last day of every batch, the student teams present the work they did during the week and submit a report. This year the students carried out projects under the supervision of Susmita Chakravorty, Hum Chand, V. Chellathurai, Sanjeev Dhurandhar, Sunu Engineer, Arvind Gupta, Ranjan Gupta, Priya Hasan, Kanti Jotania, Gaurang Y. Mahajan, Vidula Maiskar, Jayant Narlikar, Arvind Paranjpye, Vijay Mohan, Manoj Puravankara, Ashok Rupner, Saumyadip Samui, Tarun Souradeep and Kandaswamy Subramanian. The projects were diverse, covering wide ranging topics. Some students estimated the latitudes of various places seeing the IUCAA Foucault pendulum and by observing shadow of gnomon and learned to use trigonometry to measure heights. While others studied the properties of electromagnetism, Kepler's laws and our planets, planets in extra-solar systems, the galaxy, the universe, refraction, fractals, biotechnology, genetic engineering and genetically modified foods, HIV virus, human anatomy — skeletal and digestive system, . They also constructed solar system models, models of the Cassini probe, kaleidoscope, periscopes and scientific toys. Besides the team project, the students also had time for joint activities, such as, making scientific toys from scrap, exploring the the IUCAA Science Park, observing sunspots and viewing popular science movies. A new item this year were informal interactive sessions with young, budding scientists, Abhishek Rawat, Arman Shafieloo, Ujjaini Alam, Sanjit Mitra who are working towards their Ph.D. in IUCAA and IUCAA Visiting Associate Pavan Chakraborty. Besides answering questions, the young scientists shared their experiences and the joy of doing research in science. This year the students could use the facilities of the Muktangan Vidnayan Shodhika — IUCAA's new science exploratarium in the Pulastya building , and also benefited from a collaborative effort with the Centre for Research in Cognitive System, NIIT Ltd., New Delhi, who kindly sent us Computer Aided Science experience - CAX kits consisting of experiments in electricity, heat and sound. The kits allowed the students to perform (real, not simulated) science experiments first and then study the theory behind every experiment, in contrast to what is normally done in schools, where theory is done first and then a few experiments are performed.

Refresher Course in Astronomy and Astrophysics for College and University Teachers

Participants and Lecturers of the Refresher Course in Astronomy and Astrophysics

The Refresher Course in Astronomy and Astrophysics for college and university teachers was held during the period May 16 - June 17, 2005. Participants were selected from all over India and eighteen 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 Sanjeev Dhurandhar ,and Kandaswamy Subramanian, who was the coordinator of the Vacation Students' Programme (VSP). The course firstly, consisted of introductory lectures, which covered the basics of astronomy and astrophysics and secondly, of lectures providing overviews of different aspects of astronomy. A few lectures were arranged on advanced topics. There were special lectures by experts from outside Pune on frontier areas related to astronomy and astrophysics and which described the various frontline scientific projects in which India is taking part. The lecturers were from ISRO Satellite Centre, Bangalore. Indian Institute of Astrophysics, Bangalore, and the Tata Institute of Fundamental Research, Mumbai. Laboratory sessions were an important component of the course; this was in order to concretise ideas and concepts in basic astronomy. A scientific visit to the IUCAA's 2 metre optical telescope at Giravali and to the Giant Metre Radio Telescope at Narayangoan was arranged on June 13, 2005 for the participants of the refresher course and the VSP. 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. Sanjeev Dhurandhar was the coordinator of this course.

W orkshop on Observing Projects with Small Telescopes

Participants and lecturers of the workshop on Observing Projects with Small Telescopes

Twenty eight participants from various universities and colleges attended the workshop. The workshop theme was to discuss projects and exercises for M.Sc. students having course work in astronomy. Both types of projects which can be undertaken with small telescopes as well as without telescopes were discussed. Basic tools necessary for implementing such projects viz. telescopes, detectors, image processing, photometry, spectroscopy and error analysis, were covered by the lecturers. Speakers and topics were as follows:

Ajit Kembhavi (IUCAA) on Noise, Sky Brightness and Observing Limits; Ranjan Gupta (IUCAA) on Spectroscopy; S.K. Pandey (Pt. Ravishankar Shukla University, Raipur) on Projects and Exercises in Astronomy; Arvind Paranjpye (IUCAA) on Using an Astronomical Telescope; Vijay Mohan (IUCAA) on Image Processing and Photometry; and Abraham Samson (IIA, Bangalore) on Domes for Small Telescopes.

Participants also presented the facilities in their departments and observing projects being undertaken by them. A demo session was held on Image Processing using IRAF. S.K. Pandey and Vijay Mohan coordinated the workshop, and was conducted during August 29-31, 2005.

An Introductory Workshop: From Stars to the Universe

The 14 inch telescope at the Madhava Observatory

An introductory workshop titled From Stars to the Universe was organized by IUCAA in collaboration with the Physics Department, University of Calicut, Kozhikode, on the university campus on August 7 and 8, 2005. The workshop was attended by about 150 students and teachers from university departments and colleges around Kozhikode. The lectures given at the workshop were as follows :

G. Ambika (Maharaja's College) : Non linear dynamics and Astrophysics; Naresh Dadhich (IUCAA) : Introduction to Einstein's Theory; Ajit Kembhavi (IUCAA) : (i) Einstein's Gravity (ii) Opportunities in Astronomy; V.C. Kuriakose (Cochin University) : Elements of Cosmology; Jayant Murthy (IIA, Bangalore) : Diffused UV Observations; Ninan Sajeeth Philip (St. Thomas College) : Neural Networks and Their Applications in Astronomy; A. N. Ramaprakash (IUCAA) : The Use of Small and Medium Telescopes; N. Kameswara Rao (IIA, Bangalore) : Astronomy with Medium Sized Telescopes; Ulysses John Sofia (Whitman Astronomy, USA) : Interstellar Grains and Dust.

There was a discussion session on Opportunities in Astronomy led by Ajit Kembhavi. The lectures were all followed by intensive questions and answers, and discussion on the topics covered.

A special event which took place during the workshop was the inauguration of the Madhava Observatory by Naresh Dadhich, Director, IUCAA, which has a new 14" telescope to be used by students and faculty of the university. The well equipped observatory with a dome has been set up with technical assistance from the Indian Institute of Astrophysics (IIA), Bangalore, with dome design and construction being supervised by J.P. Abraham Samson of IIA. During the workshop, there was a discussion between Syed Iqbal Hasnain, Vice Chancellor of the university, his senior colleagues, and visitors from IUCAA about possible continuing collaborative programmes to be undertaken over the next few years. The coordinators of the workshop were B. Ravishankar Babu from the University of Calicut and Ajit Kembhavi from IUCAA.

International Conference on Einstein's Legacy in the New Millennium, Puri

Participants of the International Conference on Einstein's Legacy in the New Millennium

The international conference titled Einstein's Legacy in the New Millennium was co-organised by IUCAA, Utkal University and Institute of Physics, Bhubaneswar, at Toshali Sands, Puri, during December 15 – 22, 2005. This conference was co-sponsored by IAGRG, HRI (Allahabad), IMSc. (Chennai), RRI (Bangalore), SINP (Kolkata), and TIFR (Mumbai) and financial support was also received from DAE-BRNS, DST, and ISRO. The aim of the conference was to bring together people working in different areas of quantum gravity, and bring fruitful interactions amongst them. The plenary talks were delivered by Martin Bojowald, Atish Dabholkar, J. Ehlers, G. Gibbons, Rajesh Gopakumar, G. 't Hooft, Romesh Kaul, Swapna Mahapatra, H. Nicolai, Peter Van Nieuwenhuizen, T. Padmanabhan, Jogesh Pati, J. Pullin, Ashoke Sen, Parampreet Singh, Tarun Souradeep, Sandip Trivedi, W. Unruh, M. Varadarajan and B. de Wit.

In addition to the plenary talks, the conference devoted three evenings for focused discussion on String Theory, Loop Quantum Gravity, and Cosmology, and coordinated by Debashis Ghoshal, Martin Bojowald and Varun Sahni respectively.

G. 't Hooft delivered a special colloquium, which was attended by the students from the Utkal University as well. The conference was quite successful in providing a forum for very stimulating discussions and allowing free exchange of different points of view. The scientific organization of the conference was handled by a committee co-chaired by T. Padmanabhan (IUCAA) and J. Maharana (IOP), and the local organization was carried out by a committee chaired by L.P. Singh of Utkal University.

Introductory Workshop: Instruments and Observations

Participants of the Introductory Workshop: Instruments and Observations

An Introductory Workshop: Instruments and Observations was organized by the Department of Physics, Karnataka University, Dharwad, during December 5-7, 2005. The workshop was sponsored by IUCAA, Pune, with additional support from Karnataka University under unassigned UGC grant. The workshop was inaugurated by Ajit Kembhavi, IUCAA with M.I. Savadatti, former Vice-Chancellor of Mangalore University, speaking on the occasion. The aim of the workshop was to acquaint the teachers with the basics of Astronomy and Astrophysics, which will be helpful for teaching/ introducing the topics at undergraduate and postgraduate level, to provide an opportunity for the teachers from colleges and universities to undertake research activities, and mainly to learn the latest developments in the areas.

The workshop was attended by 38 teachers from university departments and colleges from Karnataka and neighbouring states. A few students and all the research students of the department also participated actively in the workshop. The resource persons spoke as follows:

Ajit Kembhavi (IUCAA): Galaxies (2 lectures); Ranjan Gupta (IUCAA): Spectroscopy, Spectroscopy Instrumentations Applications: Based on Neural Network; Vijay Mohan (IUCAA) : Optical Telescopes, Detectors and Image Processing; Tarun Souradeep (IUCAA): Introduction to Cosmology (2 lectures); B.A. Kagali (Bangalore University) : Telescopes and their Characteristics; S.C. Chakravarty (Department of Space, ISRO, Bangalore): ISRO's Space Science and Astronomy Missions.

Uday S.Raikar from the Department of Physics, Karnatka University and Ranjan Gupta from IUCAA, were the coordinators of the workshop, with B.G. Mulimani as Chairman of the Workshop Organising Committee.

Workshop on Astrostatistics

The Worskhop on Astrostatistics was jointly organized by the Inter-University Centre for Astronomy and Astrophysics, Pune, and Department of Statistics, Calcutta University, during December 21-23, 2005. The workshop was inaugurated by Asis Kumar Banerjee, Vice Chancellor, Calcutta University on December 21, 2005.

Speakers and topics of the different technical sessions were as follows: S.P. Mukherjee (Calcutta University) : Statistics for astronomy- An overview; G.J.Babu (Penn State University) : Statistical problems in astronomy and resampling techniques; Ajit Kembhavi (IUCAA): Sky is the limit; Kalyan Das (Calcutta University) : Exploratory data analysis; Somnath Bharadwaj (IIT Kharagpur) : Galaxy redshift surveys; Ranjeev Misra (IUCAA): Time series analysis of astronomical data; Asis Kumar Chattopadhyay (Calcutta University) : Statistical inference and missing data analysis; Sugata

Sen Roy (Calcutta University) : Some aspects of multivariate analysis; Ashish Mahabal (Caltech) : Clustering, classification and the search for outlier; P. K. Sen (North Carolina State University) : Some stochastic perspectives in astrostatistics; Tarun Souradeep (IUCAA): Statistics of the cosmic microwave background sky; Manisha Pal (Calcutta University): Descriptive statistics; Tanuka Chattopadhyay (S.D.B. College, Howrah) : Some case studies; Sajeeth Philip (St. Thomas College, Kozhencherry): Bayesian statistics for artificial neural network design; U.C.Joshi (PRL, Ahmedabad): Probing the inner region of the milky way; and Malay Ghosh (University of Florida): Bayesian methods.

Besides the above technical lectures, there was a special lecture on December 22, 2005 by J.K.Bhattacharya of Indian Institute for Cultivation of Science, Kolkata on the topic "Bose Einstein statistics and condensation phenomena."

About sixty participants from different universities, colleges, institutes and from different parts of the country attended the workshop.

Asis Kumar Chattopadhyay of Department of Statistics, Calcutta University and Ajit Kembhavi of IUCAA, Pune were the joint coordinators of the workshop.

