IUCAA

INTER-UNIVERSITY CENTRE FOR ASTRONOMY AND ASTROPHYSICS

(An Autonomous Institution of the University Grants Commission)

Annual Report

(April 1, 2004 - March 31, 2005)

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HIGHLIGHTS OF 2004 - 2005

This annual report covers the activities of IUCAA during its seventeenth year, April 2004 -March 2005. 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 14 core faculty members (academic), 13 post-doctoral fellows and 21 research scholars. The core research programmes by these academics span a variety of areas in astronomy and astrophysics. These topics include quantum theory and gravity, classical gravity, gravitational waves, cosmology and structure formation, cosmic microwave background radiation, active galactic nuclei, quasar absorption system, high energy astrophysics, galaxy and interstellar medium, stellar physics, solar physics, and instrumentation. These research activities are summarised in pages 15-47. The publications of the IUCAA members, numbering to about 65 in the current year are listed in pages 76-78. IUCAA members also take part in pedagogical activities like lectures, seminars, popularisation of science, etc., the details of which are given in pages 84-85of 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 48-69 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 and interstellar medium, Sun and the solar system, atmospheric and ionospheric physics, plasma physics, dynamics, theoretical physics, and instrumentation. The resulting publications, numbering to about 95 are listed in pages 79-83 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, two students have successfully defended their theses and obtained Ph.D. degrees from the University of Pune during the year 2004-2005. Summary of their theses appears in pages 70-75.

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 7such events in IUCAA and 3 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 109-113 of this Report.

The IUCAA telescope achieved engineering first light in December 2004 and is currently in the final phase of system testing and performance tuning. As was reported last year, the electrical cabling and testing of the telescope had started in mid-2004, followed by the installation of the optics by early December. Final optical alignment was achieved by February 2005. The final acceptance testing and commissioning of the telescope is planned to be carried out as soon as clear skies become available post-monsoon.

CONTENTS

The Council and the Governing Board

The Council

<u>*President*</u>

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

<u>*Vice-President*</u>

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

<u>Members</u>

N. Mukunda,
[Chairperson, Governing Board],
Centre for Theoretical Studies,
Indian Institute of Science, Bangalore.

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

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

Kota Harinarayana,
Vice-Chancellor,
University of Hyderabad.

A.K. Kembhavi,
IUCAA, Pune.

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

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

G. Madhavan Nair,
Secretary to the Government of India,
Department of Space, Bangalore.

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

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

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

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

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

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

Arnab Rai Choudhuri,
Indian Institute of Science, Bangalore.

S. S. Dattagupta,
Director, Satyendra Nath Bose National Centre
for Basic Sciences, Kolkata.

Deepak Dhar,
Tata Institute of Fundamental Research, Mumbai.

G.K. Mehta,
Vice-Chancellor,
University of Allahabad.

Janak Pandey,
Vice-Chancellor,
University of Allahabad.

R.R. Pandey,
Vice-Chancellor,
Deendayal Upadhyay Gorakhpur University.

S. R. Rajaraman,
School of Physical Sciences,
Jawaharlal Nehru University, New Delhi.

Nityananda Saha,
Vice-Chancellor,
University of Kalyani.

S.S. Suryawanshi,
Vice-Chancellor,
Swami Ramanand Teerth Marathwada
University, Nanded.

J.A.K. Tareen,
Vice-Chancellor,
University of Kashmir, Srinagar.

Professor Abdul Wahid

Vice-chancellor
University of Kashmir, Srinagar.

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

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

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

Vijay Khole,
Vice-Chancellor,
University of Mumbai.

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

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

Deepak Nayyar,
Vice-Chancellor,
University of Delhi.

Amitava Raychaudhuri,
Department of Physics,
Calcutta University, Kolkata.

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

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

Member Secretary

N.K. Dadhich,
Director, IUCAA.

The Governing Board

Chairperson

N. Mukunda, Bangalore.

Members
Shishir K. Dube
Ashok Kumar Gupta
Kota Harinarayana
A.K. Kembhavi
A.S. Kolaskar
Rajaram Nityananda
Ved Prakash
G. Rajasekaran
C.V. Vishveshwara

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

G.K. Mehta
Janak Pandey

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

H.R. Singh

Member Secretary

N.K. Dadhich

Honorary Fellows

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

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

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

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

Yash Pal, Noida.

A.K. Raychaudhuri, Kolkata.

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

P.C. Vaidya,
Gujarat University, Ahmedabad.

Visiting Professor

Russell Cannon,
Anglo-Australian Observatory, Australia.

Statutory Committees

The Scientific Advisory Committee (SAC)

Abhay Ashtekar,
The Pennsylvania State University, U.S.A.

Rohini Godbole,
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,
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.

Users' Committee

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

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

Narayan Banerjee,
Department of Physics,
Jadavpur University, Kolkata

B.P. Chandra,
Vice-Chancellor,
Pandit Ravishankar Shukla University, Raipur.

Syed Shahid Mahdi,
Vice-Chancellor,
Jamia Millia Islamia, New Delhi.

N. Unnikrishnan Nair,
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)
S.V. Dhurandhar
Ranjan Gupta
A. K. Kembhavi
Ranjeev Misra (from October 1, 2004)
A.N. Ramaprakash
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
N.K. Dadhich
R. Nityananda
Ved Prakash
A.K. Kembhavi (from 26 .05. 2004)
A. Pimpale (from 19 .08. 2004)
L. Chaturvedi (till 24 .07.2004)
T. Padmanabhan (till 25 .05. 2004)
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
V. Sahni
Tarun Souradeep
R. Srianand
K. Subramanian
S. N. Tandon

Emeritus Professor

J.V. Narlikar

Scientific and Technical

T.D. Agarkar (till 30.09.2004)
N.U. Bawdekar
S.S. Bhujbal
M.P. Burse
S.B. Chavan (from 28.03.2005)
V. Chellathurai
K.S. Chillal (from 26.08.2004)
P.A. Chordia
H.K. Das
S. Engineer
G.B. Gaikwad
S.U. Ingale
A.A. Kohok
V.B. Mestry
A. Paranjpye
S. K. Pathak (till on 24.12.2004)
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
K.B. Munuswamy
S.B. Kuriakose
N.S. Magdum
M.A. Mahabal
S. G. Mirkute
E.M. Modak
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 (from 20.07.2004)
P. Chakraborty (till 13.04.2004)
Priya Hasan (from 06.09.2004)
H. K. Jassal (till 27.04.2004)
A. Mahmood (from 01.11.2004)
M. Puravankara (from 10.01.05)
S. Ray
E. Rollinde (till 01.02.2005)
G. Sarkar (till 12.07.2004)
S. Sen (from 19.11.2004)
C.S. Stalin (from 08.09.2004)
P. Subramanian
R.S. Yadav (till 16.06.2004)

Research Scholars

A.L. Ahuja
U. Alam
S. Chakravorty
H. Chand
A. Deep
Amir Hajian Forushani
Josily Cyraic (from 29.12.2004)
G. Mahajan
S. Mitra
H. Mukhopadhyay (from 05.07.2004)
T. Naskar
Ali Reza Rafiee (till 11.06.2004)
A. Rawat
S. Samui
S. Sarkar (from 30.07.2004)
A. S Sengupta (till 05.02.2005)
Arman Shafieloo
J.V. Sheth (till 20.09.2004)

P. Singh (till 10.06.2004)
M.K. Srivastava (from 29.07.2004)
S. Sur (from 02.08.2004)

Temporary/Project/Contractual Appointments

A.P. Chordia (System Engineer)
M.B. Ghule (Steno-Typist, CEC Project)
J.A. Gupchup (Project Officer, Virtual Observatory)
M. S. Kharade (Project Officer , ERNET Project)
S.T. Koshti (Project Scientist, DST Project)
V. Kulkarni (Scientific/Technical Assistant-I, Public Outreach Programme)
P.L. Shekade (System Engineer)

N.S.Bhujbal (System Administrative Assistant) (till November 13, 2004)
P. Kulkarni (Project Officer, Virtual Observatory) (till APril 8, 2004)
V. Raskar (Assistant, Public Outreach Programme) (till July 5, 2004)

P. Barathe (from April 1, 2005)
A. Bhujbal (from February 22 to March 2, 2005)
V. Jagtap (from January 24, 2005)
V. Mhaiskar (from August 30, 2004)
A. Rupner (from August 30, 2004)
S. Sagar (from April 1, 2005)
R. Sinha (from August 2, 2004)

Part time Consultants

S. S. Bodas (Medical Services)

Long Term Visitors

Gupta Arvind

Mohan Vijay (Visiting Scientist on Deputation, from ARIES, Nainital, from 22.03.2005)

M. Sami
(On leave from Department of Physics,
Jamia Millia Islamia, New Delhi)

Visiting Members of IUCAA

Visiting Associates

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

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

Badruddin,
Department of Physics,
Aligarh Muslim University.

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

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

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

S.K. Banerjee,
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Technology, Lakshmangarh.

Rashmi Bhardwaj,
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Delhi.

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Jadavpur University, Kolkata.

Deepak Chandra,
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Kalyan K. Mondal,
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K.D. Patil,
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North Bengal University, Darjeeling.

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Department of Physics,
St. Thomas College, Kozhencherri.

S.K. Popalghat,
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J.E.S. College, Jalna.

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

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

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

Shantanu Rastogi,
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D.D.U. Gorakhpur University.

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

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

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

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

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

A.K. Sen,
Department of Physics,
Assam University, Silchar.

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

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

Rajendra N. Shelke,
Space Research Centre,
Amravati.

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

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

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

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

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

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

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

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

Anisul Ain Usmani,
Department of Physics,
Aligarh Muslim University.

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

...till June 2004

F. Ahmed,
Department of Physics,
Kashmir University, Srinagar.

B. N. Dwivedi,
Department of Applied Physics,
Institute of Technology, Banaras Hindu University,
Varanasi.

V. K. Gupta,
Department of Physics and Astrophysics,
University of Delhi.

V. H. Kulkarni,
Department of Physics,
University of Mumbai.

S. N. Paul,
Serampore Girls' College,
Hooghly.

Bikram Phookun,
Department of Physics,
St. Stephen's College, Delhi.

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

M.C. Sabu,
Department of Mathematics,
Christ College, Rajkot.

From July 2004..

Pavan Chakraborty,
Department of Physics,
Assam University, Silchar.

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

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

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

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

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

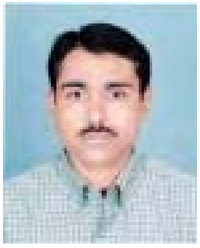
T. Ramesh Babu
Department of Physics
Cochin University of Science and Technology, Kochi.

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

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

The fifteenth batch of Visiting Associates, who were selected for a tenure of three years, beginning July 1, 2004.

S.S.R. Inbanathan



M.K. Patil

T. Ramesh Babu

J.P. Vishwakarma

The photographs of the following Visiting Associates from the fifteenth batch are not available: Pavan Chakraborty, Ranabir Dutt, Sanjay Jain, U.S. Pandey and Ramakrishna Reddy.

Appointments of the following Visiting Associates from the twelfth 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, Post-Doctoral Research
(K. Subramanian)

Head, Computer Centre
(A.K. Kembhavi)

Head, Library & Documentation
(T. Padmanabhan)

Head, Publications
(T. Padmanabhan)

Head, M.Sc. & Ph.D. Programmes
(K. Subramanian)

Head, Instrumentation Laboratory
(S.N. Tandon)

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

Head, Visitor Facilities
(V. Sahni)

Head, Associates & Visitors
(A.K. Kembhavi)

Head, Recreation Centre
(P. Chordia)

Head, Guest Observer Programmes
(R. Srianand)

Head, Workshops & Schools
(S. V. Dhurandhar)

Head, Public Outreach Programmes
(T. Souradeep)

The Director's Report

The year began with the inauguration of the `Pulastya' building and of the IUCAA Muktangan Vidnyan Shodhika (Science Exploratorium) on June 12, 2004 by our friend and mentor, Yash Pal. The programme of the day included Yash Pal, Milind Watve and Dinesh Thakur, sharing their experience and excitement of doing science with over 500 school students in the IUCAA Chandrasekhar auditorium.This building was constructed from the generous donation of Rs. 30 lakhs by Shrimati Sunitabai Deshpande, in memory of her husband, Pu. La. Deshpande, who personified Marathi cultural identity. Pu. La. had wished that there should be a free open space where young children simply play and give vent to their imagination, and have fun while learning science. The name of the building is derived from a star by this name in the Saptarishi constellation and it was a wonderful and befitting tribute paid to Pu. La. by his friend, Professor Jayant Narlikar.

I am very happy to say that MVS - the Science Exploratorium - has started very well, and has already carved out its own identity in Pune's scientific endeavour. It is wonderful to see the sparkling eyes of children reflecting wonder and excitement as they make toys with their own hands, which they carry home and in the process have good fun. That was precisely what Pu. La. had envisioned.

Nothing could be a happier news than the fact that the wonderful legacy of philanthropy and generosity has been carried forward by a person who prefers to remain anonymous and has donated Rs. 20 lakhs to MVS, of which the first instalment of Rs.10 lakhs has been received, and the second is to follow soon. This is indeed an excellent way of appreciating and encouraging MVS right in its first year of existence. I most warmly thank our philanthropist friend for the noble gesture, and I am sure it won't go without emulation and I hope to have someone to thank every year.

We began the International Year of Physics by organising a day's conference in which four eminent scholars Abhay Ashtekar, Donald Lynden-Bell, Gavin Wraith and Jayant Narlikar - spoke on various aspects of Einstein's relativistic world. It was attended by college and university students as well as other interested people. We plan to end the year with an international conference on Einstein's Legacy in the new millennium, at Puri, jointly organised with Utkal University and Institute of Physics, Bhubneswar, and sponsored by other institutes.

Professor Donald Lynden-Bell, a distinguished astrophysicist, who has been a good friend and well-wisher of IUCAA right from its conception stage, celebrated the event of his becoming an Honorary Fellow by a visit of three weeks. He had been a member of our Scientific Advisory Committee and been visiting us quite regularly. On the recommendation of the Governing Board, IUCAA has introduced a Visiting Professor scheme under which a distinguished scientist is supposed to visit IUCAA for 2-3 times in a term of 3 years, with each visit of at least 4 weeks duration. Alexi Starobinsky of Moscow State University and Anvar Shukurov of University of New Castle were invited to be Visiting Professors and both of them had accepted our invitation. Professor Shukurov made his first visit as a Visiting Professor for 4 weeks in March/April.

The installation work on the IUCAA Telescope at the Giravali site began in June 2004, and I am happy to say that it saw the First Engineering Light on December 10, 2004. It is certainly one of the important milestones to be happy about. I congratulate both TTL engineers and IUCAA scientific teams on the job well done and on excellent team work. The telescope is expected to be fully installed by mid June 2005, and then we have to wait through the monsoon to do open sky tests. I am happy to say that we are at long last nearing the completion of the project.

A comprehensive peer review of all the Visiting Associates who had completed two terms was carried out during this year. In all 36 Associates were reviewed in four subject categories. The overall performance was quite satisfactory and the grades spectrum was A+(1), A(9), A--(6), B+(6), B (5) and B -- (4), C(4), and other(1). A constructive feedback from the recommendations of the review committees has been communicated to all the reviewed Associates. I wish to specially mention S. K. Pandey of Pt. Ravi Shankar Shukla University, Raipur, and congratulate him most warmly on his pioneering effort in observational astronomy in the university sector. He has motivated and trained about half a dozen young astronomers who are working at various observatories. It is by all means, a very good contribution to observational astronomy. With our telescope coming on line, I hope many more students from universities will take up observational astronomy.

As mentioned in the previous year's report each IUCAA faculty is expected to visit a university and give a course of about 10 lectures. This programme had, though, begun with three of us visiting Universities of Rajasthan, Hyderabad, Tezpur and Guwahati, has yet to take off in full measure. I hope that next year other faculty members will also join in. Another point of strengthening interaction with universities is their Ph.D. students attending IUCAA Graduate School.

Let me conclude by saying that IUCAA continues to thrive on the excellent infrastructural and support facilities, which are the mark of dedication and commitment of our scientific/technical, and administrative and support staff who, I thank most warmly.

Naresh Dadhich

Congratulations to ...

(a) IUCAA Members

Ujjaini Alam

Awarded one of the ``Hartle Prizes" from the International Society on General Relativity and Gravitation for Best Student presentation at GR17, 2004

Sanjeev Dhurandhar

Elected Fellow of the National Academy of Sciences, Allahabad.

Amir Hajian

Gold Medal for Distinguished Ph.D. work by Iranian Student in India, presented by Minister of Foreign Affairs, Islamic Republic of Iran.

Ajit Kembhavi

Elected President of the Indian Association of General Relativity and Gravitation for 2004 -2005.

J. V. Narlikar

Prix Janssen Prize (2004) by the Societe Astronomique de France, France.

Jeevan Gaurav Puraskar from the Padmagandha Pratisthan, Nagpur.

Dr Shankar Dayal Sharma Srujan Samman from the Madhya Pradesh Hindi Grantha Akademi, Bhopal.

T. Padmanabhan

The essay ``*Gravity as elasticity of spacetime: a paradigm to understand horizon thermodynamics and cosmological constant*" received a Honorable Mention in the Gravity Research Foundation Essay contest, 2004.

(b) IUCAA Associates

P. N. Pandita

Elected Fellow of the Indian Academy of Sciences, Bangalore.

Arnab Roy Choudhury

Elected Fellow of the Indian Academy of Sciences, Bangalore.

Sailo Mukherjee

Invited to deliver the Vaidya-Raychaudhuri Endowment Fund lecture "*Cold Compact stars: A Laboratory for New Physics*" during the 23rd IAGRG meeting.

Calendar of Events

2004

April 19 - May 28	**School Students' Summer Programme** at IUCAA
May 7	**IUCAA-NCRA Graduate School** Second Semester ends
May 17 - June 18	**Introductory Summer school on Astronomy and Astrophysics** at IUCAA
May 17 - July 2	**Vacation Students' Programme** at IUCAA
August 9	**IUCAA-NCRA Graduate School** First semester begins
September 27- October 1	**International Virtual Observatory Alliance (IVOA) - Interoperability Meeting** at IUCAA
October 5-9	**Workshop on High Performance Computing** at IUCAA
October 25-29	**Workshop on Astrophysics for College Teachers and Researchers** at Kumaun University, Nainital
October 27- November 1	**Workshop on Strings and Cosmology** at IUCAA
December 6-10	**Workhop on Interstellar Medium** at Bangalore University
December 10	**IUCAA-NCRA Graduate School** First semester ends
December 29	**Foundation Day**

2005

January 3	**IUCAA-NCRA Graduate School** Second semester begins
January 2	**Special Relativity Centenary Meeting** at IUCAA
January 31- February 4	**Workshop on Observational Astronomy with Small Telescopes** at V.R. College, Nellore
February 27	**Open Day**
February 28	**National Science Day**

ACADEMIC PROGRAMMES

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

(I) RESEARCH BY RESIDENT MEMBERS

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

Quantum Theory and Gravity

Holographic structure of Einstein gravity

If we treat the macroscopic spacetime as analogous to a continuum solid and the unknown microscopic structure of spacetime as analogous to the atomic structure — a paradigm originally suggested by Sakharov — then it is possible to gain some important insights into the possible nature of quantum gravity.

First of all, one notes that the macroscopic description of a solid uses concepts like density, stress and strain, bulk velocity, etc., none of which can even be usefully defined in the microscopic description. Similarly, variables like metric tensor, etc. may not have any relevance in quantum gravity.

Second, the quantum theory of a spin-2 field ("graviton") will be as irrelevant in quantum gravity, as the theory of photons in providing any insight into the electronic structure of atoms.

Third, the symmetries of the continuum description (e.g., translation, rotation, etc.) will be invalid or will get strongly modified in the microscopic description. A naive insistence of diffeomorphism invariance in the quantum gravity, based on the classical symmetries, will be as misleading as insisting on infinitesimal rotational invariance of, say, an atomic crystal lattice. In short, the variables and the description will change in an (as yet unknown) manner. It is worth remembering that the Planck scale (10^{19} GeV) is much farther away from the highest energy scale we have in the lab (10^2 GeV) than the atomic scale (10^{-8} cm) was from the scales of continuum physics (1 cm).

It is, therefore, useful to investigate general features of quantum microstructure, which could be reasonably independent of the detailed theory of quantum spacetime — whatever it may be. *T. Padmanabhan* was pursuing such an approach — which could be called a *thermodynamic* approach to spacetime dynamics, to be distinguished from the *statistical mechanics* of microscopic spacetimes — in the recent years. This procedure throws light on several peculiar features of gravity (which have no explanation in the conventional approach) and provides a new insight in e.g., interpreting general coordinate transformations.

In general relativity, one can distinguish between the kinematics ("spacetime tells matter how to move") and the dynamics ("matter tells spacetime how to curve"). The geometric description of the *kinematics* arises quite elegantly from the principle of equivalence. To obtain the dynamics, which depends on the choice of the action principle, one uses the Einstein-Hilbert Lagrangian $L_{EH} \propto R$, which has a formal structure $L_{EH} \sim R \sim (\partial g)^2 + \partial^2 g$. If the surface term obtained by integrating $L_{sur} \propto \partial^2 g$ is ignored (or, more formally, cancelled by an extrinsic curvature term) then the Einstein's equations arise from the variation of the bulk term $L_{bulk} \propto (\partial g)^2$, which is the non-covariant Γ^2 Lagrangian.

On closer inspection, this procedure raises several questions. To begin with, it does not have the elegance or uniqueness, possessed by the geometric description of the kinematics. Second, in no other field theory (including Yang-Mills), does the symmetries of the theory lead to a Lagrangian involving second derivatives of the dynamical variables; it is clearly unusual. Third, the action is a window to the quantum theory and one might suspect most of the difficulties in quantising gravity might be due to quantising the wrong action functional based on wrong fundamental variables; it is possible that continuum spacetime is like an elastic solid and what we should be quantising is the 'atomic structure' of spacetime. Finally, in using L_{bulk} to obtain the dynamics, we are also assuming tacitly that the gravitational degrees of freedom are the components of the metric and they reside in the volume $\mathcal{V}$. But recall that, around any event, one can choose a local inertial frame so that $L_{bulk} \propto (\partial g)^2$ vanishes, since ∂g vanishes. On the other hand, one *cannot* make $L_{sur} \propto \partial^2 g$ part to vanish by any choice of coordinates suggesting that *the true degrees of freedom of gravity for a volume $\mathcal{V}$ reside in its boundary $\partial\mathcal{V}$.* (This is most easily seen by evaluating the action in Riemann coordinates in which the bulk term vanishes and only L_{sur} contributes). This point of view is also strongly supported by the study of horizon entropy, which shows that the degrees of freedom hidden by a horizon scales as the area and not as the volume.

If this view is correct, it *must* be possible to obtain the dynamics of gravity from an approach which uses *only* the surface term of the Hilbert action. Indeed, *Padmanabhan* has shown that suitable variation of the surface term will lead to Einstein's equations and that *one does not need the bulk term at all !*. What is more, he can obtain the surface term itself from general considerations thereby providing a new, self-contained and holographic approach to gravity.

In this approach, the action functional for the continuum spacetime has the form $A_{tot} = A_{sur} + A_{matter}$ in which matter lives in the bulk $\mathcal{V}$, while the gravity contributes on the boundary $\partial\mathcal{V}$. When the boundary has a part which acts as a horizon for a class of observers, one demands that the action should be invariant under virtual displacements of this horizon. This leads to Einstein's theory! Since A_{sur} is related to the entropy, its variation, when the horizon is moved infinitesimally, is equivalent to the change in the entropy dS due to virtual work. The variation of the matter term contributes the PdV and dE terms and the entire variational principle is equivalent to the thermodynamic identity $TdS = dE + PdV$ applied to the changes when a horizon undergoes a virtual displacement. (In the case of spherically symmetric spacetimes, for example, *Padmanabhan* has previously demonstrated *explicitly* that the Einstein's equations follow from the thermodynamic identity applied to horizon displacements.)

The result also shows that Einstein's theory has an intrinsic holography. The standard description is in terms of L_{bulk} and we have now shown that it has a dual description in terms of L_{sur}. It was noticed earlier by *Padmanabhan* that there is a remarkable relation between these two terms

$$\sqrt{-g}L_{sur} = -\partial_a \left(g_{ik} \frac{\partial\sqrt{-g}L_{bulk}}{\partial(\partial_a g_{ik})} \right), \qquad (1)$$

which has no explanation in standard approach. The current analysis shows that the horizon entropy and resulting thermodynamics for local Rindler observers (based on L_{sur}) leads to the same dynamics as that based on L_{bulk}, showing their interdependence.

Given the true microscopic degrees of freedom of spacetime (say, q_i) and an action A_{micro} describing them, the integration of $\exp(-A_{micro})$ over q_i, should lead to the term $\exp(-A_{sur})$ as well as to the concept of metric tensor, which is a macroscopic concept in the continuum limit, analogous to, say, the density field of a solid. In the variation $x^a \rightarrow \bar{x}^a = x^a + \xi^a$, the $\xi^a(x)$ is similar to the displacement vector used, for example, in the study of elastic solids. The true degrees of freedom are some unknown 'atoms of spacetime' but in the continuum limit, the displacement $x^a \rightarrow \bar{x}^a = x^a + \xi^a(x)$ captures the relevant dynamics, just like in the study of elastic properties of the continuum solid. Further, it can be shown that the horizons in the spacetime are similar to defects in the solid so that their displacement costs entropy. The demand that accelerated observers with horizons should be able to do consistent physics, with variables accessible to them, turns out to be as powerful in determining the *dynamics* of gravity, as the principle of equivalence (applied to inertial observers) was in determining the *kinematics* of gravity.

Cosmological constant and vacuum fluctuations

The conventional discussion of the relation between cosmological constant and vacuum energy density is based on evaluating the zero point energy of quantum fields with an ultraviolet cutoff and using the result as a source of gravity. Any reasonable cutoff will lead to a vacuum energy density $\rho_{\rm vac}$ which is unacceptably high.

This argument, however, is too simplistic since the zero point energy — obtained by summing over the $(1/2)\hbar\omega_k$ — has no observable consequence in any other phenomena and can be subtracted out by redefining the Hamiltonian. The observed non trivial features of the vacuum state of QED, for example, arise from the *fluctuations* (or modifications) of this vacuum energy rather than the vacuum energy itself. This was, in fact, known fairly early in the history of cosmological constant problem and, in fact, is stressed by Zeldovich who explicitly calculated one possible contribution to *fluctuations* after subtracting away the mean value. This suggests that we should consider the fluctuations in the vacuum energy density in addressing the cosmological constant problem.