An Introductory Workshop: Sun and Stars

The participants of the Introductory Workshop: Sun and Stars

An Introductory Workshop: Sun and Stars was organized by IUCAA in collaboration with the Department of Astrophysics, St. Xavier's College, Kolkata during November 21 -23, 2005. A total of 87 participants from different university departments and colleges attended the workshop, out of which twenty candidates were from other parts of India. The lectures given at the workshop were as follows:

Jagdev Singh (IIA, Bangalore): Instruments and techniques to observe the Sun and structure and dynamics of the Sun; Sandip K. Chakrabarti (SNBNCBS and Centre for Space Physics) : Astrophysical flows about black holes and neutron stars; Ashoke K. Sen (Assam University): Fundamentals of astronomy and photometry and polarimetry with small telescope; Ranjan Gupta (IUCAA): Earth's atmosphere, telescopes and effects and astronomical spectroscopy; Narayan Banerjee (Jadavpur University): The new turn in cosmology; Partha Sarathi Joarder (Indian Statistical Institute, Kolkata): A short introduction to solar magnetohydrodynamics; Debiprosad Duari (M.P. Birla Planetarium): Astrophysics and cosmology — Current perspectives and future challenges (Part A) and Astrophysics and cosmology — Current perspectives and future challenges (Part B); Kamales Kar (Saha Institute of Nuclear Physics, Kolkata): The theory of type II supernova explosions; Biswajit Basu (AAVSO and Sky Watchers' Association): The effect of solar flares on the VLF radiowave propagation and ionospheric disturbances. Jagdev Singh delivered one evening popular level talk on Expedition to Antarctica region to study the Sun. All the participants were taken to the St. Xavier's College Observatory, which was established in the year 1860 and is at present under renovation process since November 2004. Biswajit Basu also demonstrated a VLF receiver at the observatory for 2 days, showing the ionospheric effects including sunrise and sunset events, etc.

Young Astronomers' Meet 2005

The participants of the Young Astronomers' Meet

The 9th Young Astronomers' Meet (YAM) was held in IUCAA and NCRA during November 29 - December 2, 2005. YAM serves as a unique forum for research students working in Astronomy and Astrophysics in the country, by providing them a unique opportunity to present their work and interact with like-minded fellow-researchers. YAM was initiated in 1992 and the first one was held in NCRA. YAM 2005 was co-sponsored by DST, IUCAA and NCRA, and the organisation was handled by the graduate students of the latter two institutions under the guidance of A. N. Ramaprakash.

The schedule included technical talks and poster presentations by participants covering most of the areas in A & A, as well as three special evening colloquia, by A. K. Kembhavi (Virtual Observatories), T. Padmanabhan (Dark Energy) and R. Nityananda (The Graver Side of Light). On the last day, a trip to GMRT and the IUCAA telescope at Girawali was arranged. The meet was attended by 81 students from various institutions across the country. In all, 35 talks and 9 posters were presented. Students from Pt. Ravishankar Shukla University, Raipur, have proposed to hold the next YAM.

School on Cosmology and Very Early Universe

The participants of the School on Cosmology and very Early Universe

Taking advantage of the presence of some of the distinguished speakers at the International conference on Einstein's Legacy in the New Millennium, held at Puri, a satellite school on Cosmology and Very Early Universe was organized at IUCAA during December 26-30, 2005. It was felt that the activity in both strings and loop quantum gravity is coming up to a stage for applications in cosmology and one could expose young researchers in the country to this exciting and emerging area of research. This was the main motivation for the school, which was scientifically directed by Abhay Ashtekar.

It began with the lectures on cosmology (by Juergen Ehlers, T Padmanabhan, Varun Sahni, K Subramaniam and Tarun Souradeep), which defined the cosmological context and setting. It was then followed by lectures on string theory (by Sunil Mukhi, Jnan Maharana, Atish Dabholkar and Sandip Trivedi) and loop quantum gravity/cosmology (by Abhay Ashtekar, Martin Bojowald, Parampreet Singh, Shyam Date and Golam Hossain). There were about 30 participants from various institutes and universities.

It was a very intense and focused engagement which was rounded up by a panel discussion on the emerging canvas of synergy between quantum gravity theories and cosmology. This school was dedicated to the memory of A. K. Raychaudhuri, and coordinated by Naresh Dadhich.

Cosmology for Everyone : Lecture series

Mark Whittle delivering a lecture

Mark Whittle, (University of Virginia, USA), who was visiting IUCAA, gave a series of four informal evening lectures at Muktangan Vidnayan Shodhika, the Science Exploratorium from January 4 to 7, 2006.

The lecture titles were: Evidence for the hot big bang, Witnessing the sound and flash of big bang, and Assembly of the cosmic structure - from stars to galaxies to the tapestry. These talks were attended by about 15 amateur astronomers and visitors to IUCAA. Even though the talks were meant to be for 'every one' it turned out that those attended the talks had more deeper interest in the subject and Mark, who had planned only three talks, delivered one more talk!

W orkshop on Telescope Making

Participants of the Workshop on Telescope Making

Arvind Paranjpye conducted a workshop on telescope making at Bipin Bihari College, Jhansi, during January 27 - 28 , 2006. In this workshop, ten teams from different schools and colleges participated. The telescopes were of refracting type with 42 mm f /10 achromatic lens. The mount for these telescopes were made using PVC pipes and pipe joints.

There were lectures on history and types of telescope. The participants estimated the focal lengths of the lens by focusing on the Sun. In the night, actual observations were carried out. Next day, the participants were shown how to image the sun on a sheet of paper for the purpose of seeing the sunspots and solar eclipse. A session on telescope maintenance and a question/answer was conducted. Sunanda Kirtane and Chandrakant Gandhi were the local organizers of the workshop.

Public Outreach Programmes

IUCAA has active Public Outreach Programmes whose primary aim 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 25 and 28, 2006. These Public Outreach Programmes, are housed in the Muktangan Vidnyan Shodhika.

Activities for school students

Second Saturday Lecture and Demonstration Programme

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

Science Activity Workshop

These workshops were conducted on every Monday, Wednesday, and Friday and each session was attended by about fifty school students from class fourth to tenth. The students were shown how to make and appreciate several scientific toys, which were made of simple and easily available materials like matchsticks, cycle valve tube, old cycle tube, film cans, old newspapers, ball pen refills, etc. Some of these toys made by the students were, magnetically elevated pencils, a simple electric motor, newspaper caps, Sudarshan Chakra, balloon pump, matchstick mecanno, etc.. The aim of these workshops is to show students that science is fun and exciting. The low cost and easy availability of the materials used, allows the students to be free, leading to maximum participation in their part. This programme is especially beneficial to under privileged student who may not have access to costly scientific apparatus. FMEPL, a media group produced a short documentary film (12-minute) on this program titled “TRUTH AND JOY OF SCIENCE” which captures the inquisitive mood of the students during the workshop. This TV programme was telecasted on Doordarshan .

Advanced Projects

Interested school and college students undertake scientific projects at IUCAA, which may be a part of their curriculum.

Bakul Purohit, Prachee Bahulekar, and Solnali Deshmukh, students of Cummins College of Engineering for Women, Pune, did a project on making a Celeostat, as a part of their engineering project. Their project was rated high in their graduate examinations held by the Pune University. The Celeostat has been installed on the terrace of Muktangan Vidnyan Shodhika

Sonal R. Kasar, Jyoti P.Pagar, Vrishali A.Bagul, Shakti N.Bajaj, Jyoti R.Nikam, and Yogita P. Gangurde, B.Sc. students of the K.R.T. Arts, B.H. Commerce and A.M. Science College, Nashik, visited IUCAA for a period of six days to do project on study of solar limb darkening. During this period, they took photometric observations and reduced their data. They observed the sun in Johnson B,V, R, I passband.

Such projects done in previous years have received many national and international recognition.

Hamsa Padmanabhan, XI standard student of the Kendriya Vidyalaya, Ganeshkhind Road, Pune, had done a detailed project on a toy, in which a pen is suspended (and it also spins) in air due to magnetic forces. Her paper based on this project won three awards at the Intel International. She bagged the 2nd prize in physics at ISEF, first prize in Physics from United Technologies Corporation for excellence in the science and engineering category, and American physics teachers and the American Association for physics society jointly awarded her the third prize.

Madhura Gokhale, Department of Physics, University of Pune, and Onkar Dixit, a standard XII student of Fergusson College were invited to participate in the amateur section of 9th Asia Pacific Regional IAU (International Astronomical Union) Meeting, at Bali, Indonesia, in July 2005 for their project on the study of comet Machholz. Unfortunately, both of them could not participate in the meeting, as they were stranded at Mumbai Airport due to unprecedented rains.

Workshops and Lecture Series

To mark the “Year of Physics”, two workshops were held in collaboration with NCERT and Physics Department of Pune University, for 100 muncipal school students during November 29-30, 2005.

IUCAA organizes visits to the campus, for interested people from different professional backgrounds and age groups. These visits, which are by pre-arranged invitation only, take place typically on Thursdays. On each visit, about 35 visitors were given a brief introduction about IUCAA and were shown the various exhibits on the premises and the science park. Student visitors with more technical background were also shown the instrumentation laboratory.

Contribution to Newspapers/Articles

Muktangan Vidnyan Shodhika members have been contributing weekly science features to a local newspaper "The Maharashtra Herald". These articles explain some scientific principles and describe "Do-it-yourself" experiments which young readers can perform. Twenty-three features (12 plus 11) have been published on Fridays (for high schools students) and Saturdays (for secondary schools students) from January 2006 onwards.

National Science Day

The National Science Day was celebrated at IUCAA on February 25th and on February 28th. On Saturday, February 25th science related competitions were held for schools students. The centre was opened to the general public on February 28th, so that they may acquaint themselves with the research done at IUCAA and appreciate scientific temper and methodology.

Inter-School Competitions

Schools in Pune region were invited to participate in the inter-school science competitions. On February 25th five students each, from 80 schools took part in the quiz, essay and drawing competitions organised at IUCAA.

Topics for the drawing and essay competitions were suitably chosen to enable the students to exhibit their fertile imagination and scientific knowledge. Based on a preliminary written quiz held in the morning, three member teams from five schools took part in the final quiz contest. The students were tested for their scientific and technology knowledge and their ability to solve puzzles. Films "Truth and Joy of Science" and on the life and works of two great Indian cosmologists, Professor A. K. Raychaudhuri and Professor P.C. Vaidya (produced by Vigyan Prasar, New Delhi) were screened for the students and teachers. Winners of the competitions were taken to the IUCAA Girawali Observatory. During the two hours stay at the Observatory, the students acquainted themselves with the telescope and its operation.

The Open House for Public

A large number of people from all age groups and different walks of life visited IUCAA on February 28, 2006.

Inauguration of "Science Attitude Promotion Van" of Maharashtra Andhashradha Nirmoolan Samiti (M-ANiS) by Naresh Dadhich, marked the start of Open Day. M-ANiS, had set a poster exhibition and an exposition demonstration of "Science Behind Miracles".

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. A public talk, which explained the importance of this year's Nobel prize in physics, in non-technical language, was presented in the evening.

Short interactive lectures on different topics were held. A scaled model of IUCAA Girawali Observatory, a demonstration of the seeing affect and telescope dome operation were on display. Brownian motion and radio telescope demonstrations were conducted by students of Fergusson College, Pune.

Visitors were encouraged to get hands on experience of using do-it-yourself experiments set up in the Muktangan Vidnyan Shodhika. Students of Aksharnandan school volunteered to give the demonstrations. Films "Truth and Joy of Science" and on the life and works of Professor A. K. Raychaudhuri and Professor P. C. Vaidya were also screened.

Members of the Sky Watchers Association of Pune participated in explaining exhibits in the science park and later on carried out sky observing programme for general public.

Winners of the Drawing, Essay and Quiz Competitions

Drawing Competition
First prize
Akshay Hargude, New English School, Raman Baug
No second prize was awarded

Essay Competition Marathi
First Prize
Deepti Dilip Patil, Mahialshram High School
Second Prize
Bhakthraj Thombre, Shri Fattechand Jain Vidyalay

Essay Competition English
First Prize
Kshitij Gautam, Army School, Kirkee
No Second Prize was awarded

Science Quiz Competition
First Prize:
Team: Muktangan English School & Jr. College
Saurabh Rajendra Gandhi
Shantanu Rajendra Bhate
Ninad Hemant Watve

Second Prize:
Team: S. P. M. English School
Ameya Karambelkar
Aniket Panse
Devdnya Deshpande

Popular Talks and Articles by the IUCAA Faculty

(a) Popular Talks

Naresh Dadhich

Science and Society (a Popular Science talk delivered at the Master's Resource Training Programme organized by Rashtriya Vigyan Evam Prodyogiki Sanchar Parishad at Mumbai,) June 29.

Science and Society (a Public Lecture delivered at the Master's Resource Training Programme organized by Rashtriya Vigyan Evam Prodyogiki Sanchar Parishad at Bangalore,) July 13.

Science and Society (a Public Lecture delivered at the University of Cape Town, South Africa,) September 24.

Science and Society (a Popular Lecture delivered at the University of Srinagar, Jammu and Kashmir,) October 17.

Sanjeev Dhurandhar

The Search for Gravitational Waves, Fergusson College, Pune, September 12.

Ajit Kembhavi

Virtual Observatory, Tilak Smarak Mandir, Pune, May 5.

Albert Einstein : 1905 - *The Miracle Year,* Institute of Physics, Bhubaneswar, July 27.

Einstein and Atoms, Inauguration of book "Tarankanchya Vishwat" Mahalaxmi Sabhagriha, Parvati, Pune, September 4.

Nobel Prize in Physics - 2005, National Science Day, IUCAA, February 28.

Albert Einstein : Some simple truths, School Students Lecture Demonstration Programme, IUCAA, Pune, August 13.

Albert Einstein : Kahi Sadhi Satye (Marathi), School Students Lecture Demonstration Programme, IUCAA, Pune, August 13.

*Albert Einstein : Some simple truth*s, Conference on Einstein's Theories and Present Scenario, B.N. Bandodkar College of Science, Thane, November 19.

Black holes : From Newton to Einstein, EDUSAT Network, Consortium for Educational Communication, New Delhi, December 30.

Gravity and light, Assam University, Silchar, February 21.

Sucheta Koshti

*Ripples in Spacetime,*National Science Day, IUCAA, February 28.

J. V. Narlikar

Revolutions in physics (TRDDC Distinguished Lecture delivered at the Tata Research Development and Design Centre, Pune,) June 10.

Revolutions in physics, a public lecture delivered at the Institute of Mathematical Sciences, Chennai, July 1.

The amazing world of astronomy, Vikram Sarabhai Memorial Lecture delivered at the Ahmedabad Management Association, Ahmedabad, July 14.

Searches for extraterrestrial intelligence, a lecture delivered at the Kishinchand Chellaram College, Mumbai, July 15.

Learning to live with science and technology, Lalit Doshi Memorial Lecture organized by the Lalit Doshi Memorial Foundation, Mumbai, August 4.

Paragrahavaril Jeevshrusti (Extra-terrestrial life) (in Marathi), a lecture delivered at the Yashwantrao Chavan Sahakar Sabhagruha, Ahmednagar, organized by the Bhaskaracharya Astronomy Research Centre, Ahmednagar, August 16.

IUCAA's architecture from an astronomer's viewpoint, a lecture delivered at the National Film Archives, Pune organized by the Forum for Exchange and Excellence in Design, Pune, August 27.

School education : Some thoughts and reminiscences, V.G. Kulkarni Memorial Lecture delivered at the Homi Bhabha Centre for Science Education, Mumbai, September 3.

Pruthvibaheril jeevshrushticha shodh (Search for extra- terrestrial life) (in Marathi), a lecture delivered at the Second Saturday Lecture Series at IUCAA, Pune, September 10.

History and science, a lecture delivered at the Department of History, Nowrosjee Wadia College, Pune, September 16.

Einstein and cosmology, a lecture delivered at the Nehru Planetarium, Mumbai, September 21.

Life in the universe, a lecture delivered at the Spicer Memorial College, Pune, October 11.

Theory of relativity, a lecture delivered at the Tamil Nadu Science and Technology Centre, Chennai, October 14.

Sapakshatecha Siddhanth (Theory of relativity) (in Marathi), a lecture delivered at the Shivaji University, Kolhapur, October 19.

*Pruthvibaheril jeevshrusht*i (Extraterrestrial life) (in Marathi), a lecture delivered during the Conference on 'Albert Einstein Theories and Present Scenario' at Thane, November 17.

Searches for extraterrestrial life, a lecture delivered at the Indian Community Centre, Sunnyvale : FOWL (Friends on Same Wave Length) (68th Meeting,) January 9.

Modern cosmology from a historical perspective, Second Hasi Majumdar Memorial Oration Lecture delivered at the Calcutta University, Kolkata, March 17.

Searches for extraterrestrial life, a lecture delivered at the Tathyakendra (Dinabandhu Mancha), Siliguri organized by the Paschimbanga Vigyan Mancha, Siliguri, March 23.

T. Padmanabhan

Cosmology, Kendriya Vidyalaya, Ganeshkhind, Pune, April 16.

Understanding our Universe, Homi Bhabha Centre for Science Education, Mumbai, June.

Our universe, Cochin University, August 12.

The darker side of the universe, U.C. College, Alwaye, Cochin, August 16.

The darker side of the universe, S.D. College , Alapuzha, Cochin, August 16.

The darker side of the universe, S.N. College, Kollam, Cochin, August 16.

Dark energy, Nehru Planetarium, Mumbai, November 21.

Dark energy, YAM, Pune, November 30.

Dark energy- The mystery of the millenium, INSA, Delhi, February 28.

Cosmo-genesis, Cafe Scientifique, British Council, Mumbai, March 8.

Dark energy, Cosmological conundrum, Chennai Mathematical Institute, January 16.

K. Subramanian

Traveling through time, Lecture in Astronomy School, QUANTA 2005, City Montessori School, Lucknow, November.

The expanding universe, Lecture in Astronomy School, QUANTA 2005, City Montessori School, Lucknow, November.

(b) Popular Articles

Naresh Dadhich

Amal Kumar Raychaudhuri (1923-2005), Current Science, 89, 3, 569.

Jayant Narlikar - *All rounder par excellence,* Maharashtra Herald, October 29.

A lighthouse falls : Tribute to A.K. Raychaudhury, Physics Education, 22, 3, 219.

Einstein's audacity, V. Vidyanagar (2006), page 18.

Beacon of light, Maharashtra Herald, April 13.

J. V. Narlikar

Eclipse of reason, The Times of India, June 4.

Reaching for the stars, The Times of India, July 30.

Challenges and benefits of studying astronomy, Souvenir, 65.

Yehi hai right size, baby, The Times of India, October 15.

When exciting science is done in colleges, not in labs, Indian Express, October 22.

Hermann Bondi (1919-2005), Current Science, 89, 10, 1767.

Origin (?) of the universe : Part-2, The expanding universe, Resonance, December.

The science-society interaction, Swasti, 3, 18.

Tools for science education, People Science Education

Abstracts, 85.

The scientific temper: Indispensable to enlightened citizenship, Prabhuddha Bharata, January.

Science as an aid towards value education, Philosophy and Science of Value Education in the Context of Modern India, 147.

Kaise bane Oxford, Cambridge ki takkar ke sansthan (in Hindi) [How can we build institutions like Oxford and Cambridge], Dainik Bhaskar, July 20.

Badalti duniya mein Hindustan (in Hindi) [The role of India in a changing world], Rachana, January-April, 3.

Khatare ki aahat (in Hindi) [Signs of danger], (Aha! Zindagi, September) (Expressed in words by Ramesh Nirmal).

Phalit jyotish aur vidnyan (in Hindi) [Astrology and science], Tarksheel, 23.

Eka mahanagaracha mrutyu (in Marathi) [The death of a megapolis], Loksatta, August 7.

Mahavidyalayanmadhyehi sanshodhan karya (in Marathi) [When exciting science is done in colleges, not in labs], (Translation of article appeared in Indian Express dated October 22 under the "India empowered to me is" series), Loksatta, October 24.

Prithvibaheril jeevshristi (in Marathi) [Extraterrestrial life], Navakal, October 16, 20, 21 and 22.

Jagtikikaran : Kahi vichar (in Marathi) [Globalization: Some thoughts], Aashay, 43.

Ek upekshit shastradnya Alfred Wegener (in Marathi) [Alfred Wegener: A neglected scientist], Tonic, 18.

Project solspace (in Marathi) [Project solspace], Chhatra Prabodhan, Diwali Issue, 114.

Lambi, kshetraphal ani ghanaphal (in Marathi) [Length, area and volume], Shaikshanik Samachar Patrika, 9.

(c) Radio / TV Programmes

Ranjan Gupta

An interactive question/answer programme on Astronomy and Astrophysics, Doodarshan Silchar, Assam broadcast, February 28.

Ajit Kembhavi

Vigyan Chetna - Research in Astronomy, Doordarshan Silchar (National DD Panelists : Ajit Kembhavi, Ranjan Gupta and Asoke Sen; Anchor : Pavan Chakraborty; Participants : Six Students from M.Sc.and Ph.D. programme, February 20. Telecast on February 28 at 1800 hrs.

J. V. Narlikar

Vidnyan Parichay (Akashwani, Pune, June 12, June 19, and June 26). Manacha Mujra, ETV (Marathi) ,October.

Participation in question-answer programmes on key channels on television.

Occassional talks and interviews on All India Radio and on ETV (Marathi).

FACILITIES

(I) Computer Centre

The IUCAA Computer Centre continues to offer state of the art computing facility to users from IUCAA as well as IUCAA associates and visitors from the universities and institutions in India and abroad Today everyone relies on wide-area networks to connect employees, customers, partners and vendors. As increasing amounts of email, peer-to-peer traffic and web browsing consume WAN bandwidth, IT managers struggle to keep critical applications running at an acceptable levels of performance. Adding bandwidth a short-term solution since traffic inevitably grows until performance once again becomes an issue. To over come the bandwidth issue, an appliance called Packeteer was deployed in June 2005. Packeteer gives IT managers a powerful tool that monitors, controls and accelerates WAN traffic. It also ensures that the WAN delivers optimal performance and enhances productivity. IUCAA network has many Microsoft Windows based clients, which are prone to vulnerabilities. In the past, the network was subjected to virus attack that would deteriorate the overall performances of the local network. TrendMicro Office Scan suite 7.0 is a centrally managed antivirus server, and was setup last year to tackle this issue. The automatic updates are done everyday on all clients. This has made the network practically virus free. Astronomy is in the midst of a silent revolution. Driven by the continued advancement of computing power, storage and detector technology, the size of observational data-sets is growing exponentially. Hence, high performance computing has become an indispensable and enabling technology for modern astronomy and astrophysics. In July 2005, the high performance computing facility "Hercules" was upgraded to 8 nodes. It comprises of 32 alpha processors , 76 GB RAM and 2 TB storage to meet the demand of the HPC users.

(II) Library and Publications

During the period under review, the IUCAA library added 252 books and 400 bound volumes to its existing collection, thereby taking the total collection to 20,690. The number of journals subscribed was 130. Approximately 300 books were added to the collection of the Muktangan Science Exploratory Library.

The library has successfully installed the cd mirroring server and is currently in the process of uploading the cdrom collection onto the server.

Access to additional e-journals published by the American Institute of Physics and Springer continues to benefit users, provided by the UGC Infonet Consortia programme for e-subscriptions, initiated by INFLIBNET, Ahmedabad.

Following the meeting of the members of the Forum for Resource Sharing in Astronomy (FORSA), which was organized at the National Centre for Radio Astrophysics (NCRA), Pune, during July 26-27, 2004, consortia subscriptions were initiated for Nature and Scientific American archives.

IUCAA has full-fledged publications department that uses the latest technology and DTP software for preparing the artwork and layout of its publications like the Annual Report, Quarterly bulletin "Khagol", Posters, Academic Calendar, Conference Proceedings, etc.

(III) Instrumentation Laboratory

The staff of the instrumentation laboratory have been involved primarily in four major projects in the recent years - Focal Plane Array data acquisition system, Near-infrared PICNIC Imager, Ultraviolet Imaging Telescope (UVIT) on ASTROSAT, and the IUCAA Girawali Observatory. The second one among the above has been discussed elsewhere in this report.

IUCAA Faint Object Spectrograph Camera (IFOSC) is the primary instrument on the direct Cassegrain port of the telescope. As part of the general redundancy development programme for the observatory hardware to minimize down time, work was initiated to develop and test a complete standby replacement for the EEV data acquisition system, which is currently being used on IFOSC. All the individual electronic cards have now been populated and the final testing of the individual cards are underway. In addition to the above, a thinned back-illuminated 2K x 2K CCD was purchased from E2V and a new controller for this chip is being designed and fabricated.

At the time of last year's report, a USB-based data acquisition system was under development and a Windows platform version of it was close to completion. This version was eventually used for testing the Star250 CMOS detector, which is to be used in photon counting mode on board UVIT. The tests were carried out to identify space qualified pieces from a large number of CMOS detectors. Single card controllers for STAR250 detectors and the USB2.0 based data acquisition system developed in the laboratory were used in two setups - one with high speed (10 MHz) clocks running infinitely for Dynamic Burn In Tests and another with preconfigurable speeds, exposures and frame numbers for Pre and Post Burn Tests (Image acquisition). The setups were installed at TIFR, Mumbai laboratory, where actual Dynamic Burn In tests of thirty detectors were carried out.