This fact alone, however, would not have helped. The vacuum expectation values in question are all ultraviolet divergent and will — normally — scale as a suitable power of the UV-cutoff, L_{uv}. If the energy density behaves as $\rho \propto L_{uv}^{-4}$, the fluctuation $\Delta\rho$ will also scale as L_{uv}^{-4}, since that is the dominant scale in the problem; so the cosmological constant will still come out too large. Another difficulty is that, at least formally, the ground state is an energy eigenstate and it will have no dispersion in the energy.

T. Padmanabhan has recently shown that there is a nice manner in which de-sitter spacetime circumvents these difficulties and leads to the correct value for the cosmological constant. The key new ingredient arises from the fact that the properties of the vacuum state (or, for that matter, any quantum state in field theory) depends on the scale at which it is probed. It is not appropriate to ask questions without specifying this scale. (This, in some sense, has been the key lesson from renormalisation group.) If the spacetime has a cosmological horizon which blocks information, the natural scale is provided by the size of the horizon, L_H, and we should use observables defined within the accessible region. The operator $H(< L_H)$, corresponding to the total energy inside a region bounded by a cosmological horizon, will exhibit fluctuations ΔE, since vacuum state is not an eigenstate of *this* operator. The corresponding fluctuations in the energy density, $\Delta\rho \propto (\Delta E)/L_H^3 = f(L_{uv}, L_H)$ will now depend on both the ultraviolet cutoff L_{uv} as well as L_H. We now see an interesting possibility of boot strapping: When used as the source of gravity, this $\Delta\rho$ should lead to a spacetime with the horizon size L_H, which, in turn, requires us to compute $\Delta\rho$ using L_H as the infrared cutoff scale. Note that, it is the existence of a cosmological *horizon* at L_H which provides a clear justification for using this length scale in computing the energy fluctuations. This leads to a value for $\Delta\rho$ different from L_{uv}^{-4}, since we now have two length scales in the problem. This bootstrapping will lead to a relation between $\Delta\rho, L_{uv}$ and L_H. *Padmanabhan* has shown that this relation is $\Delta\rho \propto (L_{uv}L_H)^{-2} \propto H^2/G$ if we take the ultraviolet cut off at Planck length. That is precisely what we need.

In fact, while the energy density associated with Planck length is $\rho_{uv} \propto L_P^{-4}$ and the energy density associated with the Hubble length is $\rho_{ir} \propto L_H^{-4}$ (where $L_H = 1/H$), the observed value of the dark energy density is quite different from *either* of these and is close to the geometric mean of the two: $\rho_{vac} \simeq \sqrt{\rho_{uv}\rho_{ir}}$. This bootstrapping condition leads naturally to an effective dark energy density $\Delta\rho \propto (L_{uv}L_H)^{-2} \propto H^2/G$, which is precisely the observed value.

Classical Gravity

There is more to gravity than gravitons

The two classical fields — electromagnetism and gravity — are described by a vector field and second rank symmetric tensor field, respectively. Considerations based on Lorentz group suggest interpreting them (when suitable restrictions are imposed) as corresponding to massless spin-1 and spin-2 fields. The vector field A_i couples to a conserved current J_i but does not contribute to this current. (That is, the photon does not carry charge.) In contrast, the tensor field couples to the energy momentum tensor, since the field itself carries energy, it has to couple to itself in a non linear fashion. (The situation is similar to Yang-Mills fields which carry isotopic charge and hence are non linear.) It should, therefore, be possible to obtain a correct theory for gravity by starting with a massless spin-2 field h_{ab} coupled to the energy momentum tensor T_{ab} of other matter sources to the lowest order, introducing self-coupling of h_{ab} to its own energy momentum tensor at the next order and iterating the process. This will lead to a completely field theoretic description of gravity in a Minkowski background and is conceptually quite attractive.

This attempt has a long history. The field equation for a free massless spin-2 field was originally obtained by Fierz and Pauli. The first attempt to study the consequences of coupling this field to its own energy momentum tensor seems to have been by Kraichnan in unpublished work done in 1946-47. The first published attempt to derive the nonlinear coupling is by Gupta (1954), and Kraichnan published some of his results soon after. Feynman has provided a derivation in his Caltech lectures on gravitation during 1962-63. The problem was re-addressed by a clever technique by Deser.

Virtually, all these approaches claim to obtain not only Einstein's field equations but also the Einstein-Hilbert action. This result is widely quoted in literature and, at first sight, seems eminently reasonable. However, deeper examination by *Padmanabhan* raises several disturbing questions, if the above result is really valid.

First, in the conventional derivations, the final metric arises as $g_{ab} = \eta_{ab} + \lambda h_{ab}$ where $\lambda \propto \sqrt{G}$ has the dimension of length and h_{ab} has the correct dimension of $(\text{length})^{-1}$ in natural units with $\hbar = c = 1$. The iteration is in powers of λ, starting from the zeroth order lagrangian $L_0 \simeq (\partial h)^2$ for spin-2 field, which has the dimension of $(\text{length})^{-4}$. The final result in all the published works is the Einstein-Hilbert Lagrangian $L_{EH} = (1/4\lambda^2)R$. Since the scalar curvature has the structure $R \simeq (\partial g)^2 + \partial^2 g$, substitution of $g_{ab} = \eta_{ab} + \lambda h_{ab}$ gives to the lowest order: $L_{EH} \propto \lambda^{-2}R \simeq (\partial h)^2 + \lambda^{-1}\partial^2 h$. Thus, the full Einstein-Hilbert Lagrangian is non-analytic in λ! *It is impossible to start from $(\partial h)^2$, do a honest iteration on λ, and obtain a piece which is non-analytic in λ.* At best, one can hope to get the quadratic part of L_{EH}, which gives rise to the Γ^2 action but not the four-divergence term involving $\partial^2 g$.

Further, to carry out this programme, one need to identify the energy momentum tensor T_{ab}^G for the graviton field h_{ab} order by order in the coupling constant. The same textbooks which assert that Einstein's theory can be obtained by coupling h_{ab} to itself self consistently will also state in some other section that gravitational field does not have a well defined energy momentum tensor! It will be rather strange if a unique energy momentum tensor exists for gravitational field order by order in the perturbation series but somehow "disappears" when all the terms are summed up.

None of the previous derivations addresses these issues and most of them downplays the role of *assuming* general covariance. All these attempts make different tacit assumptions and it is difficult to judge which of these derivations can be thought of as "from first principles" in the sense that it is completely independent of our knowledge of the end result. This difficulty becomes apparent when one follows the details of many of these derivations. The technology used is very strongly influenced by the known final result. In particular, *the fact that the action for the final theory contains the second derivatives of the field and is always put in by hand.*

T. Padmanabhan has now critically re-examined the previous attempts and provided a detailed analysis aimed at clarifying the situation. First, he proves that it is *impossible* to obtain the Einstein-Hilbert (EH) action, starting from the standard action for gravitons in linear theory and iterating repeatedly. At best, one can only hope to obtain the remaining, quadratic, part of the EH Lagrangian (viz., the Γ^2 Lagrangian) if no additional assumptions are made. Second, he uses the Taylor series expansion of the action for Einstein's theory, to identify the tensor $\mathcal{S}^{ab}$, to which the graviton field h_{ab} couples to the lowest order. *Padmanabhan* shows that the second rank tensor $\mathcal{S}^{ab}$ is *not* the conventional energy momentum tensor T^{ab} of the graviton and provides an explanation for this feature. Third, he constructs the full nonlinear Einstein's theory with the source being spin-0 field, spin-1 field or relativistic particles by explicitly coupling the spin-2 field to this second rank tensor $\mathcal{S}^{ab}$ order by order and summing up the infinite series. Finally, he constructs the theory obtained by self consistently coupling h_{ab} to the conventional energy momentum tensor T^{ab} order by order and show that this does *not* lead to Einstein's theory. The analysis proves that the geometrical structure of Einstein gravity has more physical content than that obtained by iterating a graviton field.

In how many dimensions should gravity live ?

Gravity is universal. It interacts with all particles including massless ones, it is present everywhere and its range is infinite. Zero mass particle is characterized by the property that it moves with the same velocity relative to all observers so that its veolcity cannot change even when a force acts on it. Hence its interaction with gravity cannot be facilitated through the Newton's second law of motion, which determines how the velocity of a particle changes under the action of a force.

Particles of light, photons, are examples of zero mass particles which occur freely in nature. Their existence requires a new mechanics because the Newtonian mechanics cannot admit a velocity which is the same for all observers as the law of addition of velocities is $w = u + v$. Not only is a new mechanics required, so also a new theory of gravity in which light feels gravity and yet its velocity does not change. The only way this could happen is that gravity should curve the space and light should freely propagate in the curved space. Gravity then becomes the property of geometry of spacetime. The new mechanics synthesizes space and time into one entity spacetime. The former is the Einstein's theory of gravitation, known as general relativity (GR) while the latter is the Einsteinian mechanics, known as special relativity.

The curvature of spacetime should by itself determine the dynamics of gravitational field. And it does. Riemann curvature tensor (which involves second and square of first derivative of the spacetime metric) satisfies the Bianchi differential identities which on contraction leads to the divergence free second rank symmetric tensor involving contraction of the Riemann tensor. This tensor is a second order differential operator on the metric g_{ab}, which should be equated to a second rank symmetric tensor serving as the source for the field and a constant of integration relative to covariant derivative. Thus, on the right hand side one has energy momentum tensor for matter with vanishing divergence ensuring conservation of energy and momentum and the constant of integration is what is called the cosmological constant. It naturally arises as a new constant of the Einstein's gravity. One, thus, obtains the Einstein's equation for gravitation which is in principle valid in any dimensions greater than 2 (the minimum dimensions required to define curvature). This has led *N. Dadhich* to ask the question: In how many dimensions does gravity live? It is well known that the minimum number of dimensions required to fully realise its dynamics is 4 (3-space and 1-time). That means 4 dimensions are necessary; are they sufficient to fully describe gravity? This depends upon in how many space dimensions does matter live. Going by the dynamics of the matter field, it is all realised in 3 space dimensions and hence there is no compelling reason to take matter to dimensions greater than 3.

Gravitation and the electromagnetism are the only two long range classical fields. The crucial difference between them is that the latter is bipolar while the former is unipolar, because gravitational charge is the matter energy density which is always positive. All macroscopic objects down to an atom are electrically neutral. This means, there cannot occur an isolated electric charge, which will always try to neutralise itself by attracting the opposite charge. This should be true for gravity as well. How can one neutarlise the always positive gravitational charge of matter/energy density, but neutralise it must? The only thing which has not yet been tapped is the gravitational field it produces. The charge neutrality could be achieved if and only if gravitational field has gravitational charge of opposite polarity. The field energy must, therefore, be negative and hence the universal force must always be attractive. It is the simplest and most direct explanation of why gravity is always attractive.

It should be noted that negative charge of the field is non-localizable and is distributed all over the space. This means a vector theory like the Maxwell's electromagnetic theory will not be sufficient to describe gravity. A more general entity than a vector will be required, which could take into account distributional character of the negative gravitational charge. A tensor theory is required. The situation is even more complex for the field is spread all over the space so that it could be best defined as a property of space itself. This augurs very well with universal charachter of gravity demanding its geometric description. The overall charge neutrality will be achieved only when we integrate negative charge (field) over the entire space. That is, positive mass of an isolated body will be completely neutralized by negative energy of its field integrated all over the space. However, in the local neighbourhood of the body, there will be charge imbalance with dominance of positive charge. Therefore, gravity must propagate off the 3-brane in the extra dimension in the local neighbourhood. But it should not be able to go deep enough because as it propagates its strength diminishes, and larger and larger negative charge coming in through increase in its support space on the brane. Gravity will thus have to propagate in the extra fifth dimension though not deep enough.

There is yet another physical argument for gravity in extra dimension. It is clear that the gravity is a self interactive force. In GR, the metric tensor is the gravitational potential. The first iteration will require inclusion of square of first derivative of the metric in the field equation. This is indeed the case for the Einstein equation which follows from the Riemann curvature involving second and square of first derivative of the metric. The Einstein gravity is, therefore, self interactive which is its distinguishing feature. However, it only includes the first iteration. Self interaction has to be evaluated at all orders unless some physical property stops the iteration chain.

To go to the second iteration will mean to involve square of the Riemann and its contractions. This will, however, also square second derivative, which is the highest order of derivative. If the highest order of derivative does not occur linearly, the equation cannot have unique solution for a quadratic or higher powers will yield two or more differential equations. For the equation to admit unique solution, the second derivative must occur linearly. The differential geometry does provide a specific combination of square of Riemann, Ricci and Ricci scalar, called the Gauss - Bonnet combination, that yields the quasi linear equation. That is, square of second derivative terms get perfectly cancelled out. The second iteration could, thus, be accounted for by inclusion of the Gauss - Bonnet term. But this term makes non-zero contribution only in dimensions greater than 5. This means that the second iteration of self interaction of gravity takes it to the extra fifth dimension.

The next question is where does the iteration chain terminate? As we have argued earlier that all matter remain confined to the 3-brane and hence, the five dimensional bulk spacetime is completely free of matter and has purely geometric support in the Guass - Bonnet term. It would, hence, be homogeneous and isotropic and will have vanishing Weyl curvature and would be either de Sitter (dS) or anti de Sitter (AdS). Since it is gravitational field which has negative energy density and leaks into the extra dimension, it should be AdS with negative energy density. Since Weyl curvature is zero, there is no free gravity to propagate out in the next higher dimension and thus, terminates the iteration chain. For the matter confined to the 3-brane, for the realization of full dynamics of gravity, a 5-dimensional AdS bulk spacetime is required harbouring our 4-dimensional universe as a hypersurface.

Dadhich has thus argued, purely from classical standpoint, that 4 dimensions are necessary but not sufficient for full realization of gravitational dynamics. It is remarkable that this leads to the same model of brane world gravity as the popular string theory inspired Randall - Sundrum model.

Gravitational Waves

Overview and recent advances:

Einstein's theory of general relativity predicts the existence of gravitational waves (GW) and that they share certain properties of electromagnetic waves. However, GW differ from electromagnetic waves in several fascinating ways and these differences make it likely that they might bring us new insights and give us a new picture of the universe.

The existence of GW was established several years ago by Hulse and Taylor. They observed that the decay in orbit of the binary pulsar PSR 1913 + 16 is within a fraction of a percent of that predicted by the general theory of relativity. However, the direct detection of GW has not been achieved so far, but is never-the-less important for gaining new astrophysical information about our universe hitherto unavailable from other astronomical windows.

The recent technological advances in interferometric techniques has led to the development of extremely sensitive laser interferometric gravitational wave observatories around the world. Most of the interferometric detectors are either in operation or nearing operation. The LIGO project of the US consists of three detectors: two of 4 km armlength and one of 2 km armlength in Hanford and Louisiana; the French-Italian Virgo project is a 3 km detector near Pisa, Italy which will soon be conducting its first science run; the German-British GEO project is running a 600 metre detector near Hannover, Germany and the Japanese detector TAMA300, a 300 metre detector has been in operation for several years now. The Japanese also have plans to construct a 3 km armlength detector (LCGT). Australia is also in the ring and in China too there is a proposal for an underground detector which is supposed to operate at low frequencies below 10 Hz. Several of these detectors are getting close to design sensitivities and some have already taken data and are setting interesting upper limits on the GW strain h in the frequency range from 100 Hz to kHz. The peak design sensitivity in the spectral density for the initial detectors is $\tilde{h}_{\rm rms} \sim 10^{-23}{\rm Hz}^{-1/2}$ near 100 Hz. All these efforts gives us hope that gravitational waves may soon be detected, opening new horizons in physics and astronomy. GW are produced by objects predominantly having a time-varying mass quadrupole moment. To the leading order in v/c, where v is the typical velocity of the source and c the speed of light, the GW strain amplitude (or the metric perturbation) h is proportional to the second time derivative of the mass quadrupole moment. These warpages in the fabric of space-time would travel away from the source with the speed of light. The change in the distance ΔL between freely falling masses at a distance L is $\Delta L \sim hL$. The GW strain (metric perturbation) is infinitismally tiny because of the extremely weak coupling of gravity to matter. For instance, for a system of binary neutron stars at a distance of 100 Mpc, the GW strain that is produced minutes before they coalesce is of the order of $h \sim 10^{-23}$. Because of the tiny measurements involved in detecting GW, the experiment is an extremely difficult enterprise. Nevertheless, strain sensitivities of this order are being achieved by the current detectors, notably the LIGO detectors of the US.

The future for GW research looks bright: developmental work on advanced detectors has already begun whose sensitivity will be about ten times better than the present detectors. Such detectors should be able to detect neutron star - neutron star coalescences out to several hundred Mpc. blackhole-blackhole binaries are also good candidates for detection by these detectors if their masses are smaller than about $10M\odot$. Black-holes with larger masses, like at the centres of galaxies, emit stronger signals but at low frequencies, below 1 Hz. Here the ground-based detectors are insensitive because of the gravity gradient noise which is difficult to eliminate on Earth.

The solution is to build a detector in space. The Laser Interferometric Space Antenna - LISA - is a space-based detector of GW designed to study low frequency GW in the range 10^{-4} Hz to 1 Hz. The LISA is a NASA and ESA project and will be launched in early next decade. LISA consists of three spacecraft located 5 million kilometres apart forming an equilateral triangle. The spacecraft are maintained drag-free by a complex system of accelerometers and micro-propellers. Each spacecraft revolves in its own heliocentric orbit. The centre of the equilateral triangle is located on the ecliptic and lags 20 degrees behind the Earth. The spacecraft rotate in a circle drawn through the vertices of the triangle and the LISA constellation as a whole revolves around the Sun. Each spacecraft houses two lasers and two telescopes each pointing at the two distant spacecraft. The light sent out by a laser in one spacecraft is received by the telescope on the distant spacecraft. The incoming light from the distant spacecraft is then mixed with the in-house laser and the differential phase is recorded. This defines one elementary data stream. There are, thus, six elementary data streams which are formed by going clockwise and anti-clockwise around the LISA triangle. Suitable combinations of these elementary data streams can be used to optimally extract the GW signal from the instrumental noise.

The astrophysical sources that LISA could observe include galactic binaries, extra-galactic supermassive blackhole binaries and coalescences, and stochastic GW background from the early universe. Coalescing binaries are one of the important sources in the LISA frequency band. These include galactic and extra galactic stellar mass binaries, and massive and super massive black-hole binaries. Massive blackhole binaries are interesting both from the astrophysical and theoretical points of view. Coalescences of massive blackholes from different galaxies after their merger during growth of the present galaxies would provide unique new information on galaxy formation. Coalescence of binaries involving intermediate mass blackholes could help understand the formation and growth of massive blackholes. The super massive blackhole binaries are strong emitters of GW and these spectacular events can be detectable beyond red-shift of $z = 1$. These systems would help to determine the cosmological parameters independently. And, just as the cosmic microwave background is left over from the Big Bang, so too should there be a background of gravitational waves. Unlike electromagnetic waves, gravitational waves do not interact with matter after a few Planck times after the Big Bang, so they do not thermalize. Their spectrum today, therefore, is simply a redshifted version of the spectrum they formed with, which would throw light on the physical conditions at the epoch of the early universe.

The extended hierarchical search

The most important recent development was the performance of the hierarchical code in searching for inspiraling binaries on *real data* - the data from the second science run (S2) of the LIGO detectors. The usual (flat) search which finely scans the parameter space, was made more efficient by a factor between *6 and 10*. The code, however, still needs to be optimised which should yield even a higher efficiency factor.

Inspiraling binaries are the most promising sources for both interferometric detectors as well as for LISA. Their waveform can be well modelled in terms of post-Newtonian expansions and so matched filtering methods are optimal for extracting the signal from the noise. The flat search for detecting inspiraling binaries is a one step search, which utilises closely spaced templates in the parameter space. Although performing a rigorous and satisfactory search of the parameter space, this approach entails very large computational cost. A more efficient method can be employed when the occurence of the signal in the data is deemed to be a rare event. In such a case, one is mostly sifting through noise. In the first (trigger) stage of the algorithm, a coarse search is carried out and the candidate events are followed up with a fine search in the neighbourhood of such events. For the parameter space of spinless binaries, a two step hierachical search is sufficient.

A hierarchical search was performed for the first time by S. D. Mohanty in searching for inspiraling binary signals several years ago. The hierarchy was limited to the two masses of the binary stars. *A. S. Sengupta* and *S. V. Dhurandhar* and A. Lazzarini extended the hierarchy to a third parameter: the time-of-arrival. This work is within the Ligo Science Collaboration (LSC). The strategy is based on the fact that the inspiraling binary GW signal (the chirp signal) contains most of its power at low frequencies - the power in the chirp signal falls of as $f^{-7/3}$. Because of this property, the chirp signal can be cut-off at quarter of the usual upper cut-off frequency without losing too much signal power, so that the hierarchy over masses is not severely compromised. The data is then sampled at the reduced Nyquist frequency, saving the computational cost of the FFTs in the trigger stage by about the same factor. The cost gain factor over a flat search is about 65 for the initial LIGO noise power spectral density for stationary Gaussian noise. For real data (S2 run) the factor comes down to about 10 which is still substantial.

The extended search algorithm was validated and a code was written following LIGO specifications within the LIGO Algorithms Library (LAL) and the LIGO Data Analysis System (LDAS) environments. The code was first tested on a stand alone machine and then in the LDAS environment. Finally the code was run on real data.

The second science run (S2) of the LIGO was carried out for two months from February 14 to April 14, 2004. Pre-conditioned data, suitable for analysis can be queried from these LDAS sites via world wide web (WWW) remotely. At IUCAA, a data analysis software was written to analyze the LIGO data for detecting signatures of GW from inspiraling binaries. The software is written in a format that allows it to be remotely run on massively parallel Beowulf clusters available at LDAS sites remotely via WWW. For validating the code the following procedure was followed: one takes data stretches from LIGO detectors in which expected GW signals from inspiraling binaries are either added by hand (software injection) or the mirrors of the interferometer are shaken to mimic its behavior in the presence of GW (hardware injection). In either case, the data is parsed through the analysis pipeline and one hopes to make a detection at the end of the pipeline. The injection parameters are known before hand and so it is easy to check that the physical parameters corresponding to these detections match the injection parameters as closely as possible.

The detection efficiency of the code was also tested using a hypothetical uniform distribution of sources and comparing the detections with the false alarm rate as found by the code. The detection efficiency compared favourably with the flat search code while at the same time reducing the computational cost several times.

Inspiraling compact binaries are promising sources of gravitational waves for ground and space-based laser interferometric detectors. The time-dependent signature of these sources in the detectors is a well-characterized function of a relatively small number of parameters; thus, the favored analysis technique makes use of matched filtering and maximum likelihood methods. As the parameters that characterize the source model are varied so do the templates against which the detector data are compared in the matched filter. For small variations in the parameters, the output of the matched filter for the different templates are closely correlated. Current analysis methodology samples the matched filter output at parameter values chosen so that the correlation between successive samples is 97%. Correspondingly, with the additional information available with each successive template evaluation is, in a real sense, only 3% of that already provided by the nearby templates. The reason for such a dense coverage of parameter space is to minimize the chance that a real signal, near the detection threshold, will be missed by the parameter space sampling. *S. Mitra*, *S. V. Dhurandhar* and S. Finn describe a straightforward and practical way of using interpolation to take advantage of the correlation between the matched filter output associated with nearby points in the parameter space to significantly reduce the number of matched filter evaluations without sacrificing the efficiency with which real signals are recognized. Because the computational cost of the analysis is driven almost exclusively by the matched filter evaluations, the reduction in the number of templates translates directly into an increase in computational efficiency. And the computational cost of the analysis is large, the increased efficiency translates also into an increase in the size of the parameter space that can be analyzed and, thus, the science that can be accomplished with the data.

As a demonstration, the present "dense sampling" analysis methodology is compared with the proposed "interpolation" methodology, restricted to one dimension of the multi-dimensional analysis problem. It is found that the interpolated search reduces by 25% the number of filter evaluations required by the dense search with 97% correlation to achieve the same efficiency of detection for a given expected number of false alarms. Generalized to the two dimensional space used in the computationally-limited current analyses this suggests a factor of two increase in computational efficiency; generalized to the full fifteen dimensional parameter space that characterizes the signal associated with an eccentric binary system of spinning neutron stars or blackholes, it suggests a factor of 75 increase in computational efficiency.

Stability of the LISA configuration

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 gone to the basics to examine the principles of a stable formation flight and also to present an analytical treatment of the problem in the context of LISA. They first study three Keplerian orbits around the Sun with small eccentricities and adjust the orbital parameters so that the spacecraft form an equilateral triangle with nearly constant distances between them. Then they find that to the first order in the parameter $l/2R$, where $l \sim 5 \times 10^6$ km, is the distance between two spacecraft and $R = 1$ A. U. $\sim 1.5 \times 10^8$ km, the distances between spacecraft are exactly constant; any variation in arm-lengths should result from higher orders in $l/2R$ or from external perturbations of Jupiter and the secular effect due to the Earth's gravitational field. (The eccentricity e is related in a simple way to the ratio $l/2R$.) In fact their analysis shows explicitly, that such formations are possible with any number of spacecraft provided they lie in a plane making an angle of 60° with the ecliptic. This general result is established with the help of the Hill's or Clohessy-Wiltshire equations. Such analysis would be useful in order to carry out theoretical studies on the optical links, simulators etc. However, the exact orbits in the 60° plane give a maximum variation of armlengths of about 120,000 km. *S. Koshti*, R. Nayak and *Dhurandhar* have found that this maximum variation in armlength can be reduced if the tilt angle of the orbit is slightly varied from the 60° plane. This work is in progress. This observation could have profound implications for the LISA mission.

The gravitational sky map

The stochastic background of gravitational waves is a promising avenue for exploring astrophysics as well as cosmology. In addition to a nearly isotropic relic background from the early universe, stochastic backgrounds can arise in the confusion limit of astrophysical sources. The strong anisotropy in the GW background of the latter would be an invaluable discriminant between the underlying sources.

The detection and mapping of the anisotropy in stochastic GW background bears strong semblance to the analysis of the cosmic microwave background (CMB) anisotropy and polarization which is also a stochastic field statistically described in terms of its correlation properties. *S. Mitra*, *T. Souradeep* and *S. V. Dhurandhar* will first identify the key features that would allow appropriate techniques from CMB analysis to be adapted to GW.

The raw sky map of the GW background is the signal convolved with antennae pattern. The future programme envisaged by the team is as follows: Various image reconstruction techniques for the application to the GW background will be explored and compared. An efficient method to reconstruct the true sky map will be developed. Bayesian image reconstruction techniques will be explored. The measured stochastic GW background would have components arising from various astrophysical sources. The spectral signature of the sources would allow separation of the components. Efficient methods related to optimal filters and their analysis will be developed.