A linux-platform based USB data acquisition system is currently undergoing development and testing in the laboratory. This is eventually expected to replace the frame-grabber card based system, which currently being used on IFOSC and NIPI.

Another UVIT-related work, which is in progress in IUCAA laboratory is the test setup for scattered light attenuation modelling of the UVIT baffle. Tests were carried out on a factor-of-two downsized model baffle, by illuminating with laser beams at different locations and incident angles and checking the resultant scattered background at the image plane. Scattering properties of a number of surface coating materials are also being explored.

(IV) IUCAA Girawali Observatory

The observatory project successfully has completed three major milestones during the past one year: (i) completion of installation and system integration, (ii) commissioning and hand over, and (iii) commencement of science operations. After the quick achievement of engineering first light in late 2004 and the subsequent failure of the Cassegrain drive motors, the telescope system integration work could restart in earnest only in October 2005, after the monsoon season. Rapid progress was then achieved with integration, testing and performance fine tuning. This phase culminated with the final on-site acceptance tests being carried out in early February 2006 and the handing over of the telescope to IUCAA on February 14, 2006.

In October 2005, a test set up was made at the observatory off-telescope, for observers to start using the IUCAA Faint Object Spectrograph and Camera (IFOSC), the primary back end instrument. In addition to giving the observers a chance to familiarize with the instruments capabilities and limitations, this provided a lot of vital feedback primarily for the instrument control software system. Most of these bug-fixes and functionality enhancements were then incorporated to enhance the stability and usability of the software. A remarkable achievement of this was that due to the excellent state of preparedness at IUCAA, scientific observations could start at the observatory in January 2006 itself. This provided an oppurtunity to actually test the on-sky telescope performance parameters like image quality, autoguiding accuracy, sensitivity, etc. at their limits before the telescope was formally handed over to IUCAA. Figure shows the first deep sky (z = 3.9) object spectrum taken with IFOSC on January 19, 2006. The 3.5A resolution, 30 min integration IFOSC spectrum is compared with 6A resolution, 1 hour integration INT spectrum of the same source.

A second instrument for the telescope - a direct imaging LN2 cooled CCD camera with 1340 x 1300, 20 micron pixels was procured from Princeton Instruments, USA. This will be used in one of the Cassegrain side ports of the telescope and provides high spatial sampling imaging capability. A UBVRI standard filter set also has been procured, which can be used both with the PI CCD camera as well as IFOSC. The filter wheel and mounting arrangements for the camera were designed in the laboratory and is being currently tested on the telescope. The development of a third instrument for the telescope, the near-IR PICNIC Imager (NIPI) is discussed in another section of this report.

During the installation of the telescope, it was recognised that there was a problem with dust settling on the primary mirror and other optical surfaces. Efforts to identify a technique for periodic cleaning of the mirror led to the development of a CO2 snow-cleaning setup for the observatory, which has been effectively employed to keep the effect of dust minimum. In order to meet the need for re-aluminizing the optics, a coating plant is planned to be set up at the observatory. An order has been placed with M/s. Hindhivac Ltd., Bangalore, for providing a magentron sputtering based mirror coating plant.

Since the hand over of the telescope, a group of IUCAA astronomers have been carrying out science verification programmes at the observatory in order to (i) familiarize with the system, (ii) develop efficient observing techniques, and (iii) to characterize the performance and determine the limits that can be achieved with photometry, spectroscopy and polarimetry. These observations were carried out in service mode with some participation from a few interest groups outside IUCAA too. Some of the results from these observations are presented in Figures and . In summary, the science verification observations indicate that the telescope, observatory and site are performing close to the expected specifications and in certain instances better. The science verification phase is coming to a conclusion now, and the plan is to make the observatory available for the astronomy community through time allocation during the winter of 2006-'07.

In addition to the IUCAA laboratory staff (M. P. Burse, K. Chillal, P. Chordia, H. K. Das, S. Engineer, A. Kohok, V. B. Mestry, A. N. Ramaprakash, and S. N. Tandon) who were largely involved with the technical set up of the observatory, a group of astronomers (R. Gupta, Vijay Mohan, S. Ravindranath, and R. Srianand) have put in considerable efforts to carry out the science verification projects.

(V) Virtual Observatory- India

A Virtual Observatory (VO) makes possible the storage of vast quantities of astronomical data,

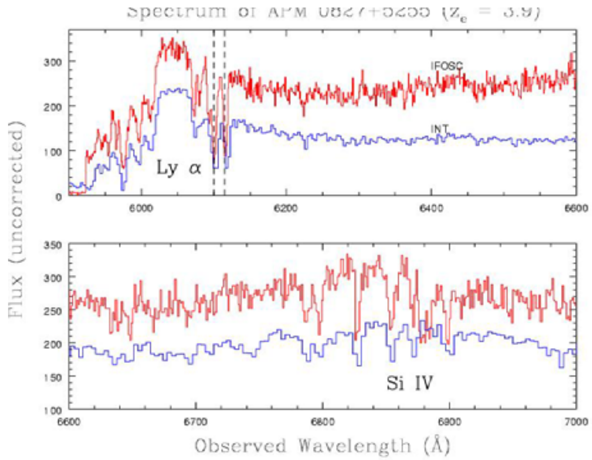

Figure 15: Quasar specturm at redshift 3.9

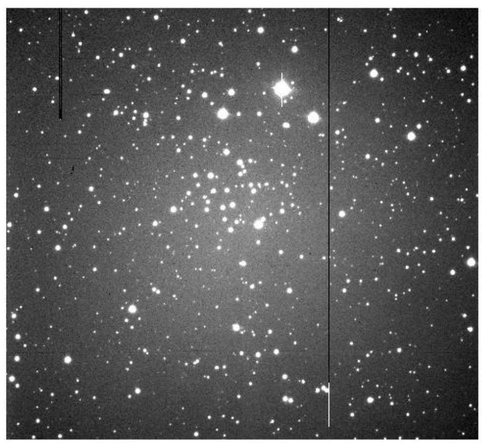

Figure 16: Open cluster King 17 V Band 10 arcmin across

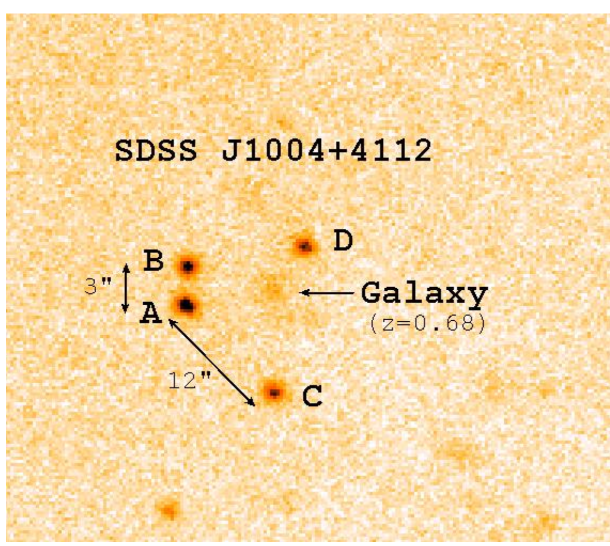

Figure 17: Gravitational lens R Band, 1 arcmin across

which can be retrieved over the internet and used by astronomers, wherever they may be located in the world. Virtual observatories have become indispensable tools in a situation, where vast quantities of data at different wavelengths are produced every night by major observatories on the Earth and in space. Data obtained at different wavelengths requires quite different techniques or analysis and expertise, which takes a long while to develop. However, the modern astronomer needs to take a multi wavelength approach to the study of astronomical objects, and it is necessary to have computational tools and resources for meeting this requirement.

A network of virtual observatories, each with large data mirrors in one domain on the other, and transparent and easy to use tools or analysis, will, therefore, prove to be a great boon to astronomers. With this in mind, virtual observatories have been set up in several countries over the last few years, and significant progress has been made in developing standards, data formats, query languages and software for analysis, visualization and mining.

The Virtual Observatory-India (VOI) project is a collaboration between IUCAA and Persistent Systems Pvt. Ltd. (PSPL), which is a major software development company in Pune, which expertise in data mining and related areas. The project is funded by the Ministry of Communication and Information Technology (MCIT) and PSPL. The hardware platform for the project is located at IUCAA, while the software development is undertaken in close collaboration at PSPL and IUCAA. VO-I has developed several tools, which have found wide acceptance in the international virtual observatory community, and have been used in making new and exiting scientific discoveries, including black holes in galaxies and rare kinds of stars.

During the period of the report, the original VO-I project came to an end, and a next generation VO-I project has been started, again as a collaboration between IUCAA and PSPL, and funded by MICT and PSPL.

The projects undertaken by VO-I during the period of the report are as follows:

1) VOPlot: VOPlot is a 2D/3D plotting and visualization package, designed for the VOTable data format, which is a XML based standard for representing astronomical catalogues. VOPlot supports position plots, histograms, statistics, overlay plots, creating new columns from existing ones and a host of other functions. The most striking feature of VOPlot is its ability to interact with other existing astronomical softwares e.g. Aladin (SkyAtlas). It has been integrated in many Astronomical Data Archives such as VizieR, Hubble Space Telescope Archive, OpenSkyQuery Portal. VOPlot lets astronomers do complex plotting, visualisation and statistics completely online, without having to download the data, and without having to issue any commands as VOPlot is completely event-driven. It is developed using Java Technologies. A number of important enhancements have been made to VOPlot during the period of the report, which include the use of multiple resources and multiple windows.

2) VOMegaplot: This is a tool used to provide much of the functionality of VOPlot, when the data sets being studied involve millions of points. Using VOPLot for such large data sets would mean prohibitive memory requirements, and to avoid which a wholly new package has been developed. The tool preprocesses the data base to be used, and creates a number of auxiliary files, which allow the plotting of millions of points in just seconds, on machines with normal specifications. The preprocessing has to be done just once for each catalogue, and features such as zooming, skyplots, etc are available.

3) VOStat: This was first developed as a VO compatible tool for statistical analysis of large data sets, as a collaboration between groups in Caltech and Penn Sate University. In collaboration with these two groups, VO-I is developing the next generation VOStat, with many statistical tests and a new interface. VOStat is being integarted with VOPlot, to provide to the community a very powerful tool.

(VI)IUCAA Radio-Physics Training and Educational Facility

IUCAA is setting up a novel Radio-Physics Training and Educational Facility in collaboration with neighbouring National Centre for Radio Astrophysics (NCRA). During 2005-06, work continued by *J. Bagchi* and NCRA collaborators towards set up of the 5 m radio telescope and the laboratory facility for experiments and calibration instruments. These will form the back-bone of this radio astronomy based educational and training laboratory. A proposal has been submitted to NCRA towards a formal collaborative venture and negotiations are on to chalk out an efficient work plan agreeable to both institutes for speedy completion of the project in near future.

The main observational facility will be a 5-metre Radio Telescope meant for solar (radio-continuum) and galactic (21cm hydrogen line) observations, which will also be used for radio astronomy training work for the benefit of university students and teachers. All major design parameters were finalised for beginnning the construction of the radio dish antenna. During phase-I, only one radio dish antenna is to be set-up and its performance would be carefully evaluated. Subsequently, in phase-II, a second similar (or better) radio telescope would be constructed for interferometric work. This radio

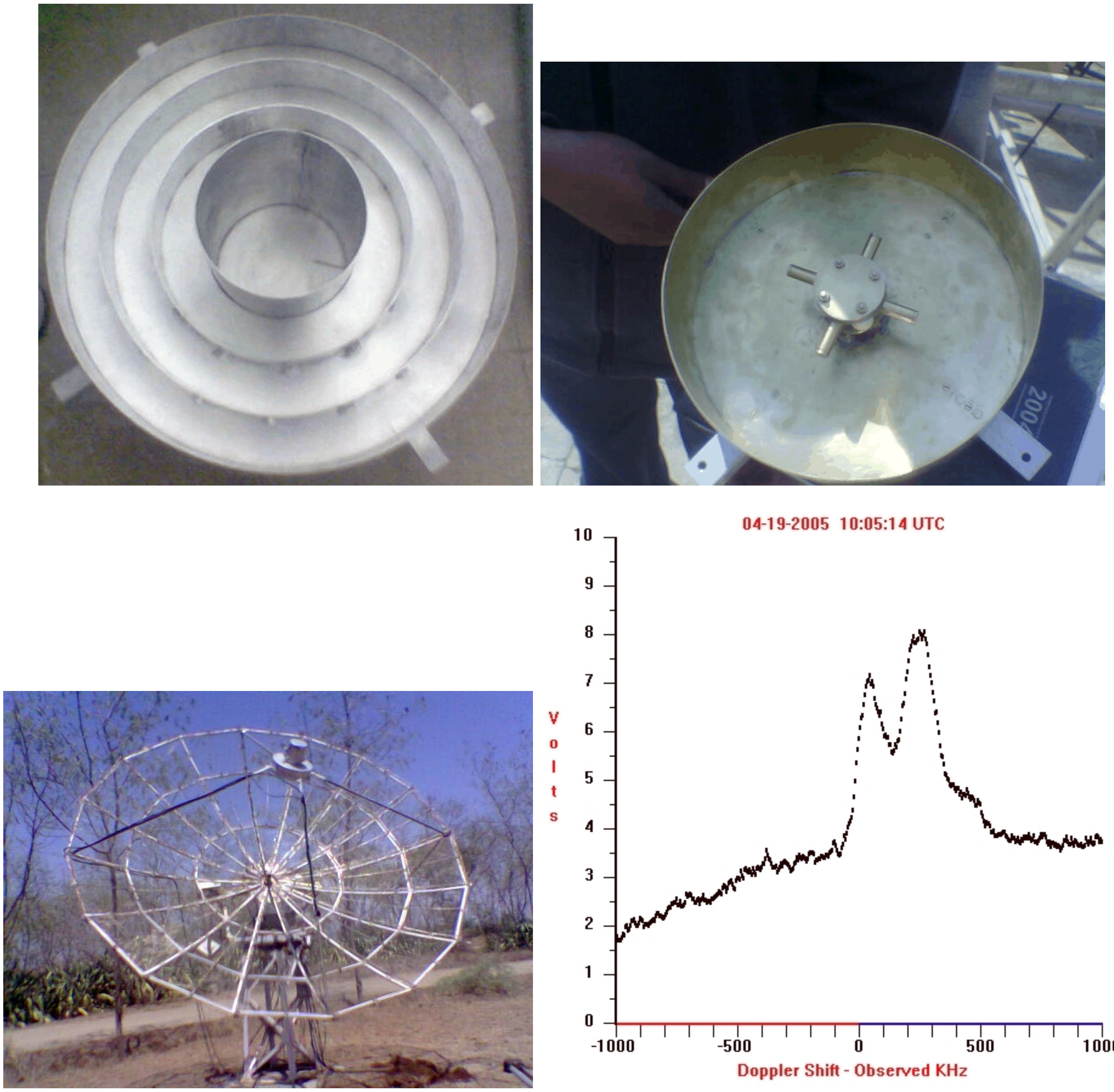

Figure 18: **Top Panel:** Two high efficiency feed systems fabricated by engineering students for 21cm (1420 MHz) radio astronomy observations. Left: A 'Chaparral' type feed horn containing multiple choke-rings or low-Q traps for higher gain and bandwidth. Right: A cavity backed dipole feed showing wide usable bandwidth range of 1.3 GHz. **Lower Left Panel:** The 21cm feed-horn is shown mounted at the focus of 4-m diameter radio antenna located at the GMRT observatory. **Lower Right Panel:** Raw data received with the 4-m radio dish antenna. It shows a complex 21cm hydrogen line spectrum from the direction of galactic Perseus and local arms. The x-axis shows Doppler shifted frequency in KHz, with red section denoting red-shift (+ve velocity) and the blue section denoting the blue-shift (-ve velocity). The y-axis is proportional to radio power or antenna temperature

antenna will be used for Solar radio astronomy, 21-cm hydrogen line observations, 6.6 GHz Methanol masers, and detection of strong extragalactic radio sources. In addition, it will serve as a vehicle for hands-on training in radio astronomy instrumentation and observational disciplines. Furthermore, this radio telescope and receiver system can also be used for SETI experiments (i.e., search for extraterrestrial intelligence) when operated at the 1420.4 MHz spin-flip transition frequency of neutral hydrogen.

Significant efforts were made by *J. Bagchi* and NCRA collaborators to promote Radio Astronomy in schools and colleges by way of lectures and many interesting hands-on type observational and instrumentational projects. As an example, A group of B.Tech. students from Pune's Wadia Institute of Technology (electronics and communication engineering), under the guidance of Rajaram Nityananda (NCRA), M.R. Sankararaman (NCRA), and *J. Bagchi* (IUCAA) used the prototype 4-metre diameter radio dish antenna located at the GMRT observatory for their project. For making radio observations with this small dish antenna, they also designed, fabricated and lab-tested a couple of innovative feed-horns operating at the 21-cm wavelength hydrogen band, as part of their project work [Figure 18] The electromagnetic performances of these students assembled feeds were found to be very good. High gain, low loss, and and a broad usable frequency range was achieved. These improved feed systems will be eventually used with the proposed IUCAA 5 m radio telescope, along with the front-end amplifiers and receivers for sky observations and radio astronomy training work.

IUCAA REFERENCE CENTRES (IRCs)

[1] Delhi University
(Coordinator: T. R. Seshadri)

During the period, 2005-2006, renovation of the IRC premises was completed, these were reoccupied by the IRC, and regular work was started afresh. There were several visitors and talks. There was an essay competition held for school students, in collaboration with Centre for Science Education, University of Delhi. V. S. Varma donated several books to the IRC library. Already, there are books lent on long term loan by IUCAA and books donated by V. B. Bhatia. The students are developing a software for keeping track of these books in the IRC.

<u>*Talks*</u>

B. Biswal: *Chaos control in epilepsy,* November 24.
A. Pradhan: *Kaluza-Klein type RW cosmological model with dynamical cosmological term Ë,* December 30.
N. Okada: *Low scale minimal SUGRA model and collider phenomenology on hidden sector fields,* January 17.
K. K. Dutta: *On the physics ideas behind the Nobel Prize for 2005,* January 31 and February 3.

<u>*Visitors*</u>

Ranjan Gupta (IUCAA, Pune), Arvind Paranjpye (IUCAA Pune), M. Varadharajan (RRI, Bangalore) and A. Pradhan (Ghazipur)

<u>*Other Activities*</u>
<u>*Essay Competition for School Students*</u>

Title: The most significant physics discovery since 1950. 43 entries were received from different schools**.**

[2] Pt. Ravishankar Shukla University, Raipur
(Coordinator: S. K. Pandey)

Faculty members, research scholars and students in the department as well as visitors have made use of the facilities available at the centre in strengthening their teaching/research activities in the field of A & A.

(a) Teaching: M.Sc. students of the department made use of the INTERNET facility for browsing and downloading articles useful for their studies. M.Sc. final year students, who had opted for A & A as specialization for their M.Sc. course used IRC facilities (INTERNET and library) in carrying out their project work. New state-of-the-art telescopes (CGE800 and CGE1400) and detectors (photometer and CCD spectrograph, etc.) procured under DST-FIST have helped the department in resuming observational exercises/projects in astronomy for the M.Sc. students.

(b) Research: the research activity of the faculty members and the research students is mainly focused in following areas:

(i) Dynamical modeling of elliptical galaxies carried out by D. K. Chakraborty and his research students.

Dr. Chakraborty is currently engaged in the study of intrinsic shapes of elliptical galaxies using photometric data. Research students working with him include Arun Kumar Singh, Firdaus and Arun Diwakar. Singh and Firdaus attended the YAM-2005 held at IUCAA and presented poster papers. A paper entitled "Variation of intrinsic shapes using photometry" has been submitted for publication and is currently under revision.

(ii) Research on Multi-wavelength surface photometry of early-type galaxies Has been carried out by S.K. Pandey and his research students, as a part of collaboration with A.K. Kembhavi and people from other institutes/observatories. The main objective of the research programme is to study properties of dust in extragalactic environment, and also to examine relationship of dust with other forms of ISM in these galaxies. A subsample of 10 nearby dusty elliptical galaxies were imaged in BVRI and H-alpha during 2005-2006 using the 2 m HCT of IIA. Preliminary data reduction is complete and detailed analysis of the dust is in progress. Laxmikant Chaware and S. Kulkarni are involved in this project.

(iii) Study of chromospherically active stars: Sudhanshu Barway has completed his thesis work in this area; he worked as SRF in a CSIR sponsored project and submitted his Ph.D thesis to the University during December 2005.

Other important activity of the centre has been to encourage M.Sc. students of the department to apply for summer schools/programmes, etc. of various institutes in the country. Applications of ten students from M.Sc. were forwarded by the IRC co-ordinators for the summer schools/summer projects to the institutes like IUCAA, NCRA, IIA, ARIES, and PRL. Four students of M.Sc. students got selected for summer school and VSP of IUCAA.

<u>*Talks*</u>

A. R. Rao: *Probing black holes using X-rays,* July 30.
P Sreekumar: *Chandrayaan-1: India's first mission to the Moon,* July 30
Ashish Mahabal: *Research avenues in A & A,* December 24

Lectures/ Radio talks delivered by S.K. Pandey

S. K. Pandey : *Bhartiya Antix Karyakrama Ke Vividh Aayam (Hindi Roopak),* February 19 (Radio talk/ interview).
S. K. Pandey: *A physicist view of the universe,* Sri Shankarcharya College of Engg. & Tech., Bhilai, April 19.
S. K. Pandey: *Our universe,* CMD P.G. College, Bilaspur, September 6.
S. K. Pandey: *How well do we know our Universe,* BSP Sr. Sec. School, September 23.
S. K. Pandey: *Discovering the cosmos,* Disha College, October 1.
S. K. Pandey: *Inaugural lecture on lfe-cycle of stars,* Physics Society at Kalyan Mahavidyalaya, Bhilai Nagar, November 12.
S. K. Pandey: *A glimpse of the universe (in Hindi),* National Science Festival for School students, SCERT, Chattisgarh Govt., November 15.
S. K. Pandey: *Discovering the universe,* Bhilai Nair Samajam College, Bhilai, November 19.

Visitors

Vivek Agrawal (ISRO, Bangalore), A.R. Rao (TIFR, Mumbai), P. Sreekumar (ISRO, Banglore), Subhash Kaushik (Govt. College, Datia (M P)), M.K. Patil (SRTM Univ., Nanded), Ashish Mahabal (Caltech, USA), Laisram Dharendra (Manipur University).

Other Activities
Sky gazing programme

On March 29, 2006 a public show of partial solar eclipse was organized using the 8-inch telescope fitted with solar filter, and this attracted attention of media/local newspaper.

[3] North Bengal University, Siliguri
(Coordinator: S. Mukherjee)

In addition to the usual visitors and lecture activities, an Introductory Workshop on Astronomy and Astrophysics was organized at J. K. College, Purulia, West Bengal during February 23-25, 2006. The programmes included lectures by Professors A. K. Kembhavi, R. Gupta (both from IUCAA), S. Kar (IIT, Kharagpur), S. Raha (Bose Institute, Kolkata) and S. Mukherjee (North Bengal University), discussion sessions, and night sky observations, which was conducted by scientists of Positional Astronomy Centre, Kolkata. About 80 students and 20 college teachers participated in this workshop. S. Mukherjee and A. Kembhavi were the academic Directors of the workshop.

Talks

G. Singh: *Liquid-gas phase transition through projectile fragmentation at relativistic energy,* April 19.
R. Tikekar: *On relativity and cosmology,* April 26.
A. Bhattacharyya: *Mixed surfactant poly-electrolyte systems: Surface rheology and other properties,* May 17
Amit Chakraborty: *Carbon Nano-tubes and its application to nano-technology,* April 29
Prabasaj Paul: *Visualizing Relativity,* November 28
T. R. Govindarajan: *Einstein's legacy and quantum geometry,* December 9
S. Mondal: *Bringing physics to Life,*
Biswajit Paul: *Sky watching in X-rays and the Indian Experiments,*
M. Narlikar: *Fun with mathematics*, March 23.
J. V. Narlikar: *Gravitational collapse with negative energy fields,* March 24.

Visitors

B. Bhattacharjee, J. V. Narlikar (IUCAA, Pune), M. Narlikar (Pune), P. Chattaopadhyay, P. Thakur.

Other Activities
Essay Competition for School Students

52 essays (32 Bengali and the rest in English) were submitted. There were entries from North Bengal, North Eastern States and Sikkim. The results of the competition have recently been announced. The first three entries will receive cash prizes. The authors of the next ten best entries will receive certificates of merit.