Cosmology and Structure Formation

Trans Planckian effects in inflation

In many of the models of inflation, the period of acceleration lasts sufficiently long so that length scales that are of cosmological interest today would have emerged from sub-Planckian length scales at the beginning of inflation. This suggests that physics at the very high energy scales can, in principle, modify the primordial perturbation spectrum and these modifications can-in turn-leave their signatures on the CMB. This has led to a considerable interest in understanding the effects of Planck scale physics on the inflationary perturbation spectrum and the CMB.

Recently, *T. Padmanabhan* and L. Sriramkumar have investigated this issue carefully and have noticed that there is a new twist to this question. They begin by noticing that, in a Friedmann universe, each mode $q_{\mathbf{k}}$ of the scalar field, labeled by the wave vector $\mathbf{k}$, evolves as an independent oscillator with time dependent parameters that are related to the expansion factor $a(t)$. Given the quantum state $\psi_{\mathbf{k}}[q_{\mathbf{k}}, t_i(\mathbf{k})]$ for the mode $q_{\mathbf{k}}$ at an initial time $t_i(\mathbf{k})$, one can obtain the state at a later time t by integrating over the (path integral) kernel $K(q_{\mathbf{k}}, t;\ \bar{q}_{\mathbf{k}}, t_i)$ for an oscillator with time dependent parameters, which can be written down in terms of the classical solution.

To make any progress, we need to *make an assumption* regarding $\psi_{\mathbf{k}}[\bar{q}_{\mathbf{k}}, t_i(\mathbf{k})]$ and our results are only as valid as this assumption. If we now further modify the dynamics (due to a phenomenological input regarding trans-Planckian physics), we will be changing the form of the kernel K. But, since we can *only* observe the integrated effect of K and $\psi_{\mathbf{k}}[\bar{q}_{\mathbf{k}}, t_i(\mathbf{k})]$, the observations can tell us something about the K (and trans-Planckian physics) only if we assume something about $\psi_{\mathbf{k}}[\bar{q}_{\mathbf{k}}, t_i(\mathbf{k})]$. The usual assumption is to consider the initial quantum state to be the Bunch-Davies vacuum, but it is only an assumption. The crucial question is whether the effects of trans-Planckian physics can be mimicked by a different choice of the initial state other than the Bunch-Davies vacuum.

Padmanabhan and Sriramkumar prove the rather strong result that *any* (modified) spectrum of fluctuations can be reproduced from a suitably chosen squeezed state above the Bunch-Davies vacuum in the standard theory. In fact, they go further and provide an explicit construction of the state for any spectrum of the perturbations that is observed. So, if some specific deviation from the standard scale invariant spectrum is seen in the CMB, a conservative interpretation will be to attribute it to a deviation from the standard initial state of the theory. Unless this possibility is ruled out, one cannot claim that the observation supports, say, a particular model of trans-Planckian phenomenology. Motivated by this result, they argue that the CMB can at most help us identify the quantum state of the scalar field in the standard theory, but it can *not* aid us in discriminating between the various Planck scale models of the matter fields.

Quintessential inflation on the brane

One of the most remarkable discoveries of the past decade is that the universe is accelerating. Evidence for an accelerating universe comes from observations of high redshift type Ia supernovae treated as standardized candles and, more indirectly, by observations of the cosmic microwave background and galaxy clustering. Perhaps the simplest explanation for acceleration is the presence of vacuum energy exhibiting itself as a small cosmological constant with equation of state $p = -\rho =$ constant. However, its un-evolving nature implies that the cosmological constant must be set to an extremely small value in order to dominate the expansion dynamics of the universe at precisely the present epoch and this gives rise (according to one's perspective) either to an initial 'fine-tuning' problem or to a 'cosmic coincidence' problem. As a result several radically different alternative methods of generating 'dark energy' at a sufficiently late cosmological epoch have been suggested. *V. Sahni*, *M. Sami* and Y. Shtanov have focused on one such approach which rests on the notion that spacetime is higher dimensional, and that our observable universe is a (3+1)-dimensional 'brane' which is embedded in a (4+1)-dimensional 'bulk' spacetime. Higher dimensional braneworld models allow the expansion dynamics to be radically different from that predicted by conventional Einstein gravity in 3+1 dimensions. An important 'surprise' which springs from the braneworld models is that *both early and late time acceleration can be successfully unified within a single scheme* in which the very same scalar field which drives inflation at early times becomes quintessence at late times.

Sahni and *Sami* have noted an intriguing issue in cosmology, namely that the universe appears to accelerate twice: once at the very beginning during Inflation and again about 10 billion years later, during the present epoch. Although, most theoretical models assume that there is no real connection between the two epochs and that inflation and dark energy are distinct physical entities, *Sahni* and *Sami* speculated that the two phenomena might, in fact, be related, and that the same scalar field which initially drives inflation, later, when its density has been considerably reduced, plays the role of quintessence. The main line of reasoning behind this approach is simple and is based on higher dimensional braneworld models based on the Randall–Sundrum scenario. In the Randall–Sundrum model, the modified Einstein equations on the brane contain high-energy corrections as well as the projection of the Weyl tensor from the bulk on to the brane. This results in the presence of an additional quadratic density term in the Einstein equations. They have showed that this new term substantially increases the damping experienced by a scalar field as it rolls down its potential. As a result, the class of potentials which lead to inflation increases and includes potentials which are normally too steep to be associated with inflation such as $V(\phi) \propto \phi^{-\alpha}, \alpha \geq 1$.

Scalar fields with steep potentials (dubbed 'quintessence') provide an attractive phenomenological model for dark energy, since a large class of initial conditions can be funneled into a common 'tracker-like' evolutionary trajectory at late times. Tracker models such as $V(\phi) \propto \phi^{-\alpha}$ significantly ameliorate the fine tuning problem faced by a cosmological constant and have been used to describe the current evolution of the universe.

In an earlier work, *Sahni*, *Sami* and *Souradeep* had shown that although quintessential inflation is indeed possible to realise within the Braneworld scenario, such a model is generically accompanied by gravitational radiation whose amplitude and spectrum are exceedingly sensitive to the details of inflation and, particularly, on the mechanism of 'reheating' the universe after inflation. Indeed, in order to ensure that the inflaton survives until today one usually invokes a method of reheating based on the quantum mechanical production of particles in the time-varying gravitational field after inflation. This method of reheating is very inefficient, and leads to a 'kinetic regime' of prolonged duration when braneworld corrections are no longer important and the scalar field rapidly drops down a steep potential, resulting in $p_\phi \simeq \rho_\phi \simeq \dot{\phi}^2/2$ and $a \propto t^{1/3}$. Gravity waves, (see Fig. 1) created quantum mechanically during the kinetic regime have a 'blue tilt' and, for a prolonged kinetic regime, their energy density can dominate the energy density of the universe and violate nucleosynthesis constraints. Thus, conventional braneworld models of quintessential inflation run into serious problems associated with copious graviton production which renders them unviable for an extended region in parameter space. *Sahni* and *Sami* have shown that it is possible to circumvent this problem if, instead of gravitational particle production, one invokes an alternative method of reheating, namely 'instant preheating' proposed by Felder, Kofman and Linde. This method results in a much higher reheat temperature and therefore, in a much shorter duration kinetic regime. (see Fig. 2). As a result, the amplitude of relic gravity waves is greatly reduced and there is no longer any conflict with nucleosynthesis constraints.

An important consequence of this unified model of inflation and dark energy is that once the inflationary regime is over and braneworld corrections cease to play an important role, the extreme steepness of the potential causes the scalar field to plunge down its potential resulting in a 'kinetic regime' prior to reheating during which $p_\phi \simeq \rho_\phi$. It is well known that the spectrum of relic gravity waves created quantum mechanically during inflation is sensitive to and bears an imprint of the post-inflationary equation of state. The effect of the kinetic regime is to create a 'blue' gravity wave spectrum on short wavelength scales, which is an important observational signature of quintessential inflation on the brane and could be tested by future gravity wave experiments (see Figure 1).

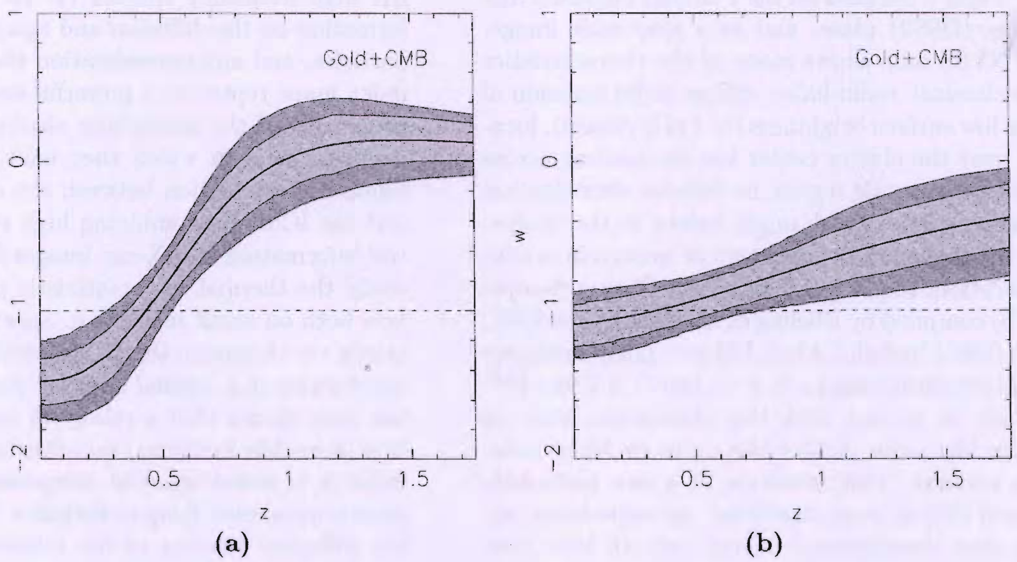


Figure 3: The evolution of dark energy equation of state with redshift for analysis using supernova and CMB data. In each panel, the thick solid line shows the best-fit, the light grey contour represents the 1σ confidence level, and the dark grey contour represents the 2σ confidence level around the best-fit. The dashed horizontal line denotes ΛCDM. In panel (a), $\Omega_{0m} = 0.4$ is the best-fit. The equation of state appears to increase rapidly from a very negative value < -1 at present to zero at a redshift of $z \simeq 0.7$. In panel (b), $\Omega_{0m} = 0.3$ is assumed. There is very mild evolution of equation of state, and the result is consistent with the cosmological constant.

lation based semi-analytic models are in progress at IUCAA. One of the goals of this endeavour would be to assess the validity of these models by simultaneously testing the clustering properties of quasars against the observational data.

Probing the nature of a Mpc scale radio-halo in galaxy cluster Abell 523: a nonthermal laboratory

Apart from enigmatic dark matter, the diffuse intracluster medium (ICM) contains two other main baryonic constituents: the commonly observed bremsstrahlung emitting hot ($T \sim 10^{7-8}$ K), tenuous ($n_0 \sim 10^{-(3-4)}$ cm^{-3}) thermal gas and a difficult to observe population of extremely high energy relativistic particles (cosmic rays: $e^{\pm}, P^{+}, \pi^{\pm/0}, \nu, \gamma$-rays, etc.) of largely unknown origin. In addition, a small fraction of galaxy clusters exhibit large scale diffuse radio sources, which have no optical counterparts and show no obvious connection to the galaxies in clusters, and are therefore, believed to be the synchrotron emission from electron/positrons of $\sim$ *GeV* energies in $\sim \mu$G magnetic fields embedded in the ICM. Diffuse radio emission from galaxy clusters is very rare phenomenon. These radio sources, which usually possess large sizes (0.1 − 1 Mpc) and steep spectra ($\alpha \sim 1 - 3$) are called 'radio halos' if they permeate the cluster centers and 'radio relics' if they are located in cluster peripheral regions. Observations found that radio halos exist only in the clusters that show X-ray substructures (Govoni et al. 2004, ApJ 605,695). Since a galaxy cluster having X-ray substructures indicates that it is undergoing subcluster merger, it is likely that the origin of radio halos is closely related to the merging process of galaxy clusters. Other than these clues, the exact process which generates radio-halos is still unknown. The properties of large scale radio halos and relics are poorly known, also because of the present observational limits. Due to synchrotron and inverse Compton losses, the typical life time of the relativistic electrons in the ICM is relatively short ($\sim 10^8$ yr), making it difficult for the electrons to diffuse over a Mpc scale region within their radiative life time. The expected diffusion velocity of the electron population is indeed of the order of the Alfven speed, ~ 100 km/s. Because radio-halo sources permeate through out the cluster volume, their electrons could not have been injected or accelerated in some localized points of the cluster, such as an active galaxy or a shock, but they need global *in situ* reacceleration mechanism.

J. Bagchi and collaborators are studying a new Mpc-scale radio halo discovered recently. This giant, ($1.1\,h_{70}^{-1}$ Mpc for LAS $\sim$ 10 arcmin, at z=0.1) diffuse radio structure was discovered at the center of rich cluster of galaxies Abell 523. A VLA 1.4 GHz image from the NVSS survey is shown in Fig-

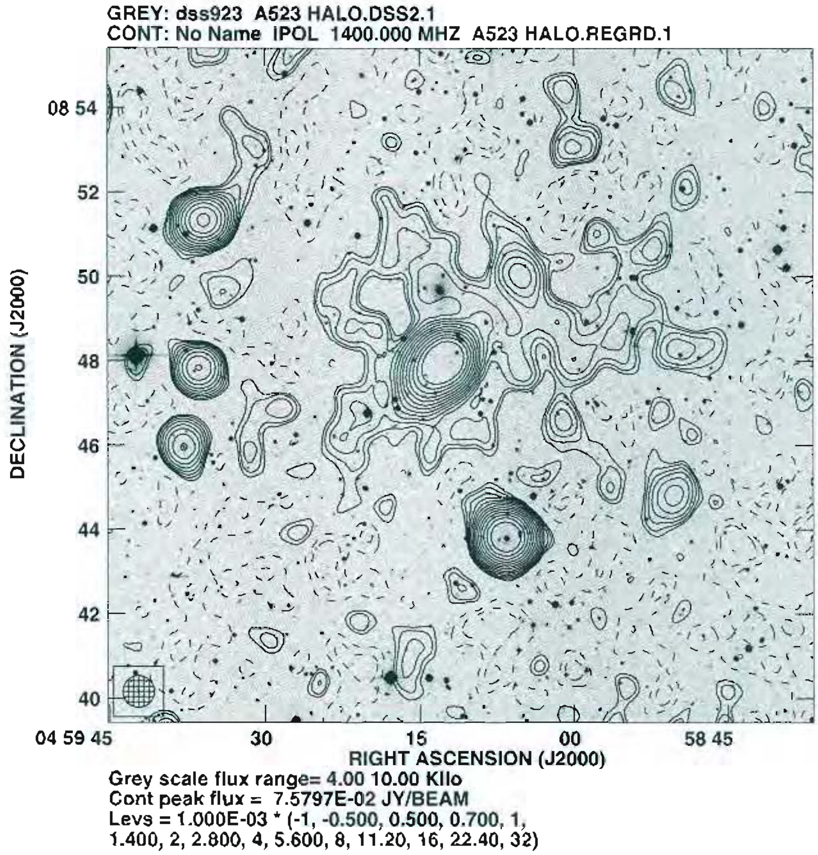


Figure 4: VLA 1.4 GHz low resolution (45 arcsec FWHM) NVSS radio map of central radio-halo discovered in cluster Abell 523. The Palomar Digitised Sky Survey (DSS2) image is shown in the background.

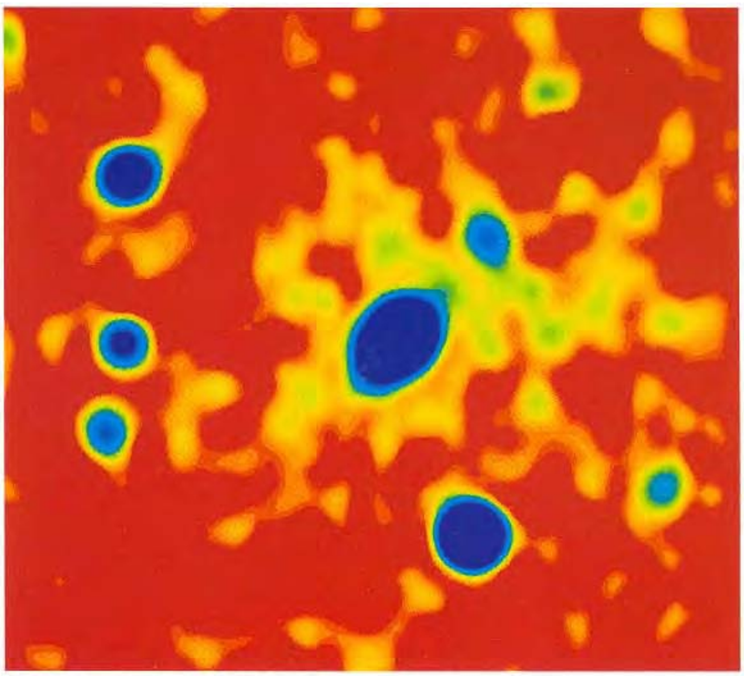


Figure 5: NVSS 1.4 GHz radio-halo image displayed in pseudo-colour rendering.

ures 4 and 5 overlaid on the Palomar Digitised Sky Survey (DSS2) plate, and as a gray-scale image. The NVSS map shows many of the characteristics of a 'classical' radio-halo : diffuse radio emission of quite low surface brightness (≈ 1 mJy/beam), location near the cluster center but permeating across a vast ~Mpc-scale region, no definite identification with any galaxy which might belong to the cluster, and a peculiar radio structure of uncertain origin. In addition, the ROSAT Brightest Cluster Sample (BCS) compiled by Ebeling et al. [MNRAS,vol.301, 881 (1998)] includes Abell 523 as a fairly luminous X-ray cluster having $L_X(0.1-2.4\,\mathrm{keV}) = 1.94\times10^{44}$ erg/sec, in accord with the observation that all known Mpc-scale radio-halos occur in X-ray luminous clusters. Our detection of a new radio-halo from NVSS is very significant as radio-halos are very rare phenomenon, having only 16 Mpc-scale examples reporetd so far in literature. The ≈ 75 mJy/beam peak radio source near the center of the radio-halo is not clearly associated with any bright galaxy -. Therefore from the NVSS map, it is not clear if it is a background object or the central 'core' of an extended radio-halo. A higher resolution GMRT map should clarify this issue and it would also enable good subtraction of other point sources from the diffuse halo emission.

The study of radio-halos and relics is directly connected to the recent dynamical activity of clusters. In any scenario, cluster radio-halos give us deep insight into the physics and properties of galaxy clusters. This opens a new window of investigation of the properties of clusters, through the formation of their relativistic components and the connection between thermal and relativistic plasma. Very likely, radio-halos give a unique probe of non-thermal processes accompanying energetic cluster merger events. Although no detailed X-ray data exists for Abell 523 as yet, *Bagchi* and collaborators are planning a better X-ray study with 'Chandra' and XMM-Newton in order to find evidences of distorted X-ray morphology, temperature variations and shock fronts, possibly indicating subcluster mergers. They have also been alloted 40 hours of GMRT observing time (90, 50 and 20 cm) and 10 hours of VLA time (90, 20 cm) for detailed study of this new radio-halo. Deeper, and higher resolution/high sensitivity imaging would not only allow the emission of diffuse radio-halo and superposed structures (both cluster and background sources) to be clearly separated, but it would also enable the mapping of the low-surface-brightness radio-halo and associated sources. Multifrequency radio imaging is essential to derive total spectra and spectral index maps. Low frequency (~ 300 MHz/90 cm) spectra are useful for obtaining the index of electron energy distribution, while the high frequency spectra (1- 10 GHz) give information on the diffusion and aging of relativistic particles, and any reacceleration process. Spectral index maps represent a powerful tool to study the properties of the relativistic electrons and of the magnetic field in which they emit, and to investigate the connection between the electron energy and the ICM. By combining high resolution spectral information and X-ray images it is possible to study the thermal vs. relativistic plasma connection both on small scales (e.g. spectral index variations vs. clumps in the ICM distribution) and on large scales (e.g., radial spectral index trends). It has been shown that a relatively general expectation of models invoking reacceleration of relic particles is a radial spectral steepening in the synchrotron emission from radio halos. Because of the low diffusion velocity of the relativistic particles, the radial spectral steepening cannot be simply due to aging of radio emitting electrons. Therefore, the spectral steepening must be related to the intrinsic evolution of the local electron spectrum and to the radial profile of the cluster magnetic field. In this framework, radio spectral index maps can be used to derive the physical conditions prevailing in the clusters, i.e., reacceleration efficiency.

Till now, only for three clusters (Coma, A665, A2163) a spectral index image has been presented in the literature, with resolutions of the order of $1'$, and only between two frequencies. Therefore, the GMRT/VLA radio (and CHANDRA/XMM X-ray) observations will be an important step forward towards the study of these very rare but very important astrophysical laboratories.

Nonlinear Gravitational Clustering

An intriguing feature of gravitational clustering is the existence of certain nonlinear scaling relations. They provide a prescription for relating the linear and nonlinear spectrum of fluctuations in gravitational clustering, and to identify the relevant process in each phase.

Nonlinear scaling relations indicate that there are three prominent regimes in evolution of gravitational clustering. When the amplitude of perturbations is small so that the density contrast is close to zero, mode coupling is not important and the evolution closely follows the predictions of linear perturbation theory. As density contrast grows and becomes comparable to unity, motions induced by gravitational collapse start to dominate over expansion of the universe. The quasi-linear regime is dominated by infall onto density peaks and the correlation function grows rapidly in this phase. Gravitational collapse leads to formation of structures in or close to dynamical equilibrium and further evolution of density contrast is dominated by depletion of average density due to expansion of the universe as the density of collapsed structures remains almost constant. One may call this the asymptotic regime.

Several studies have attempted to understand the nature of the asymptotic regime, mainly with help of N-Body simulations. Stable clustering is not reached in the range of non-linearities explored by N-Body simulations. However, the departure from stable clustering for most models is small. One of the reasons for the inability to resolve the problem of asymptotic regime has been the limited dynamic range of N-Body simulations.

The problem of dynamic range can be circumvented by simulating a two-dimensional system instead of a three-dimensional one, wherein a much higher dynamic range can be achieved with similar computational resources. Generic features like non-linear scaling relations are likely to be independent of dimension and - in fact - the scaling relations in the quasi-linear regimes were predicted by *Padmanabhan* well before these could be tested in simulations. If one can understand the nature of the asymptotic regime in two dimensions, it will help us to solve the problem in three dimensions even if we cannot map the solution directly to the full problem in three dimensions.

Previous studies of gravitational clustering in two dimensions concluded that there is no stable clustering. Both the studies mentioned above were limited to $\bar{\xi} \ll 100$ and the dynamic range in the nonlinear regime was limited. Recently, *Padmanabhan*, in collaboration with J.S. Bagla and S. Rey (HRI) has reinvestigated this problem using the powerful 2d TreePM code for N-body simulations. The TreePM code has a better force resolution as compared to a PM code; therefore, these simulations have a significantly larger dynamic range over which one can study the asymptotic regime. They investigate non-linear scaling relations for two-dimensional gravitational collapse in an expanding background using the 2d TreePM code and study the strongly non-linear regime ($\bar{\xi} \simeq 100$) for power law models. Evolution of these models is found to be scale invariant in all the simulations. The stable clustering limit is not reached but there is a model independent nonlinear scaling relation in the asymptotic regime. This confirms results from an earlier study which only probed the mildly non-linear regime ($\bar{\xi} < 40$). The correlation function in the extremely nonlinear regime is a less steep function of scale than reported in earlier studies. They show that this is due to coherent transverse motions in massive haloes. They also study density profiles and find that the scatter in the inner and outer slopes is large and there is no single universal profile that fits all cases. The difference in typical density profiles for different models is smaller than expected from the stable clustering hypothesis. Transverse motions induced by substructure are a likely reason for this difference being small.

Cosmic Microwave Background Anisotropy

Over the last decade, cosmological observations have attained a level of precision to allow for very detailed comparison with theoretical predictions. The transition to precision cosmology has been spearheaded by measurements of the anisotropy in the cosmic microwave background (CMB) over the past decade. *Tarun Souradeep* and his collaborators have continued working on a broad range of research problems in CMB anisotropy. The results of WMAP are a milestone in CMB anisotropy measurements since it combines high angular resolution with full sky coverage allowed by a space mission. The recent work on CMB anisotropy at IUCAA has looked the WMAP data with novel analysis techniques specifically planned and developed to complement standard analysis expected to be carried out by the WMAP team and other groups. This has lead to interesting results that were previously overlooked by the community.

Statistical isotropy of the CMB sky

The statistical expectation values of the temperature fluctuations of CMB are assumed to be preserved under rotations of the coordinates in 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), κ_ℓ, was recently proposed by *Amir Hajian* and *Tarun Souradeep* as a measure of violation of statistical isotropy in the CMB anisotropy map.

Amir Hajian and *Souradeep* have now completed a comprehensive BiPS analysis in collaboration with Neil Cornish (MSU) to assess the statistical isotropy of the full sky CMB anisotropy maps the WMAP satellite. The CMB maps were smoothed by a family of window functions that isolate and test SI on different range of angular scales. The published results indicate that the CMB anisotropy maps from WMAP do not strongly violate statistical isotropy.

The topology of the cosmos remains a fascinating enigma. The breakdown of statistical isotropy of CMB anisotropy is a generic feature of non trivial cosmic topology. In collaboration with Dick Bond

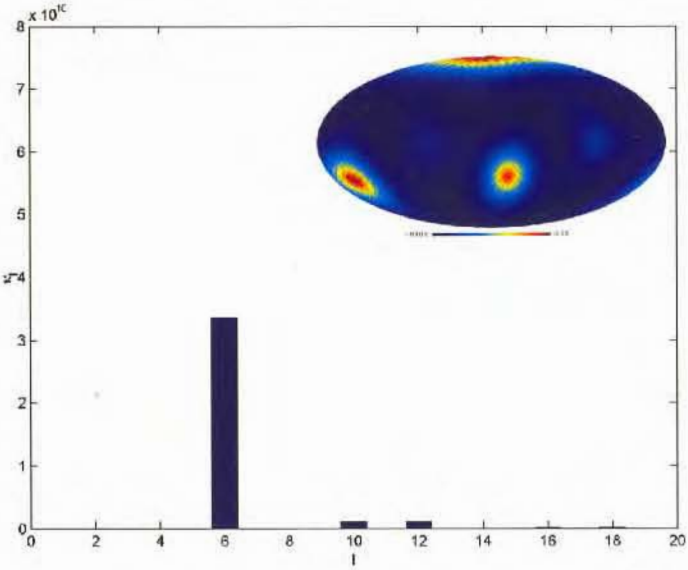


Figure 6: The figure depicts the correlation pattern of CMB anisotropy for the Dodecahedral cosmic topology and the corresponding predicted Bipolar power spectrum signature. The BiPS signature is characteristic of the shape of the compact universe allowing for constraints on cosmic topology using CMB anisotropy in an ongoing collaboration of *Hajian* and *Souradeep* with Bond, Contaldi & Pogosyan.