[4] Cochin University of Science and Technology, Kochi
(Coordinator: V. C. Kuriakose)

The facilities available at IRC has been regularly used by both M.Sc. students for their project work and Ph.D. students and the faculty members. Talks, Seminars and colloquia were held under the joint auspices of IRC and the department. The colloquia gave a chance to IUCAA Associates of this region to present their and their students' works and helped them to interact with others. The colloquia were attended by students and Faculty members who are not IUCAA Associates. The IRC Library contains 47 books and 4 computers and a printer. Internet connectivity is also provided in the IRC room. February 28th was celebrated as National Science Day and the film on Professors A.K. Raychaudhuri and P.C. Vidya was screened on the occasion. Students from neighbouring institutions also come for using the library facilities. IRC also conducted an essay competition for the students of Higher Secondary School as part of the celebration of WYP 2005.

Talks

K. Babu Joseph: *Quantum coherence.*
R. Vijaya: *Lasers*
A. Kembhavi: *Gravity and Light: Journey from light bending to cosmic lenses.*
C. D. Ravikumar: *The Cosmic dance: Galaxy interactions.*
Bala R. Iyer: *Gravitational waves.*
M. Sabir: *Quantum computing.*
K. P. Vijayakumar: *Effect of doping on the properties of ZnO thin films.*
Ramesh Babu T: *Quantum coherence.*
K. J. Saji: *Plasma diagnosis: Controlling growth of thin films.*
P. I. Kuriakose: *No-hair theorem*, October 25.
Moncy V. John: *Was there a decelerating past for the universe?*, October 25.
K. S. Sumesh: *Irregular pulsation in the mira vaiable Rhydrae*, October 25.
K. Ambika: *Patterns and their dynamics in Gumoski Mira map*, October 25.
Jisha C. P.: *Spatial solitons*, October 25.
K. P. Harikrishnan: *Stochastic Resonance with multisignal inputs*, November 19.
V. C. Kuriakose: *Quantum computing using Josephson junctions*, November 19.
R. Radhakrishnan: *Higher order stark correction in atomic hydrogen*, November 19.
R. Sini: *Black hole scattering*, November 19
P. B. Vinodkumar: *Different notions of chaos*, November 19.

Visitors

Ninan Sajeeth Philip (St. Thomas College, Kozenchery), T. Padmanabhan (IUCAA, Pune), A. Kembhavi (IUCAA, Pune), Bala R. Iyer (RRI, Bangalore), C.D. Ravikumar (GEPI, The Paris Observatory, Meudon), R.Vijaya (IIT Bombay), P.P. Divakaran (IMSc., Chennai), K. Porsezian (Pondicherry University).

Other Activities
Essay Competition for School Students

IRC has organized an essay competition for students of Higher Secondary Classes in Kerala. 75 students appeared for the competition. First prize was not awarded as advised by the judges. Second and third prizes and certificates of merit for the next 10 students were given.

Lecture series : Professor T. Padmanabhan gave a series of lectures on "Aspects of Gravitation" during August 10-14, 2005. This was attended by the M.Sc. students, and research scholars and faculty members of the department. He also led an interactive session with Higher Secondary School students from neighbouring schools.

[5] Jadavpur University, Kolkata
(Joint Coordinators: Narayan Banerjee and Asit Banerjee)

The Centre organized a few public lectures and some series of lectures and workshops in addition to the regular seminars. Some of the members participated in various activities like taking part in conferences, workshops and also giving popular lectures. An essay competition was organized for High School students. In the loving memory of Professor A. K. Raychaudhuri, a two day seminar was organized, spread over two successive Tuesdays. Five of his Ph.D. students talked about their work that they did under his supervision.

In addition to the regular Tuesday seminars at the Centre, public lectures were organized to celebrate the Year of Physics.N.Panchapakesan and C.V.Vishveshwara delivered two lectures, which were aimed at a wider audience. These lectures were well attended. They also gave a series of technical lectures, Panchapakesan on cosmology and Vishveshwara on black holes. Visitors like Naresh Dadhich, S. Mishra and T. K. Das gave seminars which were attended by senior students along with the regular members of the Centre. G.M.Hossain conducted five lecture workshop on Loop Quantum Cosmology. This workshop was also attended by research students from other institutes.

Members of the Centre, Asit Banerjee and Narayan Banerjee went to different colleges and gave talks for undergraduate students as a part of celebration of the International Year of Physics.

Narayan Banerjee gave a lecture at the IUCAA workshop at St. Xaviers College, Kokata He also gave a course on Cosmology at the AKR Gravity School organized at Saha Institute of Nuclear Physics.

Visitors

N. Panchapakesan (University of Delhi), Ranjeev Mishra (IUCAA, Pune), Naresh Dadhich (IUCAA, Pune), Golam Mortuza Hossain (IMSc, Chennai), Tapas Das (HRI, Allahabad), C. V. Vishveshwara (Bangalore).

Other Activities
Essay Competition for School Students

IRC organized an essay competition for High School students on 'The most important milestone in twentieth century physics' as a part of celebration of the International Year of Physics. There was a very good response as around 100 essays were enrolled for the competition. The results were declared in December 2005.

[6] D.D.U. Gorakhpur University
(Coordinator: D. C. Srivastava)

At the centre, visitor scientists use the library and the internet facility. Their seminar/ lectures are also organized. Weekly seminars by the faculty members and research scholars are held in the department. These provide an opportunity for interaction and exchange of ideas. The library contains the books loaned by IUCAA. At present a dial up internet facility is available. IRAF: an image analysis software is being used at centre. AIPS is also being installed for analysis of radio data. These and other activities detailed below are growing at normal pace.

<u>*Talks*</u>

D. K. Tripathi: *Studies of solar coronal mass ejection,* April 02.
Ram Sagar: *Recent devlopments in observational astrophysics,* October 06.
Ram Sagar: *Relevance of astrophysics in modern science,* October 07.

<u>*Visitors*</u>

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Seventeenth IUCAA Foundation Day Lecture
Controversies in Physics at the Planck Scale

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Abstract

Both at extremely large and at the very tiniest distance scales, the Laws of Physics are poorly understood. The best we can do is to extrapolate those Laws of Nature that we do understand. Where obstacles are encountered, opinions on how to proceed diverge wildly. The author's own position is presented here.

1. Introduction

One upon a time, there was a point. The point had no extension in space, nor in time. Yet the point was very special — nothing else existed, not even was there a Universe surrounding it. It was just a point.

Then the point exploded. It was the most violent event ever to take place, It was at this explosion that the fabric of space and time itself was being created. It was the beginning of the Universe. What happened, immediately after this explosion, is the domain of theoretical speculations. We do know for certain that the Universe underwent a spectacular expansion such that, in an extremely tiny fraction of a second, the spatial dimensions became huge, much larger than the distance light could have travelled in this short time interval[1]. Detailed calculations using all we know today about the laws of Nature, lead to the expectation that the Universe must have been filled with light, and that this light fluctuates. The earliest direct experimental evidence concerning this history is a snapshot made with microwaves. The picture obtained shows very little structure unless we enhance the contrast by a factor of nearly one million. This leads to the picture of Fig. 1.

The Universe must have been approximately 380,000 years old when this light was generated. What is exciting about this picture is the intricate pattern of correlations, which is being analyzed by theoreticians. These correlations appear to be fossils dating way back to the tiniest fractions of a second after the Big Bang. At that time, the spatial dimensions of the fluctuations were like those of the atomic nuclei or smaller, but after a few million years, they began

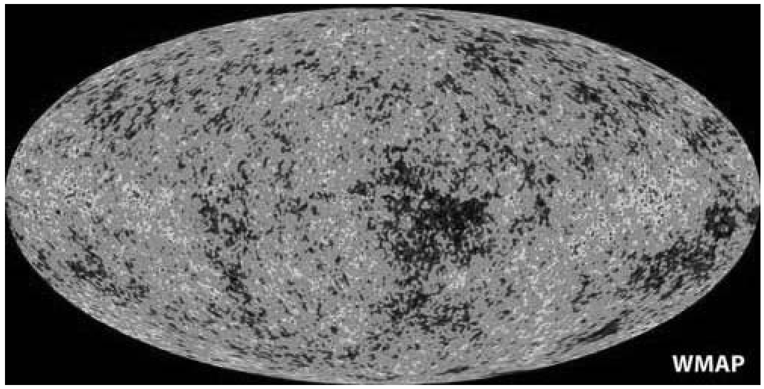

Figure 1: The Wilkinson Microwave Anisotropy Probe generated this picture of the Universe at age 380,000 years.

to accumulate matter around them, and eventually became galaxies, or groups of galaxies.

The next picture made of the Universe is shown in Fig. 2. It shows galaxies at great distance from us, indeed so far away that they are seen at a considerably younger age than that of the Universe today. Therefore, these galaxies look different from galaxies much closer to us, such as the Andromeda Nebula. Indeed, they are smaller. Today's galaxies each are the result of numerous accumulations of smaller star systems into bigger ones.

2. Gravity

The dominating force in the Universe at large, appears to be the gravitational one. It is this force that causes galaxies to form, and to accumulate into bigger ones, that causes dust and gas clouds to contract, forming stars and planets, and it is the force controlling the orbits of stars, planets and moons everywhere. As was discovered by Einstein in 1915, the gravitational force results from geometrical properties of space and time. This basic discovery had far-reaching implications.

In 1865, Jules Verne wrote his famous science fiction story *From the Earth to the Moon*. It tells the story of three well-to-do members of the 'Baltimore Gun Club', who decided to build the biggest canon ever, whose bullets could reach to the Moon. A hollow bullet, housing three astronauts, a dog and some chicken is fired to the Moon. What Jules Verne knew was that, somewhere between the Earth and the Moon, there is a so-called Lagrange point, a point where the gravitational field of the Moon counter balances the force from the Earth. When the space ship reached that point, suddenly the inhabitants felt

Figure 2: The Hubble Space Telescope took this picture of the Universe when it was only a few billions of years old.

complete weightlessness.

This, we now know, was not quite right. The astronauts must have been weightless throughout the journey, as long as they stayed outside the Earth's atmosphere. The reason for this is that the inhabitants of the bullet underwent the same gravitational forces as the bullet itself, so they were following exactly parallel trajectories. There was no reason for the travellers to be moving towards any of the walls, the floor or the ceiling of their ship. If we were to introduce a set of coordinates describing all points in space and in time, describing the immediate neighbourhood of the spacecraft, then all freely falling objects would follow straight lines in this coordinate frame. Therefore, we say, space and time in the neighbourhood of the spacecraft, in a very good approximation, are flat.

In Fig. 3, an artist's impression is given of curved space near a heavy star or planet. The coordinate frame is distorted by the curvature. If we follow a single particle, we can surround it by more or less flat coordinates, but then its trajectory becomes curved, with respect to more distant reference points. This curvature is bigger close to the planet (B) than far away from it (A). This way, one can understand gravity as being a geometrical effect.

Gravity has the peculiar feature that it is *always* attractive, and it is cumulative, with which we mean to say that massive objects tend to attract other massive objects, become even more massive and generating even stronger attraction. This situation is unstable. If large enough amounts of mass accumulate, this attraction can become so strong that nothing can be allowed to escape, even light cannot escape. The resulting configuration is called a *black hole*; the space-time curvature here becomes so strong that a singular situation is reached. One

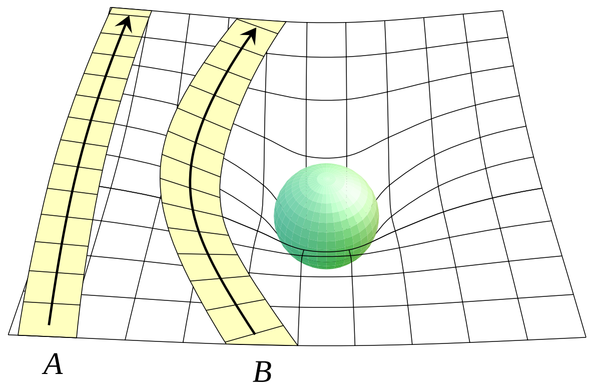

Figure 3: Curved space and time near a heavy star or planet.

can calculate that then a 'wormhole' may form, a natural connection between one piece of the Universe with another, or perhaps with an entirely different universe. Unfortunately, this wormhole only exists in an idealized, mathematically pure black hole. As soon as something falls into the black hole, disturbances would actually block the exit towards the other universe, so the wormhole cannot be used in the way speculated upon by science fiction authors, to travel from one spot in the Universe to another one, illegally violating the light speed limit.