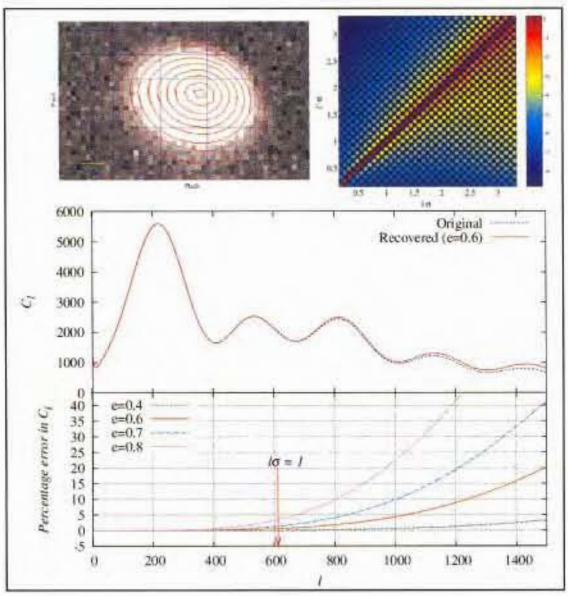


Figure 7: The collage of figures illustrate the systematic effect of a non-circular beam on the estimate of the CMB power spectrum. The top left panel is an intensity plot WMAP beam (Q-band) overlaid with fitted elliptical iso-photes. The bias matrix of the CMB power estimator in the upper right shows clear indication off-diagonal spillage due to beam non-circularity. The lower panel indicates the typical level of systematic corrections to the CMB power spectrum induced by beam non-circularity.

(CITA, Toronto), Dmitry Pogosyan (Univ. of Alberta), Carlo Contaldi (Imperial College, London), strong constraints on cosmic topology are being placed using the null BiPS results and also compared to constraints from the full-blown likelihood analysis on low resolution WMAP maps. Figure (6) shows the characteristic correlation patterns in the CMB anisotropy and the corresponding BiPS in a model universe with dodecahedral topology.

The BiPS is also a promising diagnostic tool for observational artifacts such as inhomogeneous instrumental noise and sky-coverage, residuals from foreground subtraction etc. that violate SI. The SI violation of noise contribution of a CMB experiment such as WMAP has been shown to have a characteristic BiPS signature.

Systematic effects in CMB anisotropy measurements

The non-circularity of the experimental beam has become progressively important as CMB experiments strive to attain higher angular resolution and sensitivity. When the circular assumption is inadequate, the CMB data analysis is severely complicated at all the stages of the pipeline – from map making up to power spectrum estimation. Recent CMB experiments such as ARCHEOPS, MAXIMA, WMAP have to contend with the systematic effects due to non-circular beams. Future experiments like Planck are expected to be significantly affected by non-circular beam effects. *Sanjit Mitra*, *Anand Sengupta* and *Tarun Souradeep* have carried out a comprehensive study of the effect of a non-circular beam on CMB power spectrum estimation. The effect of a non-circular beam on the estimated power spectrum was calculated for a CMB map made by an experiment with a beam which is non-circular at a level comparable to the WMAP beam. Figure (7) illustrates the systematic deviation in the estimated power spectrum for non-circular beams. Non-circular beam corrections will be included in second release of WMAP results and are expected to be in the same ball park as our estimates. Recently, the formalism has been elegantly extended to include the effect of incomplete sky coverage and beam rotation for CMB experiments together with a non-circular beam. This analytical progress promises to lead to fast numerical methods for correcting for one of the thorniest systematic effects in the current CMB experiments.

Initial power spectrum from CMB anisotropy

Exquisite measurements of the angular power spectrum over a wide range of multipoles from the WMAP has opened up the possibility to deconvolve the primordial power spectrum for a given set of cosmological parameters. *Arman Shafieloo* and *Souradeep* have implemented a method to deconvolve the primordial power spectrum from angular power spectrum of CMB anisotropy measured by WMAP using a modified Richardson-Lucy algorithm. The most prominent feature of the recovered primordial power spectrum is a sharp, but non-monotonic, infra-red cut off on the horizon scale. Non-monotonicity in the cutoff accommodates a localized, compensating, excess power below the cut-off. Work is in progress with other collaborators R.P. Manimaran, R. Rangarajan and P. Panigrahi (PRL, Ahmadabad), to employ wavelet analysis to assess the significance of the various features in the primordial spectrum. Fig. (8) illustrates the neat separation and identification of features in primordial spectrum that is allowed by wavelet decomposition.

Remarkably, similar form of infra-red cutoff is known to arise in very reasonable extensions and refinement of the predictions from simple inflationary scenarios, such as the modification to the power spectrum from a pre-inflationary radiation dominated epoch or from a sharp change in slope of the inflaton potential. *Rita Sinha* and *Souradeep* are carrying out detailed cosmological parameter estimation with a class of theoretically motivated infra-red cut-off in the primordial power spectrum. In fact, they have been carrying out parameter estimation in an extended multi-dimensional space of cosmological parameters that include a larger sub-space of parameters that characterize the inflationary epoch. The dimensionality of the space of initial conditions for primordial perturbations is large and already challenges the existing methods used in cosmology. Potentially faster alternative methods for the estimation cosmological parameters in large dimensional parameter spaces such as genetic algorithms is being studied by *Sinha* and *Souradeep* in collaboration with Sundar Rajan (C-DAC, Pune) and Ashish Mahabal (Caltech).

Quasi-Steady State Cosmology

Work by *J.V. Narlikar* on further theoretical and observable features of the Quasi-Steady State Cosmology is continuing in collaboration with G. Burbidge and R.G. Vishwakarma. Also work on the stellar background in optical wavelength range based on all the available stellar databases has been completed by J.C. Pecker and *J.V. Narlikar*.

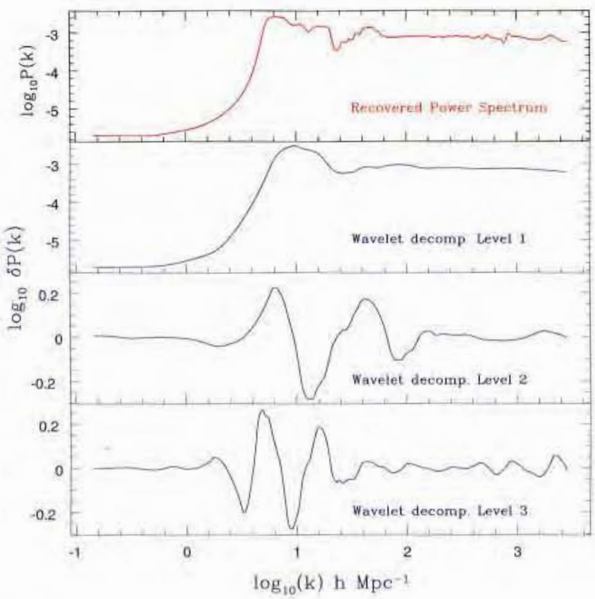


Figure 8: Wavelet decomposition allows for clean separation of the 'features' in the recovered power spectrum on different scales. The top panel shows the primordial power spectrum recovered from the angular power spectrum of CMB anisotropy measured by WMAP (Shafieloo & Souradeep, 2004). The rest of the panels show a Daubechies-4 wavelet decomposition from ongoing research work (Manimaran, Panigrahi, Rangarajan, Souradeep). The most significant feature at the coarsest resolution is a compensated infrared cutoff shown in the second panel (from top). The statistical significance of the small superimposed oscillations is under closer study.

Magnetic Fields in Astrophysics

Turbulence and magnetic fields in galaxy clusters

K. Subramanian and his collaborators (A. Shukurov, and N.E.L. Haugen) have been studying the origin and parameters of turbulence and magnetic fields in galaxy clusters, using simple analytical models and MHD simulations. Any pre-existing tangled magnetic field must decay in about few hundred million years by generating gas motions even if the electric conductivity of the intracluster gas is high. They have argued that turbulent motions can be maintained in the intracluster gas and its dynamo action can prevent such a decay and amplify a random magnetic field by a net factor typically 10^4 in 5 Gyr.

Three physically distinct regimes can be identified in the evolution of turbulence and magnetic field in galaxy clusters. First, the fluctuation dynamo will produce micro Gauss-strong, random magnetic fields during the epoch of cluster formation and major mergers. At this stage, pervasive turbulent flows with r.m.s. velocity of about 300 km s^{-1} can be maintained at scales 100–200 kpc; magnetic field is intermittent and has a smaller scale of 25 kpc. Second, turbulence will decay after the end of the major merger epoch. Magnetic field and turbulent speed undergo a power-law decay, decreasing by a factor of two during this stage, whereas their scales increase by about the same factor. Third, smaller-mass subclusters and cluster galaxies will produce turbulent wakes, where magnetic fields will be generated as well. Although, the wakes plausibly occupy only a small fraction of the cluster volume, they show that the area covering factor can be close to unity, and thus, can produce signatures of turbulence along all lines of sight. The latter allows one to reconcile observations that indicate the coexistence of turbulence with ordered filamentary gas structures, as in the Perseus cluster. The turbulent speeds and magnetic fields in the wakes are estimated to be of order 300 km s^{-1} and 2 micro Gauss respectively, whereas the corresponding scales are of order 200 kpc for wakes behind subclusters of a mass $3 \times 10^{13} M_\odot$ and 8 kpc in the galactic wakes. Magnetic field in the wakes has the scale of about 30 kpc and 1 kpc in the subcluster and galactic wakes respectively. Random Faraday rotation measure is estimated to be typically 100 to 200 rad m^{-2}, in agreement with observations. This work predicts detectable polarization of synchrotron emission from cluster radio halos at wavelengths 3–6 cm, if observed at sufficiently high resolution.

Primordial magnetic fields

Primordial tangled, cosmological magnetic fields can lead to rotational velocity perturbations of the baryon fluid, even in the post-recombination universe. These vortical modes, in turn, leave a characteristic imprint on the temperature anisotropy of the Cosmic Microwave Background (CMB), if the CMB photons can be re-scatterred after recombination. Observations from WMAP indicate that the Universe underwent a relatively early re-ionization ($z_{ri} \sim 15$), which does indeed lead to a significant optical depth for re-scattering of CMB photons after the re-ionization epoch. T. R. Seshadri and *K. Subramanian* have computed the resulting additional temperature anisotropes, induced by primordial magnetic fields in the post-recombination universe. They show that in models with early re-ionization, a nearly scale-invariant spectrum of tangled magnetic fields which redshift to a present value of $B_0 \sim 3 \times 10^{-9}$ Gauss, produces vector modes which in turn induce additional temperature anisotropy of about 0.3 to 0.4 μK over very small angular scales, with l upto ~ 10000 or so.

High Energy Astrophysics

Kilo-parsec (kpc) scale jets with knots have now been detected in several active galactic nuclei (AGN) in the X-ray band by the *Chandra* observatory. This detection strongly suggests that the jets are still highly relativistic with bulk Lorentz factors greater than ten. S. Sahayanathan and *R. Misra* have shown that the standard internal shock model can explain these observations. However, many of these jets show significant bending. They are now calculating the bending angles from different possible mechanisms, which will be later compared with observations.

It is now known that the inner regions of accretion disk around black holes have non-thermal electrons. It is possible that the same acceleration process that produces such electrons may also accelerate protons to form a non-thermal proton distribution. These protons would produce electrons, positrons and γ-rays via p-p collisions, which in turn would by Comptonization produce more pairs and γ-rays due to pair annihilation. S. Bhattacharyya, N. Bhatt and *R. Misra* have computed the steady state electron-positron distribution and the consequent high energy spectra taking into account these feedback mechanisms for different photon environments.

Recently, *Chandra* has discovered Ultraluminous X-ray (ULX) sources in nearby galaxies that are bright ($> 10^{39}$ ergs/sec) and off centre. If the emission is sub-Eddington and isotropic this would imply that these sources harbour intermediary size black holes ($10^2 - 10^4 M_\odot$). It is important to quantify spectral differences between ULX and other regular X-ray binaries that are also observed in these galaxies. A. Senorita and *R. Misra* are studying the spectral properties of these sources, using different spectral models like, a simple power-law, disk emission, etc.

Active Galactic Nuclei, Quasars and Inter Galactic Medium

Masses of the halos around galaxies that host high redshift quasars

In the local universe, the masses of the Super-Massive BlackHoles (SMBH) appear to correlate with the physical properties of their hosts, including the mass of the dark-matter halos. At higher redshifts, we can observe the growth of SMBHs indirectly through the identification of high redshift quasars. However information on their hosts is more difficult to obtain.

In a recent paper, *T.Padmanabhan* and S. Wyithe (Melbourne University) have determined the masses of the halos that host the high redshift quasars (at $z > 4$) by comparing the rate of growth of quasar density with that predicted by the Press-Schechter mass function. The host mass determined depends on how the ratio between SMBH and host halo mass evolves with redshift. Under the assumption that the ratio between SMBH and halo mass does not evolve with redshift, they find a host halo mass of $M = 10^{11.7\pm0.3} M_\odot$. (see Figure (9)) Even if the quasars shine at their Eddington limit, this host mass is significantly smaller than that seen at lower redshifts in the local universe. Indeed they find that the null-hypothesis, of a constant ratio between SMBH and halo mass at all redshifts, can be ruled out at greater than a 5-sigma level. SMBHs must, therefore, have contributed a larger fraction to the host mass in the past. This finding is consistent with expectations from models of self limiting SMBH growth. When they include the redshift evolution of the ratio between SMBH and halo mass, they find larger halo masses of $M \sim 10^{12.4\pm0.3} M_\odot$, and a ratio between SMBH and host halo mass that increases with redshift in proportion to about $(1+z)^{1.5}$ are required to be

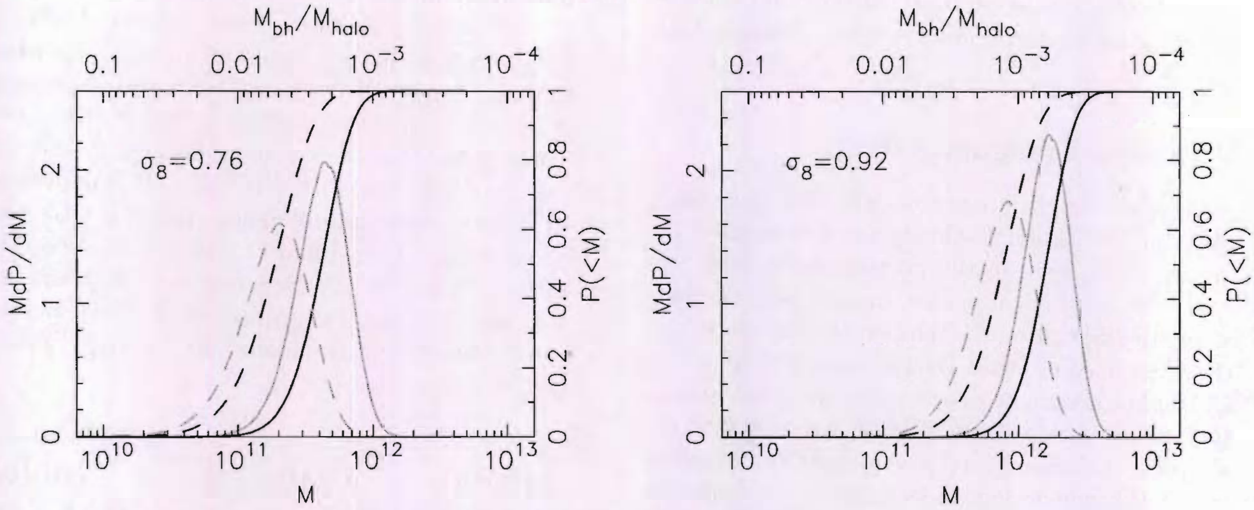


Figure 9: Constraints on the mass of dark matter halos which host quasars. The a-posteriori differential (grey lines) and cumulative (dark lines) probability distributions for M obtained using values of $\sigma_8 = 0.76$ and $\sigma_8 = 0.92$. These correspond to the $2-\sigma$ range for σ_8 determined from WMAP. The duty cycle of quasars is parametrised vary as $(1+z)^\alpha$. The solid and dashed curves in these panels correspond to $\alpha = 3/2$ and $\alpha = 0$. In each panel the upper axis shows the corresponding values for the fraction of halo mass contributed by a $10^9 M_\odot$ black-hole.

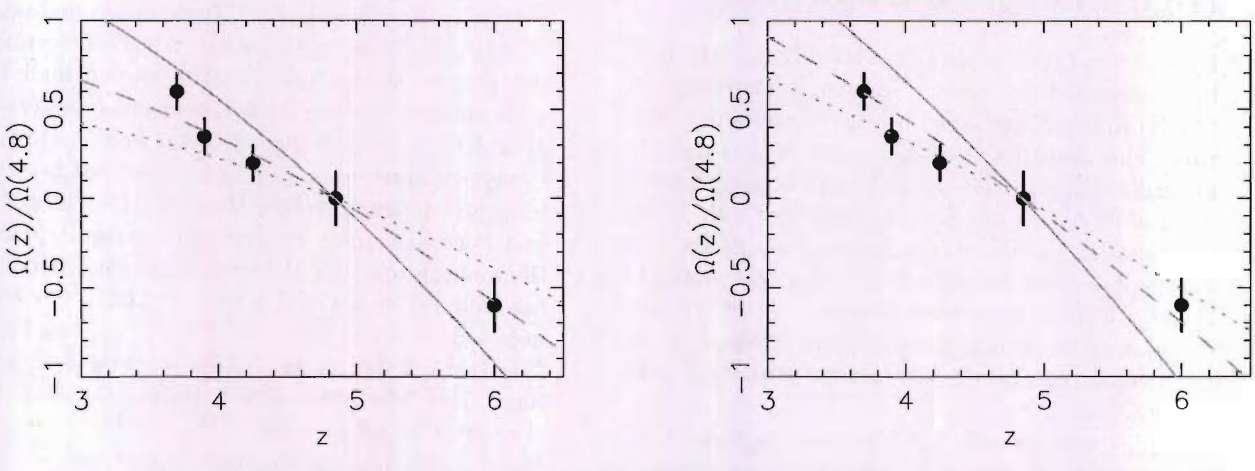


Figure 10: The evolution of density with redshift for different values of linear variance σ corresponding to halos that host high redshift quasars. The curves correspond to $\sigma = 2$ (solid line), $\sigma = 2.5$ (dashed line) and $\sigma = 3$ (dotted line). Both the model and quasar densities have been normalised to unity at $z = 4.8$. The duty cycle of quasars is parametrised vary as $(1+z)^\alpha$. *Left:* curves for $\alpha = 3/2$. *Right:* curves for $\alpha = 0$.

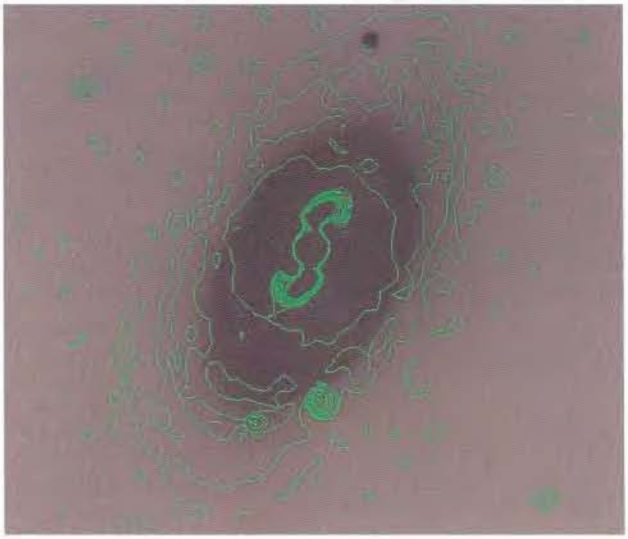


Figure 11: Near-IR JHK photometry of NGC 1553 from New Technology Telescope (NTT), European Southern Observatory (ESO). Unsharp mask subtraction revealed a spiral structure in the core of galaxy shown as contours.

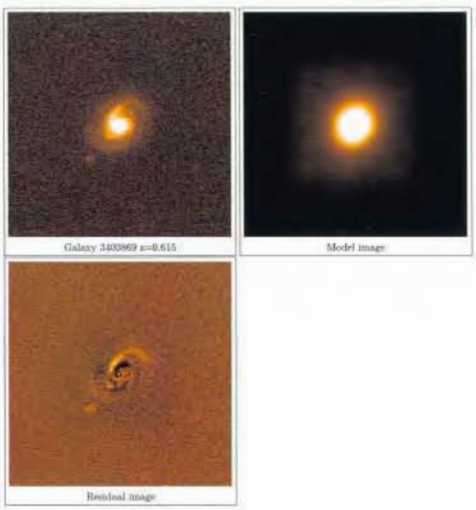


Figure 12: 2-D bulge-disk decomposition using Golfit

consistent with both local and high redshift observations. They also investigate the restrictions placed on the critical linear overdensity of quasar hosts at their epoch of virialisation and find that it cannot exceed the traditional value of $\delta_c = 1.69$ by more than a factor of two. Finally, they find that the high redshift quasars are hosted by fluctuations on scales that have a variance of $(\delta M/M) = 2 - 3$, corresponding to $(3-4.5)$-sigma fluctuations in the density field. (see Figure 10).

Molecular hydrogen at high-z

The physical conditions within damped Lyα systems (DLAs) can reveal the star formation history, determine the chemical composition of the associated ISM, and hence, document the first steps in the formation of present day galaxies. *R. Srianand* and his collaborators (Gary Ferland, Gargi Shaw, Patrick Petitjean and Cedric Ledoux) have performed calculations that self-consistently determine the gas ionization, level populations (atomic fine-structure levels and rotational levels of H_2), grain physics, and chemistry. They have shown that for a low-density gas ($n_H \leq 0.1$ cm^{-3}) the meta-galactic UV background due to quasars is sufficient to maintain H_2 column densities below the detection limit (i.e., $N(H_2) \leq 10^{14}$ cm^{-2}) irrespective of the metallicity and dust content in the gas. Such a gas will have a 21 cm spin temperature in excess of 7000 K and very low C I and C II* column densities for H I column densities typically observed in DLAs.

They have shown that the observed properties of the ~ 15 per cent of the DLAs that do show detectable H_2 absorption cannot be reproduced with the quasar dominated meta-galactic UV radiation field alone. Gas with higher densities ($n_h \geq 10$ cm^{-3}), a moderate radiation field (flux density of one to ten times that of the background radiation of the galactic ISM), the observed range of metallicity and dust-to-gas ratio reproduce all the observed properties of the DLAs that show H_2 absorption lines. This favours the presence of ongoing star formation in DLAs with H_2.

The absence of detectable H_2 and C I absorption in a large fraction of DLAs can be explained if they originate either in a low-density gas or in a high-density gas with a large ambient radiation field. The absence of 21 cm absorption and C II* absorption will be consistent with the first possibility. The presence of 21 cm absorption and strong C II* without H_2 and C I absorption will suggest the second alternative. The N(Al II)/N(Al III) ratio can be used to understand the physical properties when only C II* absorption is present. They have also calculated the column density of various atoms in the excited fine-structure levels. The expected column densities of O I*, O I**, and Si II* in a high-density cold gas is in the range of ($10^{11} - 10^{12}$) cm^{-2} for log N(H I)≥ 20 and the observed range of metallicities. It will be possible to confirm whether DLAs that do not show H_2 originate predominantly in a high-density gas by detecting these lines in very high S/N ratio spectra.

The VLT-UVES survey for molecular hydrogen in damped Lyman-α systems

R. Srianand and his collaborators (Patrick Petitjean, Cedric Ledoux, Gary Ferland, Gargi Shaw) have studied the physical conditions in damped Lyman-α systems (DLAs), using a sample of 33 systems toward 26 QSOs acquired for a recently completed survey of H_2 by Ledoux et al. They have used the column densities of H_2 in different rotational levels, together with those of C I, C I*, C I**, C II* and singly ionized atomic species to discuss the kinetic temperature, the density of hydrogen and the electronic density in the gas together with the ambient UV radiation field. Detailed comparisons are made between the observed properties in DLAs, the interstellar medium (ISM) of the Milky Way, the large and small Magellanic clouds (LMC and SMC). The mean kinetic temperature of the gas corresponding to DLA subcomponents in which H_2 absorption is detected, derived from the ortho-to-para ratio (153$\pm$78 K), is higher than that measured in the ISM (77$\pm$17 K) and the Magellanic clouds (82$\pm$21 K). Typical pressure in these components (corresponding to $T = 100-300$ K and $n_H = 10-200$ cm^{-3}), measured using C I fine-structure excitation, are higher than what is measured along the ISM sightlines. This is consistent with the corresponding higher values for $N(H_2$,J=2$)/N(H_2$, J=0) seen in DLAs. From the column densities of the high-J rotational levels, they have derived that the typical radiation field in the H_2 bearing components is of the order of or slightly higher than the mean UV field in the galactic ISM. Conversely, they have shown, the electronic density and ionization rate in the overall neutral gas are consistent with what is expected in the case of cold neutral medium (CNM) with lower (compared to the Galaxy) metallicity and dust depletion in a moderate radiation field. Combining this with the success rate of detecting H_2 in DLAs, they conclude that at least 13$-$20% of DLAs at $z_{abs} \geq 1.9$ sustain substantial star-formation activity. They have shown that 10% of DLAs with star-formation rate (SFR) similar to what is observed in the Galactic disk ($\sim 4 \times 10^{-3}$ M$_\odot$ yr^{-1} kpc^{-2}), would provide sub-

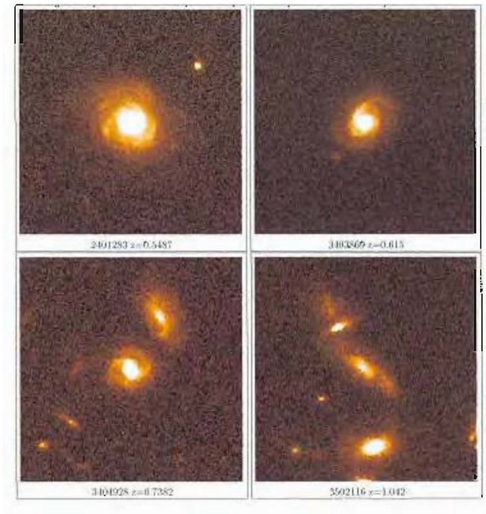


Figure 13: Some galaxies from our sample taken from the HST/ACS GOODS dataset

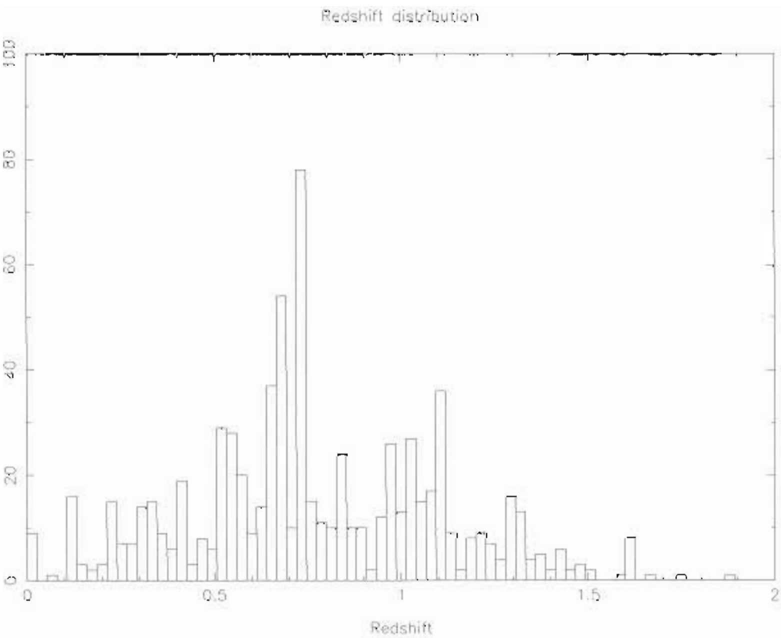


Figure 14: The redshift distribution of our sample

stantial contribution to the global star-formation rate density in the universe.

C II* absorption is detected in all the components where H_2 absorption is seen. The excitation of C II in these systems is consistent with the physical parameters derived from the excitation of H_2 and C I. They have detected C II* in about 50% of the DLAs and therefore in a considerable fraction of DLAs that do not show H_2. In part of the later systems, physical conditions could be similar to that in the CNM gas of the Milky Way. However, the absence of C I absorption and the presence of Al III absorption with a profile similar to the profiles of singly ionized species suggest an appreciable contribution from warm (WNM) and/or partially ionized gas. The absence of H_2, for the level of metallicity and dust depletion seen in these systems, are consistent with lower densities (i.e., $n_H \leq 1$ cm^{-3}) for a radiation field similar to the mean galactic UV field.

Long-term optical photometric monitoring of a SDSS quasar

The diverse observational characteristics of Active Galactic Nuclei (AGN) can be reconciled in possible unification schemes. The basic idea is that all the AGNs have broad and narrow line emitting regions (BLR and NLR) and an obscuring torus. Most of the diversity in the observed properties is caused by differences in our viewing angles to the torus axis. It has also been found that some of the physical parameters of AGNs show statistically significant correlations. For example, tight relationships exist between: (i) the radius of the BLR and the continuum luminosity and (ii) the black hole mass and the velocity dispersion of the host galaxy. With the advent of new very large surveys, some objects that appear to depart from this standard AGN picture are beginning to emerge. Understanding these observations are important to get a clearer picture of AGN formation and evolution.

Several AGNs were recently found to have peculiar emission line characteristics. In the Sloan Digital Sky Survey (SDSS), a few high redshift quasars have been discovered without emission lines. Among them, the $z = 4.67$ quasar SDSS J153259.96−003944.1 (hereafter referred to as SDSS J1533−00) is studied by *R. Srianand* and *C.S. Stalin*. They have reported optical cousins R and I band monitoring observations of this quasar do not show detectable emission lines in its optical spectrum. This object varies with a maximum amplitude of 0.4 mag during a year and three months of monitoring. Combined with two other epochs of photometric data available in the literature, they have shown that the object has gradually faded by 0.9 mag during the period June 1998 - April 2001. A linear least squares fit to all available observations gives a slope of 0.35 mag/yr which translates to 1.9 mag/yr in the rest frame of the quasar. Such a variability is higher than that typically seen in QSOs but consistent with that of BL Lacs, suggesting that the optical continuum is Doppler boosted. Alternatively, within photometric errors, the observed lightcurve is also consistent with the object going through a microlensing event. Photoionization model calculations show that the mass of the BLR to be few tens of solar mass similar to that of low luminosity Seyfert galaxies, but about orders of magnitude less than that of luminous quasars. Further, frequent photometric/spectroscopic monitoring is needed to support or refute the different alternatives for this quasar.

The density structure around quasars

Excess UV radiation field leads to a deficit of absorption lines sufficiently close to the quasar. Because the amount of absorption in general *increases* with redshift, this reversal of the trend for redshifts close to the emission redshift of the quasar is called the 'inverse' or 'proximity' effect. In the standard analysis of the proximity effect it is assumed that the matter distribution is not altered by the presence of the quasar. The only difference between the gas close to the quasar and far away is the increased photoionization rate in the vicinity of the QSOs. An important consequence is that the strength of the proximity effect should correlate with the luminosity of the quasar but such a correlation has not been convincingly established. It is in fact likely that the quasar will be in an overdense region. Indeed, the presence of absorption lines with redshift $z_{\rm abs}$ greater than the quasar redshift $z_{\rm em}$ suggests possible excess clustering of the IGM material around QSOs. Furthermore, in hierarchical models of galaxy formation, the super-massive black holes that are thought to power quasars are in massive haloes which are strongly biased to high-density regions. If the accretion rate in quasars is close to the Eddington limit, which is likely for the very bright quasars it seems plausible that the IGM density close to the quasar is significantly higher than the mean.

Emmanuel Rollinde, *R. Srianand* and *H. Chand* (in collaboration with Tom Theuns and Patrick Petitjean) have presented a method for studying the proximity effect and use it to investigate the density structure around QSOs. It is based on the pixel optical depth probability distribution and its redshift evolution. They validated the method using mock spectra obtained from hydrodynamical simulations, and then applied it to a sample of 12 bright quasars at redshifts 2-3 observed with UVES at the VLT-UT2 Kueyen ESO telescope. These quasars do not show signatures of associated absorption and have a mean monochromatic luminosity of 5.4 $10^{31} h^{-2} ergs^{-1} Hz^{-1}$ at the Lyman limit. The distribution of optical depths changes considerably when the proper distance to the QSO is less than 10 Mpc/h. This could either be due to higher value of UV background radiation field or due to the presence of over density around QSOs. Bigger sample is needed to resolve this degeneracy.

Outflowing material in the CSS quasar 3C48

R. Srianand (in collaboration with Neeraj Gupta and D.J. Saikia (NCRA)) has reported the detection of an associated absorption-line system z_{abs}=0.3654 associated in the UV spectrum of the CSS quasar 3C48. The absorbing material is blue shifted with respect to the quasar emission-line redshift, z_{em} = 0.370, suggesting an outflow velocity of $1000 km\ s^{-1}$. They have detected absorption lines over a range of ionization states from Lyβ, Lyγ, C IV , N IV , S VI to O VI and possibly O IV and Ne VIII. The kinematical properties of the absorption-line system are similar to the blue-shifted emission line gas, which is believed to have interacted with the radio jet. They suggest that the blue-shifted absorbing material has been pushed outwards by the radio jet and study the properties of the absorbing material using CLOUDY and find that photoionization models with solar abundance ratios (with overall metallicity in the range 0.1 $\leq Z/Z_{\odot} \leq$ 1.3) are enough to explain the observed column densities of all the species except Ne VIII. The estimated column density of Ne VIII requires multiple ionization zones. Since the cooling and recombination time for the gas is 105 yr, the consistency with the photoionization models suggests that the jet-cloud interaction with the absorbing material must have taken place before 105 yr. The abundance ratio of nitrogen to carbon is close to solar value, unlike in the case of high-redshift quasars which have super-solar values. They have observed 3C48 with the Giant Metrewave Radio Telescope (GMRT) to search for redshifted 21cm H I absorption but they did not detect any significant feature in the spectra leading to a 3 upper limit to the optical depth to be in the range 0.001 to 0.003. However, due to the diffuse nature of the radio source, optical depths as high as 0.1 towards individual knots or compact components cannot be ruled out.

Accretion Disks

The nature of the viscosity that operates in hot, two-temperature accretion disks around AGN has been a long-standing, unsolved problem. It has been previously suggested that protons, in conjunction with the turbulent magnetic field that is likely to exist in the accretion disk, might be crucial in providing this viscosity. Several authors have recently determined diffusion co-efficients for charged particles (cosmic rays) propagating in turbulent magnetic fields by means of extensive Monte Carlo simulations. *Prasad Subramanian*, Peter A. Becker and Menas Kafatos (George Mason University) use the diffusion co-efficients for protons determined by these simulations to find the effective mean free path for protons in hot accretion disks. This in turn yields good estimates of the viscosity due to energetic protons embedded in the turbulent magnetic field of a hot, two-temperature accretion disk. They find that energetic protons diffusing in the turbulent magentic field provide a physically reasonable source of viscosity in hot accretion disks around AGN.

Galaxies

The HST-GOODS survey

Abhishek Rawat and *Ajit Kembhavi*, in collaboration with Francois Hammer and Hector Flores (l'Observatoire de Paris-Meudon) have been working on an interesting class of galaxies, namely the Luminous Compact Galaxies (LCG) using the publicly available Hubble Space Telescope Great Observatories Origins Deep Survey (GOODS) dataset. The HST/ACS GOODS is a deep, multiband, survey in the optical region, conducted with the Advanced Camera for Surveys, (ACS) on board the HST. It covers 320 square arc minutes split evenly between 2 fields, viz: The Hubble Deep Field North (HDF-N) and the Chandra Deep Field South (CDFS). The broad objectives of this project are to apply automated techniques of photometric data analysis to LCGs for their morphological study , and to follow this with spectroscopic studies based on GIRAFFE data obtained from the Very Large Telescope (VLT).

The current project involves creating a photometric catalogue of all the objects present in the HST/ACS CDFS GOODS area. The complete catalogue for CDFS contains about 60,000 objects (including both stars and galaxies), in each of the B, V, i and z filters. From these 60,000 objects in the original source catalogue, galaxies were selected from that region of the magnitude-size plane, in which the GOODS survey is more than 90 percent

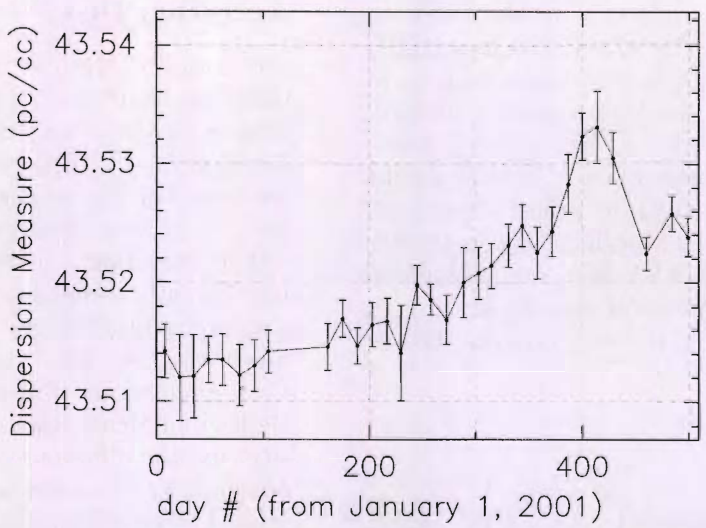


Figure 15: Final results for pulsar B2217+47] DM variation with $3\sigma_{DM_{(noise)}}$ error bars for pulsar B2217+47 observed at frequencies 610+325 MHz, over the time interval Jan 8, 2001 to May 14, 2002 as a function of day number. The catalog DM is 43.54 pc/cm^3.

complete, with a limiting magnitude of 24 in the z band. This yields an unbiased sample of 3400 galaxies. This sample was then cross-correlated with redshift catalogues available for that field from various ground based follow ups such as the VLT-VIMOS redshift survey having 1600 redshifts in the CDFS area on the sky. This redshift information is essential for calculating the rest frame magnitudes, sizes etc of the galaxies. This finally yielded a unbiased sample of 800 galaxies with known redshift. Stamp sized CCD images of these galaxies were then extracted from the available survey fields in all the 4 filters for morphological analysis. The publicly available software Galfit was used to derive the structural parameters of the galaxies through a two-dimensional modelling of their surface brightness distribution.

Since the computation time for bulge-disk decomposition of 800 galaxies was too large (4 days on a high end machine), a special software was installed on the multiprocessor computer *Hercules* at IUCAA with the help of E.W. Peng (STScI), leading to cutting down the computation time by at least an order of magnitude.

In addition to performing the bulge-disk decomposition of these galaxies on the one hand, efforts were also being made to calculate the rest frame properties for the 800 galaxies for which redshift was known. This raised the crucial question of determining the k-corrections for these galaxies. In the absence of spectra for most of these galaxies, the technique of template fitting to the observed galaxy SED is being used to obtain the k-corrections. Once this work is finished, a subsample of Luminous Compact Galaxies will be chosen from the 800 galaxies, based on absolute magnitude and size (Kpc). This subsample, coupled with the morphological parameters yielded by the bulge-disk decomposition of these galaxies will shed some light on the redshift evolution of this class of objects.

Priya Hasan and *Kembhavi*, in collaboration with Francois Hammer (Paris Observatory) and G. Fabbiano (Centre for Astrophysics, Cambridge, Ma), have been working on AGN using archival data from the HST GOODS survey, Chandra and Spitzer. Observations of overlapping fields with these missions provide a unique database of AGNs, starburst galaxies and normal galaxies in wavelengths ranging from infrared to X-ray. They are using the GOODS database to understand the morphology, spectral properties and evolution process of galaxies which have some indication of AGN activity in this sample using indicators like their X-ray luminosity, radio flux, etc. They have identified optical counterparts from the GOODS-South field of the CDFS (Chandra Deep Field South) and used various methods to estimate the probability of a true match. These sources were also cross-matched with the NVSS catalogue to get 10 sources within a typical search radius of 15". X-ray colours are good indicators of population types in galaxies. Morphological analysis of the optical counterparts is planned so that trends can be studied in the 'normal' galaxy and AGN sample. Spectral data from GIRAFFE on the VLT, obtained by Ravi Kumar and his collaborators at the Paris Observatory, is also being used in this project.

Kembhavi in collaboration with Sudhanshu Barway and S. K. Pandey (Pt. Ravishankar Shukla University) and Somak Raychaudhury, (University of Birmingham) has observed a sample of early-type galaxies in J, H and Ks band from NTT 3.5m telescope, La Silla, Chile. Surface brightness, ellipticity, position angle profiles as well as higher order Fourier coefficients have been obtained using ellipse fitting technique available within IRAF. Unsharp mask subtraction unveiled various structures and sub-structures in the sample galaxies, e.g., shells, dust lanes and patches, etc., especially a spiral structure in the core of the galaxy NGC 1553 and shells in the inner and outer regions. This is the first time such features have been unveiled from NIR images of early-type galaxies.

A programme of observing bright nearby galaxies, with a view to determining structural parameters which define their large scale morphology, is being carried out at IUCAA by *Kembhavi* in collaboration with several persons over a number of years. An important result from this programme, obtained in collaboration with Habib Khosroshahi and Yogesh Wadadekar and Bahram Mobasher (Space Telescope Science Institute), has been the demonstration of the existence of the photometric plane, which is the locus defined by the central surface brightness, effective radius and the Sersic parameter of elliptical galaxies (which describes the shape of the intensity profile). The fact that elliptical galaxies and the bulges of early type galaxies share a single photometric plane points to overall structural similarities between these objects, and possibly a common formation process. There are indications that the bulges of late type galaxies lie away from the plane, and that even those objects which share a single plane lie on different sectors of it depending possibly on the luminous mass in the galaxy, and also the environment. With a view to examining these possibilities in detail, *Kembhavi*, in collaboration with Ravi Kumar (Paris Observatory), V. C. Kuriakose (CUSAT) and Sudhanshu Barway (Pt. Ravishankar Shukla University) has analyzed a large sample of bulges of galaxies of different Hubble types including ellipticals, lenticulars, early and late type spirals and early type dwarf galaxies. There is a difference in the correlations exhibited by bright $M_K < -22$ and faint bulges, irrespective of their Hubble type, which follows from a study of the distributions of various photometric parameters and two- and three-dimensional correlations. Importantly, the bright bulges, which include typically E/S0 galaxies and bulges of early type spirals, are tightly distributed around a common photometric plane (PP), while their fainter counter parts, mainly bulges of late type spirals and dwarf galaxies show significant deviation from the planar distribution. The specific entropy, determined from the bulge structural parameters, systematically increases as one move from late to early Hubble types shows evidence for hierarchical merging and passive evolution scenarios for bright and faint bulges respectively.

Stars and Interstellar Medium

Pulsars

A pulsar is a very accurate clock and rotates at a nearly constant rate. Most of the pulsars emit the electromagnetic waves in the radio band. Due to the presence of free electrons, the inter-stellar medium (ISM) disperses the electromagnetic waves traveling through it. The periodic pulses emitted at radio wavelengths by pulsars are affected by this dispersion so that the lower frequency components of a pulse arrive later than the higher frequency components. Pulsar dispersion measure (DM) is the product of the average free electron density along the line of sight to the pulsar and the distance to it.

The pulsar DM value is needed with sufficient accuracy for proper dispersion correction to be carried out on the received signals. Precise knowledge of DM values can also be used to understand the pulsar emission geometry. Small variations in DM values take place on time scales of about a few weeks to months. Study of these variations help to understand the random electron density fluctuations in the ISM. Accurate values of DM can be used to estimate the distance to a pulsar.

This work is carried out by *Amrit Lal Ahuja* and *Ajit Kembhavi*, in collaboration with Yashwant Gupta (NCRA). They have been working on the development of a robust and reliable technique to estimate the pulsar DMs with a fractional accuracy of 10^{-4} and better. With such accuracy, it is possible to study fluctuations in DM over time. For accurate estimation of pulsar DM, they have carried out simultaneous multi-frequency observations for a sample of twelve radio pulsars every fortnight, over a period of about one and a half year, using the Giant Metrewave Radio Telescope (GMRT) which has a unique capability for such projects.

Most of the pulsars show the random variation of DM with time, but the pulsar B2217+47 shows a gradual, systematic variation (see Figure 15). The amplitude of this change ($\simeq$ 0.02 pc/cm^3/year) is such that it would require a very large radial velocity ($\sim$ 10^6 km/s) through a normal density ISM ($\sim$ 0.02 /cm^3), or a very high density ISM ($\sim$ 200 /cm^3) for normal pulsar velocities ($\sim$ 100 km/s). It is likely that the cause for this change is an electron density gradient in the ISM.

Some of the pulsars were observed with two different pairs of frequencies, and differences were found in the DM values. This may be because of different emission heights in the pulsar polar cap. Another interesting result that has been obtained is that for some pulsars (e.g., B0329+54), the DM values obtained from average profile method and single pulse analysis method show an offset.

A pulsar simulation code has been developed to understand these results. It is found that the results from average profile simulation data with simple profiles match with the input DMs. But, complex profiles evolving with frequency show significant deviation from the input values. This may be indicating possible errors in the DM measurements due to evolution of pulse profile with frequency.

Interstellar dust and extinction by non-spherical grains

R. Gupta in collaboration with T. Mukai (Kobe University), D.B. Vaidya (Ex-Gujarat College), Asoke K. Sen (Assam University) and Y. Okada (Kobe University) has revised the current model of interstellar dust based on T-Matrix computations. Figure (16) shows the effect of shape on the extinction efficiency Q_{ext} and linear polarization efficiency $|Q_{pol}| = Q_{ext}(E) - Q_{ext}(H)$ of oblate (AR>1) silicate and graphite spheroidal grains with a size of 0.1 μ and various fixed orientation angles β (angle of incoming beam of light with respect to the laboratory frame of reference). Figure (17) shows the same effect for prolate (AR<1) grains. It may be noted that the oblate and prolate silicates show considerable differences in the linear polarization efficiencies.

A spectral library in the NIR H-band

A NIR spectral library with 135 solar-type stars in the H-band has been recently completed by A.C. Ranade, N.M. Ashok, *Ranjan Gupta* and Harinder P. Singh using the NICMOS3 HgCdTe 256 × 256 NIR array based spectrometer at the 1.2 meter Gurushikhar Infrared Telescope (GIRT), at Mt. Abu. The Figure (18) and (19) shows sets of some spectra from this library.

Brown Dwarf Polarimetry

Last year, it was reported that a collaborative work of *A. N. Ramaprakash*, et. al and S. Sengupta (IIA, Bangalore) was being initiated to study the nature of polarization in relatively warm L-Dwarfs. (This project is part of the thesis work of M. Maiti, a graduate student at IIA, Bangalore.) After several attempts of making observations with IMPOL using the Vainu Bappu Telescope at Kavalur, which were hindered by bad weather, finally some successful observations were carried out during the winter of 2004-05. This data is being analysed and the initial results show that there is detectable polarization in the R-band light coming from these objects. This is encouraging, and based on the results of the data analysis, the group plans to undertake further observations of L-Dwarfs, in at least two wavelength bands.

Solar Physics

Observations of the sun with the GMRT and the Nancay Radio Heliograph (NRH)

Prasad Subramanian is working with C. Mercier, Monique Pick, and Alain Kerdraon (Observatoire de Paris) on an ongoing programme of combining data from the GMRT and NRH, in order to make composite metre wavelength images of the solar corona. Their aim is to combine the short baseline data from the NRH with long baseline data from the GMRT, in order to obtain meter wavelength images of unprecedented resolution and fidelity. They have recently obtained 17 second snapshot images of complex, noise storm emitting regions on the sun at 327 MHz see Figure (20). These are the highest dynamic range snapshot images of the solar corona to date. They are also working on obtaining high dynamic range synthesis images with a similar technique.

Electron acceleration in solar noise storms

Noise storms in the solar corona are the most accessible astrophysical sites of quasi-continuous electron acceleration. A comprehensive understanding of solar noise storms will thus shed light on several similar processes in more distant environments. In a series of two papers, *Prasad Subramanian* and Peter A. Becker (George Mason University) have examined the energetics of each stage of the noise storm process, starting from electron acceleration and culminating in the observable radio emission. In doing so, they have obtained, for the first time, a rigorous estimate of the efficiency of the overall noise storm process.

Instrumentation

CMOS imaging devices for Astrosat

In the intensified imaging detectors of UltraViolet Imaging Telescope, CCD/CMOS imaging devices

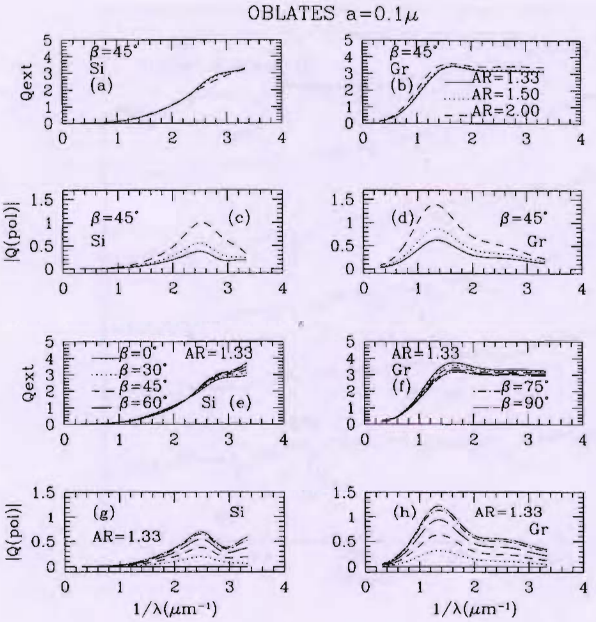


Figure 16: Extinction Q_{ext} and linear polarization efficiencies versus $1/\lambda$ for aligned oblate spheroids (Silicates and Graphites with grain size a=0.1μ). The panels (a), (b), (c) and (d) are for a fixed orientation (β=45°) and various axial ratios AR of the aligned spheroids. The panels (e), (f), (g) and (h) are for a fixed axial ratio AR=1.33 but with various orientation angles β.

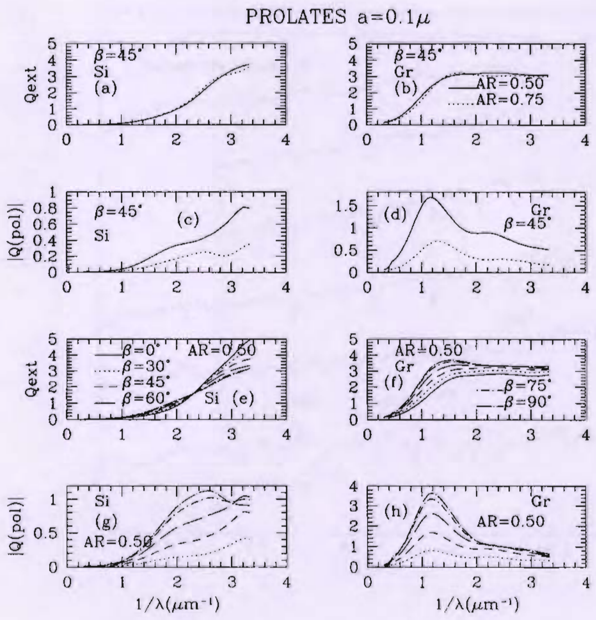


Figure 17: Extinction Q_{ext} and linear polarization efficiencies versus $1/\lambda$ for aligned prolate spheroids (Silicates and Graphites with grain size a=0.1μ). The panels (a), (b), (c) and (d) are for a fixed orientation (β=45°) and various axial ratios AR of the aligned spheroids. The panels (e), (f), (g) and (h) are for a fixed axial ratio AR=1.33 but with various orientation angles β.