3. Particles

At tiny distance scales, the forces that play a dominant role are quite different ones. There, we are dealing with the building blocks of matter: molecules, atoms, and the sub-atomic particles. There are more than 10^{80} sub-atomic particles moving around in the small part of the Universe, that is presently visible to us. When particles are in each other's vicinity, the three basic forces that determine their behaviour are the *weak*, the *electro-magnetic*, and the *strong* forces. All three of these forces have been shown to be special cases of a Yang-Mills theory. They obey the very basic Yang-Mills equations, which are generalizations of the Maxwell equations for electro-magnetism. The particles also interact with a ubiquitous scalar field, the Higgs field, and they owe much of their special structures, such as their masses, to this interaction with the Higgs field. All these are described by what is now known as the Standard Model[2], and the basic outlines of this model are so transparent that they can be pictured on a necktie.

As seen from the perspective of the sub-atomic particles, the world looks very different from the large-distance description provided by astronomy. In this domain, all dynamical features of particles and fields have to be tailored in accordance with quantum mechanics. Quantum Mechanics is a magnificent achievement of 20^{th} century physics, providing a logically coherent and exhaustive framework for all interactions. Yet quantum mechanics is also a bit mysterious, since it is not attempting to describe what exactly is going on between these particles, but directly produces expressions for the *probabilities* of the results of experiments. Well, even if Nature's laws were completely deterministic, then still the initial conditions of an experiment, such as the exact locations of particles inside a beam of particles, would not be well enough known to enable us to give more precise predictions than probabilistic ones, so in practice, nothing is lost. However, quantum mechanics not only does not describe the histories of individual particles, but indeed *cannot* provide with any particular possible history of the motion of particles, and this fact is considered disturbing by some physicists.

There are different ways to interpret these observations[3]. The first approach that has been considered over the years, is to assume that the motion of individual particles is confounded by the action of additional degrees of freedom that are difficult to monitor, or even to identify. Perhaps every particle carries with it a "flag" that indicates which of its observable operators is in a precisely defined state. It was demonstrated, however, that such ideas are untenable. The "hidden variables" would have to obey non-local equations of motion, and logically acceptable, or 'natural' models for such scenarios were not obtained.

Alternatively, one could presume that the quantum wave functions have some ontological meaning, and that the motion of an individual particle is determined in a deterministic fashion by apparently stochastic phenomena in conjunction with the wave function[4]. The ensuing pilot wave function theory can be shown to be equivalent to quantum mechanics mathematically, but its complex, non-local nature has not made it very popular.

It would perhaps be better to search for a theory, where the wave function plays exactly the same role as probability distribution functions in classical statistical physics, an approach that is being pursued by the present author. In this approach[5], all present notions of particles and fields should be replaced by different, ontological parameters, which, unfortunately, have not yet been identified or modelled in a satisfactory manner.

A majority of physicists, however, accept the idea that we have to take quantum mechanics as it is, declaring questions about its ontological meaning as being illegal ones to ask. This attitude has proven to be so successful in the past, that today almost all fundamental theories about forces and matter, about space and time, have been modelled with the notion of a quantum mechanical Hilbert space as a primary starting point, and all one has to do is to identify the operators and their algebraic relations, assuming our universe to evolve as a state in this Hilbert space.

Experimental investigations have corroborated the Standard Model at distance scales of the order of 10^{-18} m., but theoretically, the model can be extrapolated to distance scales much tinier than that. In order for this extrapolation not to be too unnatural, one is forced to assume the existence of large classes of elementary particles that have not yet been explicitly identified. The simplest way to do this is to assume an enhancement of the presently observed symmetry pattern into a *supersymmetric* one: every bosonic particle must have a fermionic partner and *vice versa*. We can then reach down to the order of 10^{-33} m, where all known forces, except gravity, become of equal strength. It is assumed that further unification of forces takes place there. At the *Planck length*, 10^{-35} m, gravity also joins in.

It may seem that we are closing a circle here: gravity dominates at the extremely large scales in the Universe, and finally at the very tiniest distance scales, again the gravitational force takes over. There are, however, fundamental differences between these extreme ends of the spectrum of scales: at the smallest scales, quantum mechanics must be playing a very dominant role as well. The dominant role of gravity modifies space and time so much at these tiny scales, that we will be forced eventually to abandon the familiar picture of nature, where in a background fabric of space and time particles follow well defined trajectories — particles make their own space and time. We will argue, however, that the standard description of quantum mechanics itself may have to be modified if we want to understand better what is going on.

4. Quantum gravity

In several respects, the gravitational force is remarkably similar to the other forces that are affecting particles. First, all fundamental forces appear to be based on a $1/r^2$ law. This distance dependence is a simple consequence of the action principle, when field equations are cast into an Euler-Lagrange form. Just as is the case with the other forces, the gravitational force can be viewed in a quantum setting by attributing it to the exchange of force carrying particles. The particles transmitting gravity, the *gravitons* only differ from photons, gluons and the weak charge carriers that they have spin *two*, a necessary consequence of the tensor nature of the gravitational field in general relativity.

The reasons why the graviton has spin two, can be illustrated graphically (see Figure 4). The gravitational field of the Moon is felt on Earth only indirectly, through the tidal force. This force causes water on Earth to be attracted towards the Moon wherever it is closer to the Moon than the Earth's own centre of gravity. Masses of water further away from the Moon, are catapulted away because of the orbital motion of the Earth around the center of gravity that Earth and Moon have jointly. Thus, there is high tide both on parts of the Earth facing the Moon, and on parts facing away from the Moon, and there is low tide on spots 90° from the direction of the Moon. While the Earth rotates with respect to the Moon, we have twice high tide and low tide during a full (relative) rotation. Thus, the strength of the tidal force oscillates with two complete periods during one full rotation. This is the wave function of

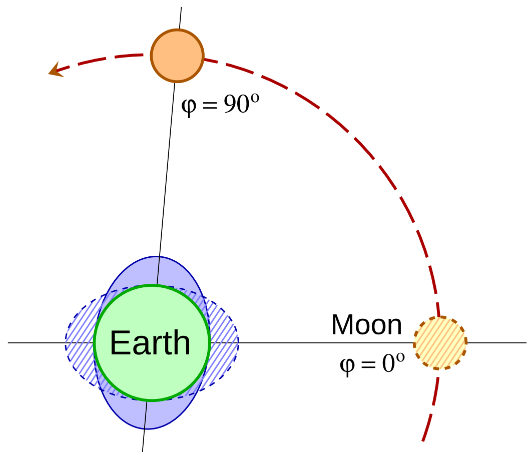

Figure 4: The tidal force transmitted by gravity switches sign when the Moon is displaced by $90°$, so it oscillates twice when the Moon goes full circle.

"something" with spin-angular momentum of two units. Thus, the graviton has spin two. We should stress, of course, that this argument should merely serve as an illustration. It does exhibit the mathematical nature of gravity, but more trustworthy derivations come from more accurate quantum field theoretical arguments.

We already mentioned a subtle difference between gravity and many of the other forces, the fact that, in gravity, sources of the same sign attract rather than repel. Since all masses are positive, all objects in nature feel attractive gravitational forces. This feature is directly related to the spin of the carrier. The rule is: force-carrying particles of odd spin, such as the photon, will cause objects whose charges are of opposite sign to attract, while charges of equal sign repel. In the case of spin 2, this is the other way around, just as in the case of spin zero: the nuclear force holding protons and neutrons together inside an atomic nucleus, is also attractive between all protons and neutrons (they all carry the same sign). The force carrier there is the pion, which has spin zero. At much smaller distances, the rho meson with spin one keeps the nucleons from approaching one another too closely.

An other subtle but important distinction enjoyed by the gravitational force is the fact that it acts on *mass* rather than charge. Indeed, there exists no other candidate sources for tensor fields than mass, because the *only* Euler-Lagrange system for relativistic tensor fields is the one that exhibits the local invariance structure of general relativity. The consequences of these minor differences are catastrophic. Since like masses attract, gravity causes an accumulation of mass. The resulting mass concentrations generate stronger and stronger gravitational fields. This may lead to a fundamental instability of gravitating systems against implosion, an instability that sometimes inevitably leads to the formation of black holes. We may also relate this instability to the fact that gravitational fields have a *negative* energy density.

Mass carries the dimensionality of energy, which is an inverse length, in units where the speed of light $c = 1$. Since

$$M = \frac{E}{c^2} \;\to\; \frac{h/c}{\text{wavelength}} \,, \tag{4.1}$$

the distance dependence of the gravitational force in a quantum-relativistic environment boils down to

$$\text{Force} \;\to\; G \times \frac{M_1 \times M_2}{R^2} \;\to\; \frac{G\,h^2}{c^2} \times \frac{1}{R^4} \,. \tag{4.2}$$

Thus, gravity will become more singular at small distances than the other forces.

The Planck scale is defined to be the domain of physics, where gravity becomes a strong force, comparable to other strong forces among fundamental particles. Using

$$\begin{aligned} h/2\pi \;=\; \hbar \;&=\; 1.0546 \times 10^{-34} \quad \text{kg m}^2\,\text{sec}^{-2}\,, \\ G_N \;&=\; 6.672 \times 10^{-11} \quad \text{m}^3\,\text{kg}^{-1}\,\text{sec}^{-2}\,, \\ c \;&=\; 2.99792458 \times 10^{8} \quad \text{m/sec}\,, \end{aligned} \tag{4.3}$$

one arrives at the natural units of length, mass and time:

$$\begin{aligned} L_{\text{Planck}} &= \sqrt{\frac{\hbar\,G_N}{c^3}} = 1.616 \times 10^{-33}\ \text{cm}\,, \\ M_{\text{Planck}} &= \sqrt{\frac{\hbar\,c}{G_N}} = 21.8\ \mu\text{g}\,, \\ T_{\text{Planck}} &= \sqrt{\frac{\hbar\,G_N}{c^5}} = 5.39 \times 10^{-44}\ \text{sec}\,. \end{aligned} \tag{4.4}$$

Phenomena that take place at these extreme scales of length, time and mass, require relativity theory, gravity theory and quantum mechanics for a proper description. All these effects are than comparably strong. Attempts to understand their consequences, are hampered by several quite severe difficulties, leading to intense disputes among theoreticians:

- Space-time fluctuations run put of control; consequently, ultraviolet contributions to the quantum amplitudes are dominated by infinities that cannot be handled by any of the standard renormalization schemes.

Superstring theory is making strong claims of being able to handle these infinities[6]. The superstring diagrams do not require infinite renormalizations, so they should act as 'regulators' for these infinities. However, in superstring theories only the *on shell* amplitudes are finite; the others are ill-defined. Analogously to conventional field theories, this appears to mean that, although the theory can make predictions for experimental output, it is not properly describing what goes on at small distances. Therefore, we obtain no physical insight as to what it exactly is that happens at small distance scales.

- The definition of *time* becomes ambiguous; one cannot talk of the 'state of the Universe' at a given time.

Here, the standard answer is that the Schrödinger equation is to be replaced by the Wheeler - DeWitt equation[7]. There is a similar objection here. The Wheeler - DeWitt equation cannot tell us how, at any given time, the state of the Universe evolves and how this evolution can be tested against unitarity and causality. In *perturbative* quantum gravity, we encounter no such problem. In perturbative gravity, we still are allowed to keep clocks and yard sticks at spatial infinity, and define time by imposing gauge conditions on Cauchy surfaces. This theory is unitary and causal in the usual sense[8].

- The Universe might close into itself, in which case, the exact interpretation of quantum amplitudes in terms of the 'probability' that something happens, becomes problematic.

The answer to this puzzle is usually assumed to be that we have to consider the 'statistics of possible universes'. However, the real universe does not close into itself, and experimental tests of the abundances of different universes are fundamentally impossible.

- Notions such as"distance" and "locality" become ambiguous.

Some theoreticians see no problem here; they claim that the ultimate laws of physics apparently are non-local. Admitting non-locality, however, would be like opening Pandora's box. We would no longer be able to assume a chain of deductive arguments explaining the physics of large scale phenomena in terms of smaller scale phenomena, and the internal logic of our attempts to understand things would be seriously undermined.

We should address such problems with extreme care and try to keep our links with conventional, well-understood theories as strong as possible. We could start with asking the question: if indeed gravitational fields are causing such severe problems for us when they become strong, then exactly which are the circumstances where these field take the *strongest* possible values? What are the most essential features of the gravitational force in that case?