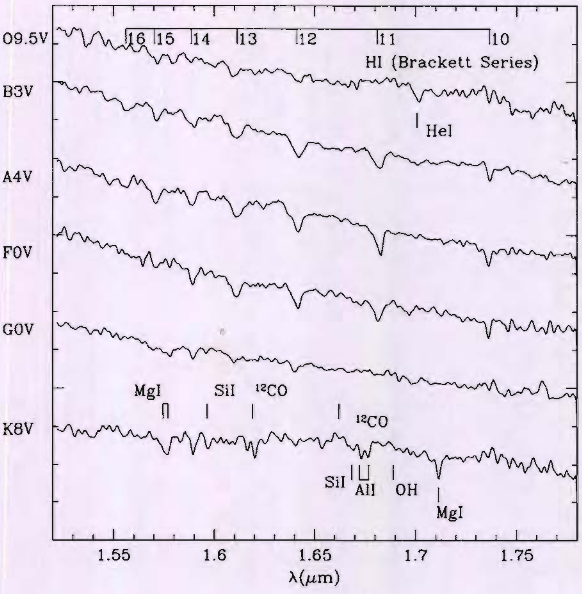


Figure 18: This figure shows the spectra of six dwarf stars, covering a large range of MK spectral type, which are plotted to illustrate the basic dependence of spectral features. The stars plotted, top to bottom, are HR6175, HR1239, HR4357, HR4090, HR4375 and HD88230. The spectral types are listed on the vertical axis. Also shown are some of the prominent absorption features like HI Brackett series and other species seen in the late type spectra.

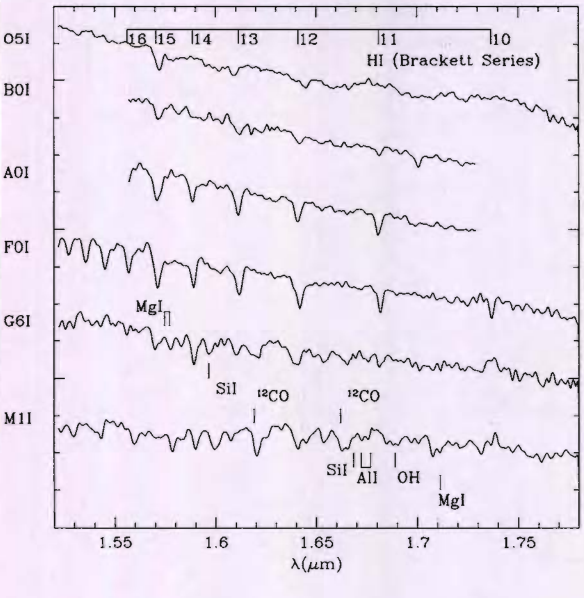


Figure 19: This figure shows the spectra of six supergiant stars, covering a large range of MK spectral type, are plotted to illustrate the basic dependence of spectral features. The stars plotted, top to bottom, are HR3165, HR1903, HR3975, HR1865, HR3045 and HR2508. The spectral types are listed on the vertical axis. Also shown are some of the prominent absorption features like HI Brackett series and other species seen in the late type spectra.

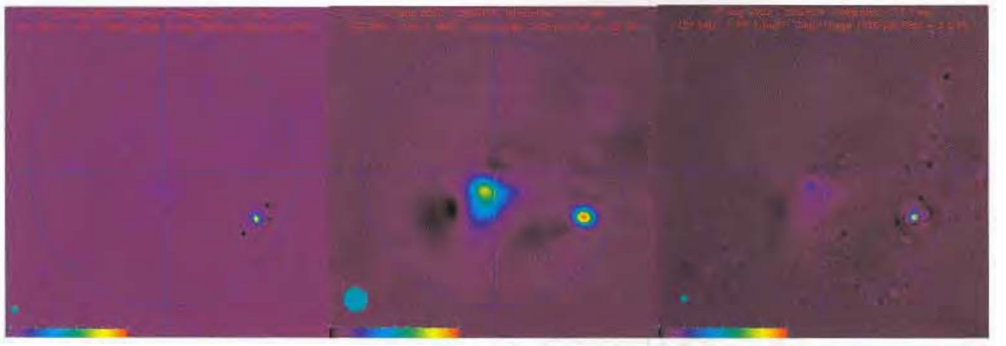


Figure 20: 17 second snapshots of the solar corona at 327 MHz, around 09:04:04 UT, Aug 27 2002. Left panel: Image with the GMRT only. Middle panel: Image with the NRH only. Right panel: Composite image with the GMRT and NRH. The resolution of the composite snapshot is 49$''$ and its dynamic range is 283.

are used for read-out. In order to get a large aperture of the optical field with a small CCD/CMOS device, the intensified photon spot is imaged on the device with a reduction of 3-5. Therefore, to get a high overall resolution it is required that centroids of the individual intensified spots on the devices be measured with an accuracy about 0.1 pixels. *S. N. Tandon* and *A. Kohok* have checked the limits on resolution achievable by a CMOS device: Star250 by imaging pores of Micro Channel Plate (MCP) in the intensifier.

Output of the intensifier was fed to Star250 through a 3:1 (reducer) fibre taper, and about a million images were taken with ultra low light level. The ensemble of analysed images clearly showed two dimensional structure of the pores in MCP, placed on a grid of 0.14 pixels, i.e. individual photon spots are located to better than 0.05 pixel.

Based on this clear demonstration of resolution of Star250, this sensor has been selected for use in detectors of the telescope, as these provide the most economical option for this need.

NIPI - Near-Infrared PICNIC Imager:

NIPI will be the first near-IR instrument to be used on the IUCAA telescope. It is a camera that can cover the J, H and K bands in the near-infrared, employing the Rockwell 256x256 PICNIC array. The 40 micron pixels of the array translates to a sampling of 0.8 arcsec on the sky per pixel due to the factor of two focal reducer optics. The double achromat focal reducer has been designed to work at about 150K inside the cryogenic chamber. *A. Deep, A. N. Ramaprakash, S. N. Tandon*, and others in the instrumentation laboratory are working on this project.

It was reported last year that a bare multiplexer (electrically equivalent to the PICNIC, but without the HgCdTe layer) was tested in the laboratory to understand the electrical operation of the detector array. Following this, a set up was made in the laboratory to test the PICNIC detector itself. The detector has to be housed in a cryogenic environment for this purpose and operated at temperatures close to that of liquid nitrogen (about 77K), to reduce the detector dark current. In the laboratory set up, by keeping the PICNIC detector in close contact with a liquid nitrogen cooled surface inside a Dewar, it was possible to bring the operating temperature close to about 90K. This reduces the detector dark current to acceptable levels of about 100 electrons per pixel per second.

Since thermal stresses induced by fast cooling of the detector can lead to damage, arrangements have been made to control the cooling rate of the detector. This is achieved by controlling the rate of filling liquid nitrogen into the chamber. Temperature sensors on the cold mounting blocks allow actual monitoring of the cooling rate and the final temperature that is achieved.

Further, the amount of thermal radiation which reaches the detector has to be controlled so that the pixels do not saturate with the background light. To achieve this, the detector mount socket assembly is covered with a cap, which in turn was maintained at a temperature of about 150K. A floating radiation shield is used to isolate the detector assembly from the outer wall of the dewar. The resultant unfiltered background is found to fill the full well capacity of the pixels in about six seconds. This is sufficient to carry out further characterization tests and performance optimization of the data acquisition system. The ability to configure through software, the levels and timings of the various clocks and bias signals needed for data acquisition, has been found very useful for these tests.

A cryogenic dewar of required capacity, which carries the liquid nitrogen container and the evacuation ports have been procured by Infrared Labs, USA. The second part of the cryogenic vessel, which houses the lenses, filter wheel, detector etc. has been designed in house. This chamber is to be built with an aluminium alloy AL7075-T651, ingots of which with required sizes have been ordered. There has been some delay in procuring this material due to export licence restrictions in Germany, where it is manufactured. The export licence has now been awarded and the material is soon to be shipped. Meanwhile, the design of the mechanical components has reached the final stage and will be completed by the time the aluminium ingot is delivered.

The embedded instrument control system, which allows control of the instrument from the control room of the observatory is ready for use now. This system allows observers to change filters, monitor temperature, control the window fan etc. It has been tested in the laboratory and interfaced with the telescope.

(II) RESEARCH BY VISITING ASSOCIATES AND LONG TERM VISITORS

Gravitational Theory and Gravitational Waves

Ahsan, Zafar

It is known that the Riemann curvature tensor can be decomposed in terms of the Weyl conformal tensor, the Ricci tensor and the metric tensor. This decomposition involves certain irreducible tensors. In empty space time, the pure gravitatinal radiation field is described by the Weyl conformal tensor. However, when gravitational waves propagate through matter, the Weyl tensor is still pertinent. In 1962, C. Lanczos thought that the Weyl tensor can also be derivable from a simpler tensor field, and this can indeed be done through the covariant differentiation of a tensor field. This tensor field is now known as Lanczos potential. In G*ö*del geometry, a two rank symmetric tensor which satisfies the wave equation and generates a Lanczos potential has been constructed by Zafar Ahsan in collaboration with J. H. Caltenco and J. L. Lopez-Bonilla of Mexico.

Using the Newman-Penrose formalism, a conformally flat solution of Einstein-Maxwell equations for null electromagnetic field has been obtained.

Banerjee, Asit

Recent Supernovae observations indicate an accelerated expansion of the universe and lead to the search for a new type of energy, said to be the dark energy, which violates the strong energy condition. The Chaplygin gas obeying an equation of state like $p = -B/\rho - n$ provides such a model, which evolves asymptotically to a cosmological constant model with accelerated expansion. Asit Banerjee along with his collaborators has found a model which, is valid from the radiation era to Λ CDM stage and studied its characteristics with the help of statefinder parameters.

Szekeres family of solutions for quasi-spherical spacetime with dust has so far been generalized by many workers to perfect and also imperfect fluid with heat flow, fluid with cosmological constant and even to higher dimensions. Banerjee, and collaborators have obtained a family of higher dimensional solutions in the scalar tensor theory of gravitation. In fact, the Brans-Dicke field equations expressed in Dickes revised units are solved and exhaustively studied for all the subfamilies. A particular group of solutions may also be interpreted as due to the presence of the so called C-field of Hoyle and Narlikar with a choice of the coupling parameter.

Ghosh, Sushant

One of the most famous conjectures in general relativity is the so called *cosmic censorship conjecture*, (CCC) which states that, for physically reasonable initial data, spacetime cannot evolve towards a naked singularity, i.e., the spacetime singularity is always hidden inside black holes, indicating that a far away observer will not be influenced by it. Despite almost 30 years of effort, the CCC remains as one of the most outstanding unresolved questions in GR. It turns out that such a theorem is intractable due to complexity of the Einstein field equations.

S. Ghosh and A. K. Dawood have proved a theorem that characterizes a large family of nonstatic solutions to Einstein equations, representing in general, spherically symmetric Type II fluid. It is shown that the best known dynamical black hole solutions to Einstein equations are particular cases from this family. The solutions found can be useful to get insights into more general gravitational collapse situations and in general better understanding of CCC.

S. Ghosh and D. W. Deshkar in collaboration with N. Dadhich have studied the spherically symmetric collapse of a fluid with nonvanishing radial pressure in higher dimensional spacetime. They obtain the general exact solution in the closed form for the equation of state ($Pr = \gamma\rho$), which leads to the explicit construction of the root equation governing the nature (black hole versus naked singularity) of the central singularity. A remarkable feature of the root equation is its invariance for the cases; $(D, \gamma = 0)$ and $(D + 1, \gamma = -1)$ where D is the dimension of spacetime. For the ultimate end result of the collapse, these two cases are absolutely equivalent, which is indeed a very interesting new result that brings out the interplay between dimension D of space$\sim$Vtime and the equation of state parameter γ.

Ghosh has investigated the occurrence of naked singularities in the gravitational collapse of an inhomogeneous dust cloud in an expanding de Sitter background - a piece of Tolman-Bondi de Sitter spacetime. It turns out that the collapse proceed in the same way as in the Minkowski background, i.e., the strong curvature naked singularities form and thus, violate the cosmic censorship conjecture. His result unambiguously supports the fact that the asymptotic flatness of spacetime is not a necessary ingredient for the development of naked singularities.

Ibohal, Ng.

By applying Newman-Janis algorithm to a spherically symmetric seed metric, Ibohal Ng. has discussed general rotating metrics in terms of Newman-Penrose (NP) quantities involving Wang-Wu functions. From these NP quantities, he derives a class of rotating solutions including (i) Vaidya-Bonnor, (ii) Kerr-Newman-Vaidya, (iii) de Sitter, (iv) Kerr-Newman-Vaidya-de Sitter and (v) Kerr-Newman-monopole. The rotating Kerr-Newman-Vaidya solution represents a black hole that the Kerr-Newman black hole is embedded into the rotating Vaidya radiating universe. In the case of Kerr-Newman-Vaidya-de Sitter solution, one can describe it as the Kerr-Newman black hole is embedded into the rotating Vaidya-de Sitter universe, and similarly, Kerr-Newman-monopole. He has also discussed the physical properties by observing the energy momentum tensors of these solutions. These embedded solutions can be expressed in Kerr-Schild forms describing the extensions of Glass and Krisch superposition, which is further the extension of Xanthopoulos superposition. It is shown that, by considering the charge to be a function of radial coordinate, the Hawkings continuous radiation of black holes can be expressed in classical spacetime metrics for these embedded black holes. It is also found that the electrical radiation will continue to form instantaneous charged black holes and creating embedded negative mass naked singularities describing the possible life style of radiating embedded black holes during their continuous radiation processes. The surface gravity, entropy and angular velocity, are also presented for each of the embedded black holes.

In another paper, Ibohal Ng. and Dorendro have derived a class of *non-stationary* rotating solutions including Vaidya-Bonnor-de Sitter, Vaidya-Bonnor-monopole and Vaidya-Bonnor-Kerr. These rotating solutions describe embedded black holes. By considering the charge to be function of u and r, they discuss the Hawking's evaporation of the masses of variable-charged *non-embedded*, non-rotating and rotating Vaidya-Bonnor, and *embedded* rotating, Vaidya-Bonnor-de Sitter, Vaidya-Bonnor monopole and Vaidya-Bonnor-Kerr, black holes. It is shown that every electrical radiation of variable-charged black holes will produce a change in the mass of the body without affecting the Maxwell scalar in *non-embedded cases*; whereas in *embedded cases* the Maxwell scalar, the cosmological constant, monopole charge and the Kerr mass are not affected by the radiation. It is also found that during the Hawking's radiation process, after the complete evaporation of masses of these variable-charged black holes, the electrical radiation will continue creating (i) negative mass naked singularities in *non-embedded* ones, and (ii) embedded negative mass naked singularities in *embedded* black holes. The surface gravity, entropy and angular velocity of the horizon are presented for each of these non-stationary black holes.

Kuriakose, V. C.

The discovery of emission of thermal radiation by black holes led to the belief that a black hole can exist in thermal equilibrium with a heat bath possessing a characteristic temperature distribution, otherwise the black hole would have evaporated completely. Back reaction programme is found to be useful in explaining the thermal equilibrium of black holes. P.I. Kuriakose and V.C. Kuriakose have studied the back reaction effect for the Schwarzschild - anti de Sitter and Schwarzschild - de Sitter black holes and calculated the change in entropy due to back reaction effect. One of the most useful and efficient ways to study the properties of black holes is scattering of matter waves by black holes. This study is crucial to the understanding of the signals expected to be received by the new generation of gravitational detectors. R. Sini and Kuriakose are now investigating this problem in detail.

Nandi, Kamal Kanti

One of the frontier areas of theoretical physics is the topic of traversable Lorentzian wormholes. Kamal Kanti Nandi, along with collaborators, studied static, spherically symmetric traversable wormhole solutions in the vacuum low energy string theory and in general relativity. Two related topics of investigation are: the constraints imposed on the size of the wormholes at semiclassical and quantum field theoretic level and the proposal of a volume quantifier for exotic matter. They are presently engaged in calculating the entropy of quantum fields in the background of brane world black holes.

Patil, K. D.

Today, a well known and challenging open problem in general relativity is the cosmic censorship conjecture(CCC). The higher dimensional theory has opened up new and exciting direction of research in quantum gravity. Hence, to prove or disprove CCC, it becomes necessary to study the gravitational collapse in the higher dimensions as well. K. D. Patil and R. V. Saraykar have studied necessary conditions for the occurrence of naked singularities in the higher dimensional dust collapse. They have analyzed the higher dimensional non-marginally bound inhomogeneous dust collapse, where the initial data consist of finitely differentiable functions of comoving coordinaters. It has been shown that as the dimensions of the spacetime increase, the calculations of the derivatives of both, density as well as velocity distribution functions of less orders near the centre, are required to decide the nature of the singularity.

Pradhan, Anirudh

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 consequence, one includes 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 and S.K. Singh, considering an anisotropic homogeneous Bianchi type I metric.

The general dynamics of tilted models have been studied by A. R. King and G. F. R. Ellis. Ellis and J. E. Baldwin have shown that we are likely to be living in a tilted universe and they have indicated how we may detect it. Spacetimes of Bianchi type I, V and IX universes are the generalization of FRW models and they would be interesting to construct cosmological models of types which are of class one. A. Pradhan and Abha Rai have studied tilted Bianchi type V cosmological models field with disordered radiation in presence of a bulk viscous fluid and heat flow.

Several modifications of Einstein's general relativity have been proposed and studied extensively so far by many cosmologists to unify gravitation and many other effects in the universe. Barber has produced two continuous self creation theories by modifying the Brans-Dicke theory and general relativity. The modified theories create the universe out of self-contained gravitational and matter field. However, the solution of the one-body problems reveal unsatisfactory characteristics of the first theory and in particular the principle of equivalence is violated severely. The second theory retains the attractive features of the first theory and overcomes demerits thereof. The second one is an adaptation of general relativity to include continuous creation and is within the observational ambit. In view of the consistency of Barbers second theory of gravitation, A. Pradhan and H.R. Pandey have studied some of the aspects of this theory and investigated LRS Bianchi type I cosmological model in Barbers second theory of gravitation.

Ray, Saibal

Experimental result regarding the maximum limit of the radius of the electron ($\sim 10^{-16} cm$) and a few of the theoretical works suggest that there might be some negative energy density regions within the particle in the general relativity. As a continuation of the studies on "Electromagnetic Mass" models, where gravitational mass of an electron originates from the electromagnetic field alone, S. Ray and S. Bhadra have argued that such a negative energy density also can be obtained with a better physical interpretation in the framework of Einstein-Cartan theory.

S. Ray has also studied the history of electromagnetic mass models and hence, search a clue for unification of electromagnetic and gravitational fields after describing the status of mass in relativity theory and quantum mechanics.

Saraykar, R. V.

Gravitational collapse of type I matter fields starting from regular initial data comprising of continuously differentiable mass functions and velocity distributions results into either a black hole or a naked singularity (one that is visible to a far away observer) depending on the choice of initial data. The interesting question is whether the occurrence of naked singularities is stable under small changes in the initial data, and whether this occurrence is generic? R. V. Saraykar and Sanjay B. Sarwe have investigated this and proved that the occurrence of naked singularities is stable under small changes in the initial data, small changes being in the appropriate functional analytic sense. They also proved that though the initial data leading to both black holes and naked singularities form a big subset of the initial data set, their occurrence is not generic. The word generic is appropriately defined following the theory of dynamical systems. Furthermore, they illustrated the particular case of radial pressure to get clear picture of how a naked singularity is formed and how it is stable with respect to initial data.

Saraykar, in collaboration with Sarwe, has also studied gravitational collapse of five dimensional spherically symmetric self - similar perfect fluid spacetime with adiabatic equation of state, considering all families of future directed non-space like geodesics. They have proved that the spacetime admits globally strong curvature naked singularities in the sense of Tipler and thus, violates cosmic censorship conjecture. For this, weak energy condition is necessary, so that the singularity is visible for a finite period of time. Moreover, the solution is matched to five dimensional Schwarzschild solution using junction conditions.

In another paper, Saraykar, along with K. D. Patil, investigated higher dimensional non-marginally bound inhomogeneous dust collapse, where initial data consists of finitely differentiable functions of comoving coordinate. They have proved that with the introduction of a velocity distribution function, the results on the occurrence of a naked singularity get slightly modified in comparison with the marginally bound collapse. They have also discussed the nature of families of radial null geodesics emanating from the singularity.

Causal structure of spacetime has been studied by many researchers working in classical general relativity and it has been successfully applied by Hawking, Penrose, Geroch et. al. in proving singularity theorems. In 1996, Sorkin and Woolgar defined the concept of K- causality, which is more general than usual concept of causality. Recently, in 2003, Garcia - Parrado and Senovilla introduced the concept of causal maps and studied causal structure of spacetime with a new perspective. Causal maps are more general than conformal maps. Saraykar and Sujatha Janardhan, in a recent paper, combined these works to prove some results in the K-causal, structure setting which are generalizations of results of Garcia- Parrado and Senovilla. They defined concepts like future sets, reflecting and distinguishing spacetimes etc. in K-causal setting, and proved that these properties are preserved under K-causal maps. Path-metric Lorentz manifolds which satisfy K-causality condition (which is stronger than strong causality) are a special case of C^0 - Lorentz manifolds and some more properties can be proved for these spacetimes. They found that this approach is simpler and more general as compared to traditional causal approach.

Sarmah, Bhim Prasad

Einstein's general theory of relativity predicts the existence of gravitational waves, propagating virtually unimpeded through spacetime at the vacuum speed of light and carrying the imprints of the dynamics of the source. These are very weak waves and quadrupolar in nature, i.e., a source having 2^{nd} order time rate of change in asymmetric distribution of the mass/mass current can emit gravitational waves. Among the prospective astrophysical sources include the coalescence of binary compact objects (Black Hole/Black Hole, Black Hole/Neutron Star, Neutron Star/Neutron Star), the supernova explosion, rapidly rotating and/or oscillating Neutron stars and CFS instabilities that can develop in fast rotating neutron stars, etc.

Bhim Prasad Sarmah is presently looking into the gravitational waves generated from (1) r-mode instability in neutron stars (2) core collapse supernova with the help of simplified collapse model. Further, some calculations are being carried out to estimate the gravitational waves that can be emitted from the mini-creation event - the key component in the quasi-steady-state model of the universe.

Singh, G. P.

Higher-dimensional view of the world geometry suggests that the universe started in (4+D) dimensional phase with extra D dimensions either collapsing and stabilizing or remain at a size close to the Plank length, while three others continued to expand. The study of physics in higher dimensional spacetime has been stimulated by investigations of superstring and supergravity theories. A number of researchers have studied higher dimensional spacetimes both in localized and cosmological domains. In connection with localized sources, higher dimensional generalizations of the Schwarzschild, Reissner-Nordstrom, Kerr-de Sitter, Tolman and Vaidya spacetimes have been studied by several authors. G.P. Singh and S. Kotambkar have studied charged fluid distribution on the background of higher dimensional spheroidal spacetime. It has been observed that the new solution obtained in their study, generates several known solutions for compact star having spheroidal spacetime geometry.

Classical and Quantum Cosmology

M. Sami

M. Sami and his collaborators, have been involved in the investigations of models of steep braneworld inflation and observational constraints. It was demonstrated that steep brane world inflation can be made consistent with WMAP observations if Gauss-Bonnet correction is invoked in the bulk. Part of activities were devoted to D-brane inflation and tachyon assisted inflation. A way to solve the reheating problem in these models was pointed out in the recent work.

In context with dark energy, M. Sami has been involved in the study of tachyon field models. In a series of papers with collaborators, he has studied the general features of tachyon field if it is to be suitable to dark energy. His latest work focuses on the possibility of coupling of dark energy with matter. Special emphasis in this work is given to the role of scaling solutions in the scenarios of dark energy. The study of observational constraints in these models is under active consideration.

Chaudhuri, Sarbeswar

In brane cosmology it is assumed that the standard model particles are confined in a hypersurface, called the brane, embedded in a higher dimensional space called the bulk. Only gravity and other exotic matter such as dilaton can propagate in the bulk. Our universe may be such a brane like object. Randall and Sundrum [Phys. Rev. Lett. 83, 3370 (1999); Phys. Rev. Lett. 83, 4690 (1999)] considered a model in which the brane is at a constant tension and the bulk spacetime has negative cosmological constant.

S. Chaudhuri, in collaboration with S. Chakraborty, is now engaged in generating solutions of gravitational field equations for an anisotropic brane with Bianchi type I universe with perfect fluid and scalar fields as matter sources having non-vanishing Weyl tensor of the bulk. The pressure is assumed to bear a linear relation with the matter density. It is shown that the inclusion of the energy term for non-vanishing Weyl tensor in the bulk, in the general gravitational field equations is reflected in the final result by means of an additive term in the parametric expressions as compared to the works of Chen, et. al. [Phys. Rev. D64, 044013 (2001)]. By redefining the initial cosmological time, it is shown that the brane cosmology evolves from a singular state with volume scale factor equal to zero from time t=0. For a particular non-zero value of the pressure but less than the matter density, the solutions are obtained in an exact analytic form with and without the cosmological constant for a Bianchi type I universe. The expressions for the volume scale factor, expansion scalar, deceleration parameter, shear and anisotropy are evaluated in both the cases.

Jain, Deepak

The nature of the dark components (dark matter and dark energy) that dominate the current cosmic evolution is a completely open question at present. Motivated by recent developments in particle physics and cosmology, there has been growing interest in a unified description of dark matter and dark energy scenarios.

Deepak Jain along with Abha Dev, and Jailson S. Alcaniz, has investigated the predictions of one of the candidates for a unified scenario for dark matter/energy, the so-called generalized Chaplygin gas using the CLASS lensing sample and supernova data. The generalized Chaplygin gas is parametrized by an equation of state $p = -A/\rho^{\alpha}$, where A and α are arbitrary constants. It is shown that, although the model is in good agreement with this radio sample, the limits obtained from CLASS statistics are only marginally compatible with the ones obtained from other cosmological tests.

Jain, Dev and S. Mahajan have used CLASS statistical sample to constrain the properties of dark energy described by an equation of state ($w = P/\rho$). They exploit observed image separations of the multiply-imaged lensed radio sources in the sample. They use two different tests: (1) image separation distribution function $n(\Delta\theta)$ of the lensed radio sources and (2) $\Delta\theta_{pred}$ vs $\Delta\theta_{obs}$ as observational tools to constrain the cosmological parameters w and Ω_m. The results are in concordance with the bounds imposed by other cosmological tests.

John, Moncy V.

Using a significantly improved version of a model-independent, cosmographic approach, Moncy V. John has attempted to address 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. He also attempts to provide and improve another example of Bayesian model comparison, performed between some Friedmann models, using the same data. The conclusion was that the apparent magnitude-redshift data alone cannot discriminate these competing hypotheses. It was argued that the lessons learnt using Bayesian theory are extremely valuable to avoid frequent U-turns in cosmology.

Pradhan, Anirudh and Jotania, Kanti

In recent times, the cosmological constant (Λ) has interested theoretician and observers for various reasons. The non-trivial role of vacuum in the early universe generates a Λ-term that leads to inflationary phase. Observationally, this term provides an additional parameter to accommodate conflicting data on the values of Hubble constant (H_0), the deceleration parameter (q), density parameter(Ω) and the age of the universe. The Λ owes its origin to vacuum interactions. It follows that it would be in general, a function of space and time coordinates rather than be static constant.

A. Pradhan, P. K. Singh and Kanti Jotania have considered symmetric non-static cosmological models representing a bulk viscous fluid distribution, which are inhomogeneous and anisotropic. They obtain a cosmological constant as a decreasing function of time (*without assuming any 'ad hoc' law*). In this study, they have focused upon establishing a formalism for studying the general relativistic evolution in presence of bulk viscous in an expanding universe. It is well known that in an early stage of the universe when the radiation in the form of photon as well as neutrino decoupled from matter, it behaved like a *viscous fluid*. The viscosity coefficient of bulk viscous fluid is assumed to be power law function of mass density.

In their detailed study, they have found two viable models by fixing reasonably well boundary conditions on metric potential, namely, m, a and k with equation of state $p = \gamma\rho$ ($0 < \gamma \leq 1$, with moderate value of $\gamma = 0.5$). The values of cosmological "constant" Λ for these models are found to be small and positive. Strong point of these models, is that it incorporates the matter density naturally and so makes feasible, which can incorporate the physical constraints. These models needs further study to include some mechanism of Λ with either matter or radiation.

Pandey, Sanjay K.

Probing large scale structure of the universe at high redshifts by studying redshifted 1420 MHz emission from neutral hydrogen (HI) at early epoch has been an interesting recent trend. Sanjay Pandey has used this to probe non-Gaussianity in HI distribution at the epoch of reionization of the universe. The HI distribution at the epoch of reionization (EOR) is largely determined by the sizes and distribution of the ionized regions. In the scenario where the ionized regions have comoving sizes of the order of a few Mpc, the large scale statistical properties of the HI distribution are dominated by the Poisson noise of the discrete ionized regions, and it is highly non-Gaussian. He has investigated the possibility of probing reionization by studying these non-Gaussian features using future radio interferometric observations of redshifted 21 cm HI radiation. He has developed a formalism relating correlations between the visibilities measured at three different baselines and frequencies to the bispectrum of HI fluctuations. For visibilities at the same frequency, this signal is found to be of the same order as the two visibility correlation which probes the HI power spectrum. For visibilities at different frequencies, we find that the correlations decay within a frequency difference of $\sim 1\,\text{MHz}$. This implies that it is, in principle, straightforward to extract this HI signal from various contaminants, which are believed to have a continuum spectra and are expected to be correlated even at large frequency separations.

Another problem, he has been interested in, is synthesis of deuterium in the incipient Pop II stars. Deuterium is regarded as an ideal "baryometer" for determining baryon content of the universe. Sites for incipient low metallicity (Pop II) star formation can support environments conducive to Deuterium production up to levels observed in the universe. This could have a deep impact on Standard Cosmology.

He has also investigated a case of nucleosynthesis in slowly evolving models. He presents a case for cosmological nucleosynthesis in an FRW universe, in which the scale factor expands linearly with time. It is demonstrated that adequate amount of baryon density that saturates mass bounds from galactic clusters is required. There is a collateral metallicity production that is quite close to the lowest metallicity observed in metal poor Pop II stars and clouds. On the other hand, sites for incipient low metallicity (Pop II) star formation can support environments conducive to deuterium production up to levels observed in the universe. A profile of a revised "Standard Cosmology" is outlined.

Ray, Saibal

Einstein equations have been solved by S. Ray and U. Mukhopadhyay for some specific dynamical models of the cosmological term Λ. Connecting the free parameters of the models with the cosmic matter and vacuum-energy density parameters, it is shown that the models are equivalent. Using the selected models, present values of some of the physical parameters have been estimated and a glimpse of the past decelerating universe has also been presented. Most of these nicely agree with the values as suggested by the Type Ia Supernovae data.

It has also been shown by them that the estimates of different cosmological parameters from the model under perfect fluid distribution with a stiff equation of state $\rho = p$ are in good agreement with the experimental results, especially 13.79 Gyr as the age of the universe is quite satisfactory.

Seshadri, T.R.

Anisotropy in the Cosmic Microwave Background Radiation arising from vector type (rotational) velocity fields (induced by primordial magnetic fields) in models with homogeneous re-ionization have been computed by T. R. Seshadri and K. Subramanian. It has been shown that re-ionization leads to an additional anisotropy of about 0.3 to 0.4 μK for small angular scales corresponding to $l \sim 10,000$. Transition to homogeneity in the SDSS slices have been investigated. It is shown that the distribution of galaxies on scales of $80\,h^{-1}$Mpc and above is homogeneous and the transition from fractal behaviour to the homogeneity is somewhere around $60\,h^{-1}$Mpc. It is further shown that the distribution of galaxies is similar to that in ΛCDM model of bias 1.6. This work was done with Jaswant Yadav, Somanth Bharadwaj and Biswajeet Pandey.

Scalar fields whose energy density grows exponentially with scale factor have been investigated. It has been shown by T. R. Seshadri and S. Unnikrishnan that these can be candidates of dark energy. It has further been shown that in certain cases, the scalar filed is a phantom field. Bounds on parameters of such fields from the observations of the late time accelerated phase of the universe have been studied.

Chakraborty, Subenoy

Quasi-spherical spacetime in higher dimension has been studied by Subenoy Chakraborty and coworkers. S. Chakraborty and U. Debnath have found cosmological solutions in arbitrary spacetime dimension of Szekers model with perfect fluid as the matter content and have examined the asymptotic behaviour of these solutions. Cosmological solutions in Brans-Dicke theory for higher dimensional Szekers model have been obtained by S. Chakraborty, U. Debnath and A. Banerjee, and they have obtained C-field cosmology in a particular case.

A detailed study of gravitational collapse in higher dimensional Szekers spacetime has been investigated by S. Chakraborty and U. Debnath. They have determined conditions for naked singularity in different physical situations, both for marginally and non-marginally bound cases. Also, they have examined null geodesics for global visibility of naked singularity.

In studying quintessence problem, S. Chakraborty in collaboration with A. Banerjee and U. Debnath has examined the role of modified chaplygin gas for accelerating universe. They have shown that the model can describe the universe from radiation to Λ CDM era.

Variable gravitational constant and cosmological constant have been studied in anisotropic brane cosmology by S. Chakraboty, U. Debnath and S. Nath. They have presented the solutions for various cases and compared their results with observations. Lastly, string - dust cosmology in brane world scenario have been discussed by S. Chakraborty, A. K. De and S. Bhanja.

Paul, B. C.

In recent years, there are interesting developments that led to the study in string inspired cosmology. Particularly, in higher dimensional scenario, our observed universe may be described by a brane embedded in higher dimensional spacetime with the usual matter field and force confined on the brane. The gravitational field may propagate through the bulk dimensions perpendicular to the brane. One can accommodate a large number of dimensions with extra space. While discussing the applications of brane worlds, one often assumes Einstein gravity in the bulk and then projects the dynamics on the brane. This leads to the high energy corrections in the Friedmann equation which changes in the expansion dynamics of the early universe. B. C. Paul and A. Beesham have shown that in the brane world, the anisotropic universe approaches the isotropic phase via inflation much faster than in GTR. They have noted a case where the curvature term initially drives power law inflation on the isotropic brane which is, however, not permitted in GTR. All Bianchi models except Bianchi type IX, transit to an inflationary regime and B. C. Paul and A. M. Sami have studied the tachyonic inflation in brane with Gauss-Bonnet term in the bulk. They have obtained exact solution of slow roll equations in the case of an exponential potential. They attempt to implement the proposal of Lidsey and Nunes [*Phys. Rev.* **D 67**, 103510 (2003)] for the tachyon condensate rolling on the Gauss-Bonnet brane.

Galaxies and Quasars

Chatterjee, Tanuka

To investigate the formation process of galaxies a model has been developed using Cluster Analysis Technique to the globular clusters in M31, LMC and our galaxy to find the optimum number of clusters in these systems. In every case, they exhibit multi-population structure instead of bimodality with respect to colour as have been found in many giant elliptical galaxies and spiral galaxies. It also increases the importance of inclusion of many parameters and at the same time eliminating redundant parameters and helps to enunciate a modified theory of globular cluster formation of the young extragalactic as well as old GCs with respect to more than a single parameter at a time to find the optimum number of clusters. This is unlike the method of drawing histograms, which only can consider one parameter at a time, and unsuitable for a multivariate set up. These histograms show bimodality with respect to colour in bright elliptical galaxies while cluster analysis shows multimodality.

Jog, Chanda

N-body simulations of mergers of galaxies in the new regime of unequal-mass galaxies with the mass ratio 4:1-10:1 have been studied by Chanda 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 systems. It is shown that such mergers result in very peculiar, mixed systems that have the morphology of a spiral galaxy but have kinematics similar to an elliptical galaxy (see Bournaud, Combes, and Jog 2004 for details). It is argued that such mergers are more likely to occur than the equal-mass mergers studied so far in the literature, and will affect the dynamics and evolution of galaxies.

A theoretical model for gravitationally coupled stars and gas in a galactic disk embedded in a dark matter halo is developed. The observed vertical distribution of the atomic hydrogen gas in the outer galaxy is used to constrain the parameters of the dark matter halo. The best fit is given by a spherical halo with a density profile that falls faster than the usual isothermal halo. This has important implications for the size and mass of the galaxy (for details see Narayan, Saha, and Jog 2005).

Khare, Pushpa

Pushpa Khare along with her collaborators obtained the metal abundances in 4 Damped Lyman Alpha systems (DLAs) with redshift smaller than 0.6, using the Hubble Space Telescope. They combined these measurements with their earlier measurements taken with Multiple Mirror Telescope (MMT) at Arizona and other abundance measurements reported in the literature to determine the rate of chemical evolution in the universe. The global mean metallicity seems to increase only weakly with decreasing redshift and does not seem to rise to solar abundance even at $z \simeq 0$. She along with her collaborators observed seven low redshift DLAs in the spectra of QSOs in May 2004 and February 2005, with the MMT with the aim of determining the metal abundances in these systems. They have also been awarded 3 nights at the Very Large Telescope at Chile for observations of DLAs. She continued to be involved in the preparation of a catalogue of absorption lines in the spectra of QSOs observed by the Sloan Digital Sky Survey (SDSS) as an official member of the SDSS collaboration working on QSO absorption lines.

Pandey, S. K.

With the objective of establishing evidence for the multiphase (hot, warm and ionized, cool molecular gas and dust) ISM in elliptical galaxies, a well defined sample of elliptical galaxies was chosen for carrying out observations in optical, infrared as well as in X-ray bands. A subsample of nine galaxies was observed in near-infrared (NIR)-JHK-bands using 3.5m NTT and near-IR camera SOFI at the European Southern Observatory (ESO) during December 2002. Ellipse fitting procedure was used to derive the surface brightness, ellipticity, position angle profiles as well as higher order Fourier coefficients. The unsharp masking technique was then applied to the galaxy images in the Ks-band to look for substructures in them. This led to detection of a spiral structure in the core of the galaxy NGC 1553 (figure 21). This is the first time such substructure has been unveiled from near IR band images of early-type galaxies. Detailed analysis is in progress. Three observing nights has been allotted to this observing programme on NTT/SOFI at ESO during May-June 2005 for carrying out near-IR JHKs observations of a set of 20 galaxies. These observations will be the first of its kind for a well defined large sample, and will lead to a detailed understanding of the nature, origin and evolution of ISM in elliptical galaxies. People involved in this joint collaborative programme include A. K Kembhavi, S. Raychaudhaury, and Sudhanshu Barway.

As a part of an ongoing programme on studying properties of dust in early-type galaxies, deep images in BVRI and H-alpha of about 25 galaxies were obtained during the period 2004-05 using the 2m HCT of IIA. Data reduction and analysis is in progress. Results on NGC3801 a S0/a galaxy with rather complex dust features was reported at the XXIII meeting of ASI held at ARIES, Nainital. D. K. Sahu, M K Patil, S. Barway, Rabin Chhetri and Laxmikant Chaware are also involved in this project.

Pandey, U. S.

An interesting work on self-gravitating gaseous disks has concerned the behaviour of the precursor of the massive central dark object that might be energy source existing at the centre of galaxies and powering quasars. With this view, U. S. Pandey has presented a model of self-gravitating gas flattened in a disk.

He makes the following assumptions: (i) the interaction force between individual pairs of particles is negligibly small, (ii) the distribution function f in phase space satisfies collision-free Boltzmann equation, and (iii) the system is conservative. They

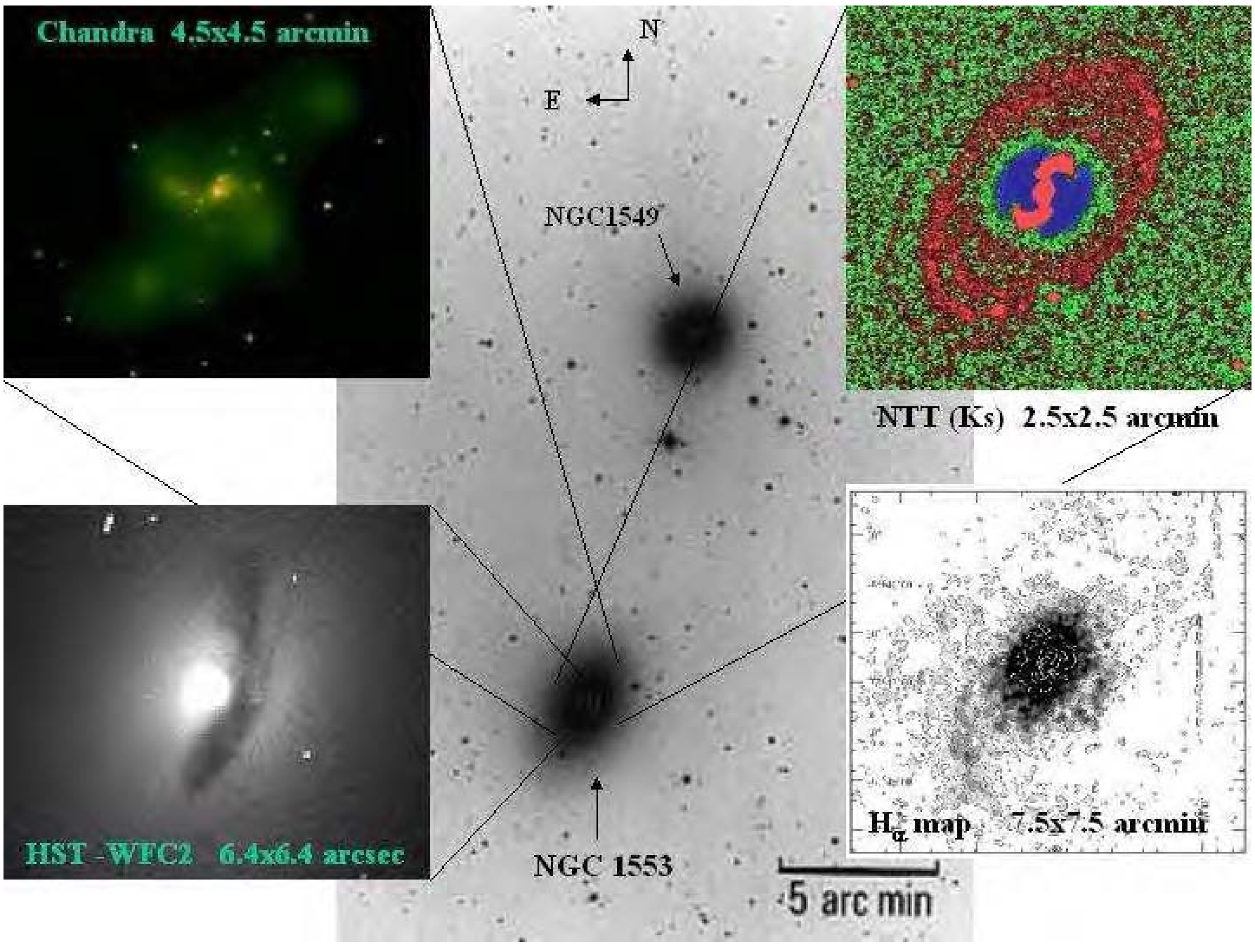


Figure 21: A mosaic of various observations of the elliptical galaxy NGC1553. The optical image in the middle was used by Malin to show the presence of shells in this galaxy. The Chandra X-ray to the left shows spiral structure in the hot gas, as does the H-alpha image in the bottom right. Unsharp-masked near-IR Ks image on the top right taken with NTT/SOFI shows spiral structure in the core, on a smaller scale and not aligned with the structure in the hot gas.

set up a third order differential equation satisfied by the dusk for the asymmetric cases. They obtain a particular solution for the disk in steady state.

It has been suggested by him that a nuclear activity at the centres of galaxies might be due to instabilities in the self-gravitating gaseous disks. Active galactic nuclei might involve subsequently through LINER starburst - centre nuclear burning phases. The surface mass density σ and core temperature are two parameters which may decipher the evolution of AGNs.

The work on perturbation of self gravitating gaseous disk is being done jointly by U. S. Pandey and Sanjeev Kumar Tiwari.

They discuss the stability of a thin, self-gravitating gaseous disk flattened (in a plane) around the nucleus of a galaxy. The instability criterion demands that it would be sensitive to star formation provided surface mass density is larger than a critical value. They derive the expression for wavelength of critical perturbation. They find that critical Toomre wavelength is larger than the radius of a disk for typical Jeans disk. Using simple analysis, they show that an uniformly rotating collision-less disk with finite temperature will be unstable via gravitational radial perturbation for practically all wavelengths.

Patil, M. K.

Traditionally, early type galaxies were believed to be the inert systems, mostly composed of population II type stars, essentially devoid of gas and dust, and virtually a total absence of on-going star formation process, barring few exceptions. However, this scenario has changed drastically over last two decades due to the excellent observing facilities throughout the electromagnetic spectrum and the use of powerful imaging devices in astronomy. Deep CCD imaging of early-type galaxies and their careful analysis has revealed that a significant fraction of the early-type galaxies do harbour the multiphase ISM. Though origin of multiphase ISM in early-type galaxies is controversial subject at the moment, a detailed study of morphologies of dust and other phases of ISM in these galaxies along with their environment lead one to assess the validity of various theoretical models that have been proposed for the secular evolution of ISM in the early-type galaxies.

M. K. Patil, in collaboration with S. K. Pandey, Ajit Kembhavi, U. C. Joshi and D. K. Sahu has carried out a detailed surface photometric analysis of a sample of early-type galaxies in the near-IR as well as optical pass bands, with the objective of deriving the extinction properties of dust in extragalactic environment and comparing those with dust in the Milky Way. Extinction curves derived for majority of galaxies run parallel to the canonical curve of the Milky Way, indicating similar dust extinction properties in external galaxies. However, the R_V values derived for these galaxies were found to vary as a function of the dust morphology as well as the environment of the host galaxy, in the sense that the galaxies in the dense region show larger R_V value compared to those in the isolated regions. Estimates of dust masses from optical extinction were found to be an order of magnitude less than those derived from IRAS flux densities, implying that a large fraction of dust distributed throughout the galaxy remained unattended in the optical method.

They have also made an attempt to explore the physical association of the multi-phase ISM (hot gas, warm gas, and dust) in early type galaxies by analyzing broad band CCD images as well as X-ray images from the Chandra X-ray observatory. The morphologies of optical emission line (H_α images) are found to be strikingly similar with those of the dust morphologies as well as the hot gas morphologies (diffuse X-ray emission maps), implying a strong association of all the three phases of ISM. They found a strong correlation between the dust and cool as well as warm gas, however, a marginal anti-correlation was observed between the dust content and the X-ray flux, in the sense that galaxies with large scale dust features exhibit lower X-ray flux. Further, the X-ray spectra extracted from the analysis of the high-resolution X-ray images shows the signatures of OVIII and FeXVIII emission lines, showing the metal enrichment nature of the hot gas.

Compact Objects and X-ray Binaries

Chandra, Deepak

Deepak Chandra, Meenu Dahiya and Ashok Goyal have continued their study of the phase structure of the Nambu-Jona-Lasinio model. They are examining the parameters of compact hybrid stars using the NJL model for the quark EOS.

Deepak Chandra, along with Ashok Goyal has studied quark gluon plasma formed in heavy ion collisions. They have found that the interactions in QGP and the hadron gas reduce the delay in the phase transition, but the curvature energy has a mixed behavior. Lower values of surface tension increase supercooling in contrast to that in early universe studies. Higher values of bag pressure tend to speed up the transition.

Paul, B. C.

B. C. Paul has obtained a class of relativistic solutions of compact stars in hydrostatic equilibrium considering it embedded in a higher dimensional spacetime. The spacetime geometry is assumed to be a (D - 1)-spheroid immersed in a D-dimensional Euclidean space. Here, he obtains a solution of the field equation which is a generalisation of the Mukherjee, Paul and Dadhich [*Class. Quantum Grav.* **14**, 3475 (1997)] solution in higher dimensions. It is noted that the spheroidal parameter plays here a very important role in determining the equation of state of a very compact cold star. It is observed that the higher dimensional spacetime can accommodate a more massive compact object for a given size compared to that in the usual four dimensional spacetimes.

Tikekar, Ramesh and Jotania, Kanti

The studies of the recently discovered stellar objects such as X-ray pulsar Her X-1, X-ray Buster $ U 1820-30, SAX tend to indicate that their physical content is likely to be strange matter - quark matter and these objects seem to be strange stars or hybrid neutron stars, which are likely to be formed during collapse of supernova cores. The usefulness of the Vaidya-Tikekar ansatz, which effectively prescribes the density variation in the spherical compact stars in equilibrium, assuming their content to be in the form of a perfect fluid, in the absence of definite information about the nature of their content is known to provide instructive models of such configurations. Two families of relativistic models of spherical compact stars have been proposed based on two classes of general solutions of relativistic equations characterized by three parameters, following the Vaidya-Tikekar approach of prescribing the geometry of the interior 3-space of the configuration. The set up is shown to provide physically viable models of compact spherical stars if the compactification parameter, density variation parameter and the surface density of the matter for the configuration are known. The EOS of the interior matter of the models is seen to get approximated to linear form in this set up. The causal bahaviour, adiabatic aspects and stability against radial pulsations of the models are being examined. The set up is also found to accommodate models of compact spherical stellar stars with anisotropic pressures. The models of such super dense stars, in the general set up provided by the three parameter families of solutions of relativistic equations, are being studied following the core-envelope approach which prescribes that the interior of the star comprises of two regions, a core containing fluid with anisotropic pressure surrounded by an envelope filled with a perfect fluid. The work is being pursued by Ramesh Tikekar and Kanti Jotania.

Dey, Jishnu

Careful assessment of four good superburst events for GX 17+1 reveals that a superburst is possible at near Eddington mass accretion rates. Jishnu Dey in collaboration with Monika Sinha, Mira Dey and Subharthi Ray has given an alternative scenario for superburst, i.e., that they originate from a strange star's surface, which is a micron-thick layer of diquarks. The diquarks break up due to repeated Type 1 bursts during high accretion like an avalanche, due to the two-fermion to boson transformation. After this, the reverse process takes over. The crucial fact is that the recombination time scale is long, since the strong interaction pairing process is supplemented by beta equilibrium and charge neutralization which are slower than weak electromagnetic processes.

Four experimental groups reporting on relativistic heavy ion collisions (RHIC), with gold on gold, show that quark gluon plasma with asymptotic freedom and chiral symmetry restoration (CSR) may never be realized in RHIC although a non-hadronic phase is reached. Manjari Bagchi, Jishnu Dey and collaborators calculated strange star properties using large N_c approximation with built-in CSR where they performed a relativistic Hartree-Fock calculation, using Richardson potential as an interquark interaction. This potential has the asymptotic freedom and a confinement-deconfinement mechanism built into it. In their calculation, they employed two scale parameters Λ and Λ'. The linear confinement string tension from lattice calculations is 350 MeV and the Coulomb - like part has the parameter 100 MeV from deep inelastic scattering experiments. They also took the effect of temperature (T) on gluon mass in a simple way, following Alexanian and Nair in addition to the usual density dependence and found that the transition T from hadronic matter to strange matter is 80 MeV, close to the 100 MeV estimated by Witten in 1984.

It appears that there is a genuine shortage of radio pulsars with surface magnetic fields significantly smaller than $\sim 10^8$ Gauss. It has already been established that pulsars with low magnetic fields are the products of x-ray binaries where they undergo accretion-induced field decay. In these binaries the neutron stars are also likely to undergo an accretion-induced deconfinement transition and convert into strange stars. J. Dey, in collaboration with R. Ray Mandal S. Konar, M. Sinha and M. Dey calculated the Landau-Ginzburg free energy of a rotating strange star and found that a particular value of the magnetic field would minimize the free energy. For a suitable set of QCD parameters this value is $\sim 10^7$ Gauss. They proposed that the pulsars with very low magnetic fields are actually strange stars locked in a state of minimum free energy and therefore at a limiting value of the magnetic field which can not be lowered by the system spontaneously.

Dey, Mira

The study of different aspects of strange quark matter and its formation of compact quark star is continued. The surface vibrations of strange stars are related with observational emission spectrum from six compact stars which are believed to be strange star candidates. In the previous work, the equation of state (EOS) of strange quark matter was derived with phenomenological Richardson potential with same asymptotic and confinement scale. Since these two scales are different, in principle, Richardson potential was modified and it was tested for hadron properties like Δ^{++} and Ω^- magnetic moments (with latest experimental numbers) and their masses. With these two different scales the new EOS is derived and further work is in progress.

Shanthi, K.

Neutron star X -ray binaries exhibit a wide range of timing phenomena, which can be quantified by computing the Fourier transform of the observed light curve. The power density spectra (which are the amplitude squared of the Fourier transforms) often exhibit Gaussian like features at certain frequencies, which are called Quasi Periodic Oscillations (QPO).

RXTE observations of the atoll source 4U 1636 - 53 over the last five years were analysed by K. Shanthi and R. Misra and an automated search for kHz QPO was done. The fraction f of the time the system exhibits a kHz QPO decreases from near unity for the lowest flux state ($\sim 1400c/s$) to zero for the highest ($> 2550c/s$). The variation of frequency with count rates has revealed three distinct parallel tracks which are coincident with the three flux states.