5. Black Holes

The strongest gravitational fields are found near black holes[9]. At the horizon of a black hole, the gravitational potential has the highest possible value, which is always such that, in a test body, it cancels the rest energy, mc^2, entirely. The gravitational field strength is the highest for the tiniest black holes. A black hole is a completely legitimate solution of Einstein's gravitational field equations, and, at least in principle, there seems to be no limit to the size of a black hole: it could be very large or very small, as long as quantum effects can be neglected. Only when the size is assumed to be comparable to the Planck size, $L_{\rm Planck}$, the quantum effects are expected to become so large that the notion of a black hole ceases to make sense.

A nice feature of black holes is that applying quantum corrections seems to be straightforward. Field operators can be assumed to be present in the geometry of space and time defined by the black hole, and we can investigate what the known laws of nature tell us about how they evolve. As was discovered by Hawking[10], one must conclude that there is a steady emission of particles. A possible interpretation of this emission process is as follows. Outside the black hole, in the part of the universe accessible to us, called region I, quantum fluctuations take place, generating pairs of particles with positive or negative energies, such that the total energy has the fixed value zero. Negative energy particles cannot exist freely, since there exist no solutions to their field equations with negative energy, so these particles quickly annihilate against other fluctuating particles that happen to have positive energies.

However, some of these fluctuating particles might enter into the black hole, in a region called region II. There, different laws hold: particles are allowed to have negative energies, but they are not allowed to emerge from the black hole; they proceed inwards towards the singularity at the centre. If a particle pair is formed right at the horizon separating regions I and II, it may happen that the negative energy particle falls into the black hole, and the positive energy particle escapes to infinity. Since, negative energy is fed into the black hole, it looses energy, hence it looses mass, and becomes smaller. This result is not much disputed, although one might question the validity of the usual normalization conditions for amplitudes at a horizon; it could be that an unusual normalization condition should be required, which could strongly affect the intensity of the radiation: the radiation temperature could be twice of what one usually expects.

The implication of this radiation phenomenon is astounding. If we would take *any* tiny material object that is capable of both absorbing and emitting particles, such as a molecule that can emit or absorb radiation, or a snowflake that can condense or evaporate, in short, an object for which an interaction as well as the time reverse of that interaction can be calculated, then we find that the *ratio* of the probability of an event and that of its time reverse to be determined by an essential factor: the *total phase space of all of its states.* The logarithm of the number of these states turns out to be the total entropy of the object. For black holes, this simple observation directly yields the value of their entropy. It turns out that the entropy of a black hole is equal to the area of its horizon, multiplied with a universal coefficient with Planckian dimensions. Or, in other words, a black hole carries one bit of information for every 0.724×10^{-65} cm^2 of its horizon area.

Thus, black holes come in distinct states, and as such, they are now very reminiscent of elementary particles, which also come in distinct states that can be listed in tables such as the ones published yearly by the Particle Data Group. The theory of general relativity now suggests that all physical properties of the horizon of a black hole can be *mapped* onto the properties of a practically flat, and empty, spacetime, so we should be able to determine in great detail everything we wish to know about this list. Unfortunately, this is not at all so straightforward. If black holes were like elementary particles, it should be possible to represent them as *pure* quantum states. In contrast, the thermal nature of the Hawking emission process, at first sight appears to imply that the horizon can only be understood as a quantum mechanically *mixed* state.

The way one arrives at the Hawking radiation feature, one starts out with particles in well-defined quantum states before they enter into the horizon of a black hole. The Hilbert space of states then evolves as a product of two such spaces, one consisting of particles inside the black hole (region II), and one consisting of all particles that can still be observed from the outside (region I). Since one cannot observe the particles in region II, one has to trace out the contributions of their wave functions, and, as is well-known in statistical physics, this procedure leaves us behind with a quantum mixture. However, ordinary quantum systems cannot spontaneously evolve from pure states into mixed states. If they would, then there would not exist such a thing as a scattering matrix for black holes. Something is wrong.

6. The Horizon

In the 1980s, when they became more acutely aware of the problem, the community of physicists divided into three different schools of thought. The dividing lines were roughly along the lines that separated specialists in general relativity from those in superstring theory and those of more down-to-earth elementary particle physics:

(*i*) The first group[11] accepted the fact that black holes entire do not obey quantum Schrödinger equations. They are 'doorways to an other universe', and so they cannot be quantum mechanically unitary — unless one includes the entire Hilbert space of that other universe — which is far too large to generate the discrete states mentioned in the previous Section. There would be a problem with energy non-conservation, which could be circumnavigated, at the expense of some fundamental non-locality. But one then cannot sustain the hope that black holes just extend the spectrum of elementary particles, and a fundamental bit of predictability of the physical laws will be lost. Since black holes can be formed as vacuum fluctuations at the Planck scale, this would mean a complete loss of quantum predictability at the Planck scale. But then why is it that quantum mechanics survives so beautifully at larger distance scales?

(*ii*) The second school of thought was that, if particle physicists really want information to be preserved, they can have it, but the information would be piled up inside the black hole until its last moments of evaporation. At that point, black holes would be forbidden to decay entirely into ordinary particles, so, they would leave some balls of information behind, the 'black hole remnants'[12], a kind of dust grains with masses comparable to the Planck mass, but containing a practically *infinite* amount of information. These remnants would be fundamentally different from ordinary particles of matter, since they are basically non-quantum mechanical. It sounded as by far the ugliest theory, but it was seriously proposed and defended.

(*iii*) Only a small minority saw the real truth[13]. Black holes *are* quantum mechanical, but the 'quantum information' simply leaks out disguised as Hawking radiation. This would turn black holes into completely conventional forms of matter, and it would be exactly what one gets if a calculation is done in a limit, where the number of degrees of freedom becomes large and has to be treated statistically. The only point here is, that Hawking's derivation then is not *exactly* right, but only in a statistical sense. This is very important. It is not a criticism against Hawking's derivation, because it was exact, but it made use of the laws of Nature *as we know them today*. Do we know them sufficiently accurately? There is no reason to believe that. If we would even try to imagine a pure quantum state at the horizon, it would require a particle density that goes beyond the reach of the presently known Standard Model. Presumably, this model has to be modified under such circumstances. In fact, we *know* it has to be modified there, since the particle density would otherwise tend to diverge.

Superstring theoreticians later all converted to this latter view, although the exact details of a generic horizon continue to be mysterious in this language. Only recently some of the pure-sang general relativists were converted[14]. Hawking radiation carries out the information that was brought in by the imploding matter. How does this happen? At first sight, it seems to be very odd. As seen by the outside observer, ingoing particles only cross the horizon at $t \to \infty$, whereas the Hawking particles formally were already there at $t \to -\infty$. If these Hawking particles are supposed to carry all the information of the ingoing matter, would this not violate causality?

Our claim is that it does not[15]. The point is, that on their way out, the Hawking particles interact with the ingoing matter. Indeed, this interaction is very strong, since their *gravitational* interaction becomes very strong. As seen by a local observer, the centre-of-mass energy of these two sets of particles exponentially diverges to infinity, and since gravity couples to energy, the gravitational interaction rapidly grows out of control. The argument that quantum purity in black holes would be lost, was hinging upon ignoring this infinite force.

We found how the dominant part of this force can be taken into account[16]: it implies that ingoing particles cause a shift in the coordinates of the outgoing ones. This shift goes across the horizon, and, therefore, completely upsets the original picture. If we include the shift, we do obtain an interesting pure scattering matrix for black holes. However, so-far we were only able to account for the longitudinal parts of the gravitational force properly, whereas, it is understood that also the transverse parts are needed if one wishes to understand the finite information density at the horizon.

Anticipating the results of a correct and complete calculation, we expect the following picture of spacetime and its matter contents: we may have

- elementary particles of the usual kinds, such as the ones being detected today, forming ingredients of the Standard Model;
- bound states of such particles, such as atoms and molecules, and, eventually, planets and stars;
- imploded bound states, or small black holes: they form literally little voids in spacetime, surrounded by horizons that are populated by quantum states with a finite information density on their surface; and
- very large black holes. They have horizons that are nearly flat, and in spite of the fact that they do not fundamentally differ from the horizons of tiny black holes, they have the striking property that they can be viewed by observers 'falling in', who mistake these horizons for (practically) empty sections of space and time. It is this latter feature that necessarily follows from general relativity, but is the most difficult to understand.

These four types of matter cannot be distinguished very sharply; there may be gradual transition regions between all of them.

7. Superstrings and the Landscape

Superstring theory has been mentioned many times. This author has repeatedly ventured his objections against calling this approach a 'theory'. We have very little direct evidence that the laws of Nature should be those of a string or superstring. The 'theory' was in fact too poorly formulated to allow it to be compared with experimental data at all, even if we would have been able to do experiments at the Planck scale. When it was found that several versions of (super-)string theory exist, attempts were made to prove that they are all 'equivalent'. What this would mean for experimental observations at the Planck scale would be obscure, because certainly the spectrum of states in the different theories would be different. It was hoped that it meant the following: Nature has only one true ground state, and if these theories are equivalent in the sense that transitions from one mode into another would be allowed, then Nature would choose exactly the one configuration, where the vacuum has the lowest energy.

But this hope had to be abandoned. The equivalence is merely a mathematical one: the equations of one theory are related to those of the others, but only if their interaction parameters would be allowed to grow beyond the perturbative domain. Apart from the dubious nature of such statements, this also implies a concession: there are many different competing vacuum states, and only experiment will be able to tell us which of these we are living in at present. Our optimism turned into despair when it was subsequently realized that we do not just have five different string theories, as was thought for some time, but nearly uncountably many. Numbers such as 10^{500} were quoted, but what they really mean, of course, is that the number of string theories is unlimited, though presumably denumerable in the mathematical sense.

Then the cosmological viewpoint arrived[1][17]. All these 10^{500} or so solutions exist somewhere in our universe, or rather, in a more grandiose world called the 'Omniverse'. It could be that, during its evolution our omniverse shows distinct regions of expansion, where different vacuum states are approached. An important role is here played by the cosmological constant, which only allows expanding universes to be worth-while when it is sufficiently tiny. Its natural value is not very tiny, but certainly a substantial subset of the 10^{500} expanding regions *does* have a tiny or practically vanishing cosmological constant.

Is this an unavoidable direction for theoretical physics to go? If so, then we would no longer be able to use fundamental principles to determine the ultimate laws of physics. Historically, it would be a drastic departure from the way science in general, and physics in particular, has developed. We have always been able to identify new principles helping us to pin down, which of the numerous possibilities is actually realized in Nature. Is this course of our chain of discoveries coming to an end? My suspicion is that there are other options.

The clue is in quantum mechanics itself. A philosopher recently asked me the question: "Suppose that the Big Bang would occur again, with *exactly* the same initial conditions as before, steered by exactly the same laws of physics. Would everything evolve in exactly the same way? Would the same meteorite terminate the same dinosaurs exactly as it did before? Would we be sitting here dressed the same way?" I had to answer that, according to what we know presently, the answer is a resounding "NO!". Everything would be different. Quantum mechanics would only give us the same probabilities, but they could, and would, be realized differently.

But I don't believe this answer. Yes, we do not know the laws of physics very well, but why should that imply that they don't exist? Is it not by far more natural to suspect that the universe *would* evolve exactly as before? Quantum mechanics is a mere reflection of the sobering reality that *we* are not able to make accurate predictions at all. But maybe deterministic laws of Nature do exist[5]. In fact, we can imagine schemes[18] that could explain how such deterministic laws could produce random behaviour simply because the solutions are too complex to be completely and fully analyzed. The rule of statistics could be what we call 'Quantum Mechanics' today. Since string theory, super- or not, assumes quantum mechanics as a starting point in lieu of a deterministic mechanism, it cannot be more than a crude approximation of reality. If this is so, string theories should be treated for what they really are: they are *models*, not theories. This view makes sense. String theory started out as a crude model for hadronic physics; it may well turn out to become useful as a more accurate model for QCD, for instance in the large N limit, provided we learn to understand not only how to break supersymmetry, but also how to realize some spontaneous breakdown of general relativity, in a manner similar to the Higgs mechanism for vector gauge theories.

In this respect then, string theory might turn out to be the opposite of the Standard Model. The Standard Model, in its first concoctions, was proposed indeed as a model, a mere idealization of reality. It came as a surprise for many that the Standard Model would turn out to be much more than that: it is the Standard *Theory* now. It conforms to the experimental observations with impressive accuracy. String theory was propelled as a 'theory', but it could not be confirmed. It may never represent reality very closely. It should be called a model. As such, string theory, superstring theory and their holographic projections may well become extremely valuable, but their status as representatives of reality should be corrected.

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