In continuation of this work they are systematically studying the spectra of this source at different flux levels and also when the QPO is present or absent, which will throw light on the origin of the phenomena and the nature of these systems. Data from another low mass X-ray binary, 4U 1608-52 is being analysed to ascertain the generality of the results obtained earlier.

Stars and Interstellar Medium

Das, M. K. and Saha, L. M.

Based on Principal Component Analysis (PCA) a mathematical framework has been developed by M. K. Das and Manabu Yuasa (RIST, Kinki University, Japan) to analyze the effect of missing data. This method can be used in the spectral classification of stars. It happens frequently that the observational data is not complete but missing partly by various reasons. IRAS 3 colours of mass-losing stars and their expanding velocity on the ground based observations were used as an experiment and the adjusted values were restored using the formalism developed. The original data and restored ones are compared and the distribution of the restored errors have been studied by Das and L. M. Saha.

Pandey, S. K.

Continuing the work on photometric monitoring of chromospherically active stars, S. K. Pandey and Sudhanshu Barway have obtained the multi-wavelength (BVRI) photometry of two active stars, namely, HD52452 one of the shortest period non-eclipsing binary star, and a newly identified RS CVn binary star HD61396, was analysed and results were published. Detailed investigation of the long-term photometric variations in an active late-type giant FK Com (HD 11755), a prototype of the FK Comae group of active stars, which are rapidly rotating, single, late-type giants with strong chromospheric and transition region emission, has been carried out. The V band light curves collected from previously published photometric observations during the period 1966-2003 were modeled in the frame work of standard star-spot model. Activity cycles were searched in the star using various activity tracers such as minimum, maximum and mean magnitude, amplitude, integrated magnitude and total spot area. The analysis reveals presence of two dominant types of spot activity cycles; one has long period of 28 years and another with short period of 6 years. The long period correspond to the time scale of variations in the total spottedness, while the short period corresponds to the cycle of "flip-flops" behaviour, in which the dominant part of the spot activity shifts 180 degrees in longitude over a short period of time and remains at this new active longitude for some time.

Low-resolution spectroscopic observations of a sample of newly identified as well as suspected chromospherically active stars were also carried out using HCT 2m telescope at Hanle during the year 2004-2005 for seven nights. The spectra were taken in H- alpha region using HFOSC instrument. All the stars except HD 61396 show the absorption in

H-alpha. The star HD 61396 was found to exhibit the emission in H-alpha. Detailed investigation is in progress.

Singh, H. P.

Harinder P. Singh in collaboration with Ranjan Gupta (IUCAA) and their counterparts, James Rose (UNC, Chapel Hill), Frank Valdes and Dave Bell (NOAO, Tucson) have just completed a major task of creating a database of spectra of 1273 stars. The spectrum of a star gives astronomers the information about the chemical composition and physical nature. They used the 0.9 m Coude-Field Telescope at the Kitt Peak National Observatory in Arizona, USA and it took about 7 years for them to complete the painstaking work. This mammoth work was supported by an INDO-US project funded by Department of Science and Technology, New Delhi, India and National Science Foundation, Washington, USA. The data is available online on the web at www.noao.edu/cflib and is also published in the Astrophysical Journal.

In collaboration with R. Gupta, K. Volk and S. Kwok (Calgary), an artificial neural network scheme was employed to classify 2000 bright sources from the IRAS low resolution spectral database. A classification accuracy of more than 80 percent was achieved. The scheme will be utilized to classify another 8000 sources in the IRAS database.

A stellar spectral library in the near infrared is being built in collaboration with A. Ranade (Vigyan Prasar), N.M. Ashok (PRL) and R Gupta. The first release containing reduced H-band spectra is available at the Virtual Observatory India website: www.iucaa.ernet.in/ voi

Chandra, Suresh

Suresh Chandra and his group is working on asymmetric top molecules of astronomical interest. Recently, they have suggested that the molecule C_5H_2 may be identified in cosmic objects through its transition $3_{13}-4_{04}$ at 4.3 GHz in absorption against the cosmic microwave background. Further, for the molecule and Si_2C, they found that it may be identified in cosmic objects through its transitions $4_{14}-5_{05}$, $5_{15}-6_{06}$, $2_{12}-3_{03}$, $3_{13}-4_{04}$, and $1_{11}-2_{02}$ at 15.9, 5.1, 33.6, 24.9, and 42.3 GHz in absorption against the cosmic microwave background, in a region having low temperature.

Depending on the relative orientations of nuclear spins of two hydrogen atoms, the hydrogen molecule (H_2) has two species: para (I=0, antiparallel spins) and ortho (I=1, parallel spins). The ratio of the population N_1 of ortho-H_2 in $J = 1$ level to the population N_0 of para-H_2 in $J = 0$ level are quite often related through the standard Boltzmann factor. Chandra has written a comment on this relation.

Indulekha, K.

K. Indulekha along with K. Ambili has worked on the puzzle of bound open clusters. The feasibility of star -gas, dynamical friction, and interactions with low mass stars as mechanisms which would lead to the formation of open clusters was investigated. The analysis, applied to observational data, led to the conclusion that high and low mass clusters had different histories of formation. K. Indulekha and A. Cherian are investigating using a toy model, the importance of random distributions of sensors in the case of human and insect eyes as well as in the case of adaptive optics. The localization of neutrinos in dense stellar matter, and its impact on stellar evolution is being investigated along with G. V. Vijayagovindan and S. Sreedevi.

Rastogi, Shantanu

IR emission fhas eatures at 3050, 1610, 1310, 1165 and 885 cm^{-1} (3.28, 6.2, 7.7, 8.6 and 11.2 μm) correspond to the emissions from Polycyclic Aromatic Hydrocarbon (PAH) molecules are known as Aromatic Infrared bands (AIBs). The AIBs 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. These IR features seem to be a result of emissions from a family of PAHs consisting of neutrals, cations, anions and hydrogenated/dehydrogenated molecules. Observations show source to source variations in the IR bands related to the type of PAHs present in the surrounding medium. To get a better understanding of the interstellar spectra, spectral variations with shape, size and ionization state of PAHs have been studied by Amit Pathak and Shantanu Rastogi. 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 decrease. Theoretical IR spectra for catacondensed and pericondensed PAHs in both neutral and ionic forms show that large compact PAH cations are prefered in the ISM. Study of very large PAHs is also underway using the High Performance Computing facility at IUCAA.

PAHs are also believed to contribute to

the overall UV interstellar extinction hump at 217.5 *nm* and are thought to be carriers of some of the Diffuse Interstellar Bands (DIBs) (a number of absorption features superposed on the interstellar extinction curve) observed in the visible and near infrared spectral ranges. Ab-initio calculation of electronic transitions from PAH cations shall be simulated for comparison with DIBs.

Sun and the Solar System

Badruddin

Badruddin and his coworkers have carried out a detailed analysis of the time lags and hysteresis effects of cosmic rays intensity and solar activity indices (Sunspot number, 10.7 cm radio flux and Solar flare index). They have utilized the neutron monitor data and solar data extending over a period of 50 years covering five solar activity cycles (19-23). Polarity state of the heliosphere changes after every 11 years. They have carried out their analysis during alternating polarity states of the heliosphere and studied the effect of polarity reversal on the motion of galactic cosmic rays in the 3-D heliosphere.

Adopting the superposed epoch analysis method, they have also studied the temporal variation of cosmic ray intensity during the course of carrington rotation periods in low solar activity conditions when transient eruptions from the sun are almost absent. They have calculated average oscillations in the cosmic ray intensity during different solar magnetic conditions. Regression analysis between intensity oscillation and tilt of the heliospheric current sheet has also been carried out by them.

Narain, Udit

U. Narain and his coworkers are working on mechanisms responsible for maintaining the million degree hot solar and stellar coronae. At present they are investigating the heating of solar and stellar coronae by nano-/micro-flares, which is one of the most likely agents to heat the solar and stellar coronae. Here, two oppositely directed magnetic fieldlines come closer, and closer which increases the current density to large values. A small resistivity of corona increases dissipation considerably. This process is called magnetic reconnection. Such events take place throughout the corona and thus heating takes place. Here, magnetic energy is converted to thermal energy, which is spread to other regions by thermal conduction.

Prasad, Lalan

Several mechanisms have been suggested to contribute the heating of solar corona. Generally, each model predicts to deposits energy along solar coronal loops in a characteristic way. S. Chandra and Lalan Prasad have studied the temperature structure in a loop by expressing the magnetic field and fluid velocity in terms of Chandrasekhar Kendall functions. One of the most outstanding questions in solar physics concerns the heating of solar corona. Since it was realized that the sun is surrounded by a million degree hot plasma, numerous ideas for its heating have been put forward. The solar magnetic field plays a leading role in both transporting the required energy up from the photosphere and releasing it in the solar corona.

In connection with the problem, an analytical method for the heating of solar coronal loops by phase-mixing process is discussed by using Alfven waves. Under typical coronal heating condition by ohmic dissipation, phase-mixing can provide magnetic energy on a time scale comparable with the coronal radiative time. Under the assumption of large Lundquist numbers, the phase-mixing can attain a hot coronal loops. They introduce two models of loop (1) half symmetric loop model and (2) cylindrical symmetric loop model. The magnetic field assumed to be static and associated with only in inhomogeneities plasma density. The solution under initial boundary condition and the ohmic dissipation have been discussed.

The concept of coronal heating by nanoflare are shown to the characteristics of active regions which results presumably from a large number of more or less random heating agents. The flares associated with impulsive agents of magnetic energy dissipation from 5×10^{24} to 10^{26} ergs, are called nanoflares. The analysis of these agents are represented by a power law distribution as a function of their energies with a magnetic slop of 1.5. Lalan Prasad and collaborators consider coronal heating by nanoflare in the lower energy population of a broad spectrum of flare like events. An adjacent group of nanoflares are responsible for coronal heating in terms of heating agents.

Sahijpal, Sandeep

S. Sahijpal has been investigating several aspects related to the formation and the early evolution of the solar system. Based on the recent X-rays flare observations of low-mass protostars made by *Chandra* X-rays satellite, he has developed detailed numerical simulations that deal with the thermal processing and irradiation of Ca-Al-rich inclusions (CAIs, the earliest condensed solar system grains) in magnetic reconnection ring. The magnetic reconnection ring results from the interaction of circumstellar accretion disc with the protosun's magnetosphere. Observed X-rays flare luminosities of low-mass protostars in the Orion molecular cloud were used to model various flare characteristics. This work has been attempted for the first time. Approximations were made regarding the thermal evolution that involves condensation, evaporation and coagulation of CAIs. Over two dozens of simulations were run in order to explore the diversity and complexity of the irradiation environment prevailing in the magnetic reconnection ring. Ensembles of refractory cores with ferromagnesium mantles were evolved for production of short-lived nuclides, ^{7,10}Be, ^{41}Ca, ^{53}Mn, ^{26}Al, ^{36}Cl, by irradiation. Around 30 proton, ^{3,4}He induced nuclear reactions were considered for the production of the short-lived nuclides. Production rates of the short-lived nuclides were found to have wide-ranging spreads of at least two orders of magnitude with no canonical value inferred for their initial abundances in the early solar system. Superflares corresponding to X-rays luminosities $\geq 10^{33}$ ergs/s. that could result in widespread evaporation of CAIs and thorough mixing of the inventories of short-lived nuclides would be essential to homogenize the inferred spreads and explain the initial abundances of the short-lived nuclei in the early solar system.

Sahijpal has also initiated numerical modeling of the accretion and planetary differentiation of asteroids in the early solar system. Based on detailed studies of meteorites, there is ample evidence that some asteroids underwent moderate to severe thermal processing in the early solar system. In certain cases, this resulted in large scale melting and planetary differentiation of asteroids into iron-cores with rocky-mantles thereby, suggesting that planetary differentiation of terrestrial planets initiated at planetesimal stage. On the basis of detailed numerical simulations involving linear accretional growth and planetary differentiation of asteroids with the short-lived nuclides, ^{26}Al and ^{60}Fe, as the heat source, Sahijpal has found that in order to have significant silicate melting, the onset of asteroid accretion and formation of iron-core should occur within $\sim$ 1.5 and $\sim$ 0.5 million years, respectively, from the time of condensation of CAIs. The developed thermal models numerically simulate sinking of iron-melts towards the centre and upward flow of silicate melt towards the surface of asteroids in a realistic manner. This is for the first time that the gradual movement of iron and silicate melts has been parametrically studied to understand the dynamics of the flows and the time scales involved in planetary differentiation.

Sen, Asoke K.

After the last apparition of comet Halley in 1985-86, a number of other comets were observed in polarimetry with IHW-continuum filters. From the in-situ dust measurements of Halley, dust size distribution functions were obtained (Lamy et al., 1987; Mazets et al., 1986), which were later used by several authors to interpret polarization data of Halley. In a recent work done by A. K. Sen, polarimetric data of various comets have been analyzed, using Mie theory and assuming that the composition of dust particles does not differ from comet to comet (Delsemme 1987). The individual grain size distribution functions so obtained for various comets suggest different values for relative abundance of coarser grains. Introducing a 'relative abundance of coarser grains' index g, one may study any possible dependence of g on the dynamical age of a comet, where the dynamical age can be defined in terms of some of the orbital parameters of the comet. For the four non periodic comets available for an analysis, he finds a clear empirical relation $g = -2.5.q^{2/3}$ emerging out. This relation strengthens the concept that comets whose grains are processed more by the solar radiation (these comets may be dynamically older) do contain relatively lower number of finer grains.

Atmospheric and Ionospheric Physics

Reddy, R. Ramakrishna

The experimental potential energy curves for the electronic ground states of molecules like CO^+, CH and CH^+ observed in comets are constructed by R. Ramakrishna Reddy and collaborators by using the Rydberg-Klein-Rees method as modified by Vanderslice, et al. The ground state dissociation energies are determined by curve fitting technique using the five parameter Hulburt - Hirschfelder (H-H) function. The estimated dissociation energies are $8.33 \pm 0.19, 3.48 \pm 0.903$ and $3.89 \pm 0.102 eV$ for CO^+, CH and CH^+ respectively. These values are in good agreement with the literature values. Estimated dissociation energies of CO^+, CH and CH^+ are used in the relation given by Gaydon and ionization potentials are evaluated for CO and CH molecules. The estimated ionization potential are 14.03 and 10.85 eV respectively for CO and CH. The Franck-Condon factors and r-centroids for the band system of A $^2\Pi$ - X $^2\Sigma^+$ of CO^+ molecule have been calculated employing an approximate analytical methods of Jarmain and Fraser. The absence of the bands in this system is explained.

Plasma Physics

Khan, Manoranjan

Secondary electron emission from a charged dust grain is a new mechanism identified for charging mechanism in a complex plasma. This is equivalent to the flow of a positive current to the dust surface and the secondary electron yield depends on the nature of the dust material and the kinetic energy of the incident electrons. The effect of secondary electron emission on Dust Acoustic Wave (DAW) propagation has been studied by Manoranjan Khan, in collaboration with M.R. Gupta, S. Sarkar, B. Roy, and A. Karmakar, based on orbit motion limited theory of dust grain charging. In this three component plasma, the effect of ion and electron capture and ionization of neutral atoms and recombination have been included. It is shown that if the dust charge is positive, there may occur zero frequency exponentially growing perturbation about the equilibrium characteristics.

DAW has been studied in a complex plasma for non-thermal ions. In collaboration with S. Ghosh, M.R. Gupta and R. Bharuthram of West Ville University (Durban, South Africa) instabilities of DAW has been investigated by M. Khan.

In the area of instrumentation science, biological samples are studied by Atomic Force Microscopy (AFM) and Lateral Force Microscopy (LFM) images, in collaboration with K. Bhattacharyya, T. Guha, R. Bhar, V. Ganeshan, and R. L. Bhramachary. AFM, LFM images of human, avian, reptilian, amphibian and piscine erythocytes are examined to determine the general pattern of erythorocyte membrane architecture.

Kumar, Nagendra

The behaviour of nonlinear Alfven waves with small and finite amplitude in an ideal viscous plasma has been investigated by Nagendra Kumar in collaboration with H. Sikka. They consider a viscous and compressible plasma in which the perturbations are restricted along z axis only. Since the perturbation is caused by a low frequency small amplitude Alfven wave propagating along z axis, this allows us to consider the dependence of the perturbation on z and t only. Using derivative expansion method, a nonlinear Schrodinger (NLS) equation describing the nonlinear evolution of Alfven waves is obtained. It is concluded that a dispersive term appears in the nonlinear Schrodinger wave equation only due to viscosity and does not appear when we do not take viscosity into account. Thus, in the absence of viscosity higher order dispersive effects are required to contain nonlinear growth of the wave. It is suggested that our results would be useful in solar atmosphere and interstellar space, for example, Alfven waves propagating in solar corona, and stellar winds driven by Alfven waves. Partially ionized dusty plasmas are of great importance in the context of study of planetary magnetosphere, nebulas and comet tails. The study of instabilities in these partially dusty plasmas has drawn considerable interest in recent past particularly in filamentary structures of molecular clouds and density condensation in accretion disks. Nagendra Kumar in collaboration with Vinod Kumar studied the fluid dynamical instabilities in magnetized partially ionized dense dusty plasma. They consider a magnetized partially ionized dense dusty plasmas with dynamics governed by dust and neutral gas components. The dynamics of dusty plasma are characterized by collective behaviour for parameter regime of ordering $a << \ddot{e} << \ddot{e}d$, where a, d and $\ddot{e}d$ are the dust grain radius, the average intergrain distance and the plasma Debye length. The electron dynamics is not considered as the electrons have no significant influence on the overall behaviour of dusty plasma. The plasma is considered quasi-neutral. The homogeneous magnetic field is taken along the z-axis and the homogeneous gravitational field is taken as $g = -gey$. They consider interface along the z-axis, i.e., along the magnetic field and relative flow between dust and neutral gas. An instability condition is obtained and discussed. They follow the Hurwitz criterion and construct the test sequence to obtain the condition for instability from the third Hurwitz sub-determinant. It is also interesting to note that stabilization occurs for modes with kz=0 due to dust -neutral gas collisions. The results might be useful in many situations of astrophysical magnetized dusty plasmas namely, comets and circumstellar dusty disks, e.g., T-Tauri stars.

Mondal, K. K.

The linear and nonlinear properties of various dust associated electrostatic waves (DA, DIA, DL waves, etc.) in dusty plasmas have been intensively investigated and reported in a large number of regular and review articles or books during last few years.

In recent times, there has also been much interest in different novel electromagnetic eigenmodes in magnetized plasmas contaminated with massive charged dust grains. A number of investigations have been made on low frequency dust-electromagnetic waves propagating parallel and perpendicular to the ambient field direction. These are based on linear theories, which are true for the small-amplitude waves. However, there are numerous processes through which unstable modes can saturate and attain large amplitudes. For the large-amplitude waves, one should take into consideration nonlinearities, because they lead to various types of interesting nonlinear coherent structure viz. solitons, shocks, vortices, etc.

Verheest (1995), Mamun (1999), and Shukla and Verheest (2003) have investigated the nonlinear propagation of low frequency electromagnetic Alfven waves (propagating along the ambient field direction) in a magnetized multispecies dusty plasma and have discussed the properties of envelope solitons. Meuris and Verheest (1996) have derived the K-dV equation for the weakly nonlinear propagation of dust magnetosonic waves propagating perpendicular to the ambient magnetic field direction. Mamun, et al. (2003) have developed a complete theory (including linear, weakly nonlinear and fully nonlinear) for the oblique propagation of hydromagnetic waves in a magnetized dusty plasma containing negatively charged dust grains and positively charged ions.

Mondal, et al. have made a detailed linear analysis of the hydromagnetic waves in a dust-ion plasma with the consideration of charge fluctuation of the dust grains. They have derived a dispersion relation and analyzed it numerically to study various modes of wave propagation and instabilities of the waves.

Dynamics

Ambika, G. and Harikrishnan, K. P.

G. Ambika has studied numerically the phenomenon of Stochastic Resonance (SR) in a dynamical system modeling a Josephson junction, together with K. P. Harikrishnan. This system has the novel feature that it can function both as a bistable set up and a threshold set up for realizing SR. However, as a bistable set up for composite but weak signals or signals of multiple frequencies, it detects only individual frequencies while as a threshold system with a proper resetting mechanism it detects the difference frequencies also. In both cases, the system is dynamically in an under damped state.

The occurrence of SR in a Coupled Map Lattices (CML) with a bimodal cubic map as onsite dynamics is studied in detail in the temporal iterates of the central site as well as in the spatial iterates for a frozen patterns at different times. The analysis is done for different coupling strengths and system size, so as to arrive at optimum conditions. The spatial SR has the welcome feature that the Signal to Noise Ratio (SNR) remains unchanged over a range of noise strengths.

The different dynamical states of a 2-dimensional recurrence relation called the Gumowski - Mira map is analysed to explain the wide variety of patterns it produces under iterations. It is found that the patterns correspond to the intermittency regions of the map and possible bifurcation patterns are worked out. By coupling two such maps, the nature of synchronization and its characterization are being done. The stability of a crystal lattice that is harmonically coupled to its neighbours but has a double well potential at each lattice point is being analysed using a CML model.

In collaboration with A. K. Kembhavi, R. Misra and K. P. Harikrishnan, detailed nonlinear time series analysis of the X-ray data from the black hole system GRS 1915+105 has been carried out by Ambika. Out of the 12 temporal states analyzed, 4 clearly indicate low dimensional chaotic behaviour, while 3 shows stochastic nature. More over the possibility of distinguishing chaos from coloured noise is studied using the correlation dimension as the measure and several realizations of the surrogates of the data. This is being repeated with the Lyapunov exponent as the measure.

Das, M. K. and Saha, L. M.

M. K. Das and L. M. Saha have continued their work on nonlinear stability of motion in binary star system within the frame work of restricted three-body problem. The effect of radiation pressure from binary components on the trajectories of a small mass element was investigated using the method of nonlinear forcasting, as used in nonlinear dynamics. Stability of motion has been also studied using the Poincare surface of section. It has been shown that the results of both the methods compare well, but method of nonlinear forcasting is much simpler and provide insight into the details of dynamics involved. Saha along with his students, and Das has worked in the area of nonlinear dynamics and studied different systems using maps and other tools.

Kuriakose, V. C.

Recently, much interest have been shown to study pulse propagation through realistic optical fibres. M. N. Vinoj and V. C. Kuriakose have studied pulse propagation through dispersion decreasing fibres and found that high quality compressed ultrashort soliton pulses free from pedestals pulses can be generated when light propagates through a dispersion decreasing fibres with fibre loss. Another area in nonlinear optics where soliton finds applications is in photo refractive and photonic crystals. C. P. Jisha and Kuriakose have studied photo refractive solitons from the point of photonic switching applications. P. D. Shaju and Kuriakose have proposed a simple method to create a double-well potential in semiannular Josephson junctions and obtained the methods for the manipulations of a vortex trapped in the junction. This finds applications in quantum information and quantum computing and Chitra and Kuriakose have started studying these aspects.

Mittal, A. K.

Seasonal mean rainfall anomalies are largely determined by sea surface temperature anomalies. In particular, it is known that year-to-year variation of tropical Pacific sea surface temperature associated with the El Nino/Southern Oscillations event have a strong influence on the inter-annual variations in the monsoon. During the summer monsoon season, the large-scale rainfall oscillates between active spells with good rainfall and weak spells with little rainfall. Typically, the transition time between active and weak spells is shorter than the residence time of the spells themselves. Lorenz model is a widely used for predictability studies in meteorology. Constant forcing terms have been introduced in the Lorenz model by Palmer to give a paradigmatic model for discussing long-range monsoon predictability. The forcing terms in this model represent the tropical Pacific sea surface temperature anomaly. These terms cause a shift in the probability distribution function between the two wings of the Lorenz butterfly, which represent the regimes of active and weak spells of the monsoon.

R. S. Yadav, S. Dwivedi and A. K. Mittal have investigated rules for forecasting regime changes and their duration for this model. They have discovered simple regime change rules that make predictions with near perfect accuracy. They have also found similar regime prediction rules in some other two-regime attractors, suggesting operation of some universality mechanism. These rules can be applied using observed data alone, without any knowledge of the underlying dynamical system. They have shown how these rules can help predict intra-seasonal rainfall variability for a toy rainfall model. These results have led them to conjecture a positive correlation between magnitudes of maximum anomaly during active rainfall spell and duration of subsequent break (dry) spell. Preliminary analysis of actual rainfall data appears to support the conjecture.

Hasan, S. N.

The research work done by S. N. Hasan involves the three-body problem and galaxy dynamics. Application of Clifford Algebras to the problems of celestial mechanics has been studied since a few years. It can be shown that this serves as a very powerful tool to the study problems in dynamics. Various important theorems have been derived to demonstrate this and the Sun-Earth-Moon system studied in this formulation. Dynamics of ejections from stellar systems have been studied and a comparison made between ejecting and colliding systems in the light of galaxy interaction. It was found that disruptive effects are considerably less in the case of ejections if the ejected system is compact. Work has also been started in an Indo-French project with Ajit Kembhavi in collaboration with Bruno Guiderdoni on GalICS. Preliminary results based on the SQL database have been obtained.

Vishwakarma, J. P.

The imploding shock wave has been an attractive topic in fluid dynamics, applied physics and engineering. In fact, imploding shock and detonation waves offer interesting possibilities of attaining extremely high temperature, pressure and density. Also, 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 K. K. Singh considered the implosion of a cylindrical shock wave in a non-homogeneous ideal gas or in a homogeneous non-ideal gas in presence of an azimuthal magnetic field. The shock velocity and other flow variables just behind the shock are determined by Whithams rule, in the cases, when (i) the gas is weakly ionized before and behind the shock front, (ii) the gas is strongly ionized before and behind the shock front, and (iii) the non-ionized gas undergoes intense ionization as a result of the passage of the shock. It is shown that the non-idealness of the gas, the variable density of the initial medium and the presence of azimuthal magnetic field have significant effects on the shock propagation.

J. P. Vishwakarma, in collaboration with S. Vishwakarma has obtained the similarity solutions for the region behind a converging cylindrical shock wave, where the flow is approximately isothermal due to intense radiation heat transfer. The initial density of the gas is assumed to be varying as r^{-w}, where r is the distance from the axis of symmetry and w, the inhomogeneity index. The requirement of a single maximum pressure in the shocked-flow leads to an approximate determination of self-similarity exponent for different values of w and γ, where γ is the ratio of specific heats of the gas. It is shown that the above requirement is fulfilled only when the inhomogeneity index w

satisfies the inequality $0.25 < w < 4/(\gamma+1)^2$.

Theoretical Physics

Dutt, Ranabir

During last few years, Ranabir Dutt has showed that the algebra of supersymmetry may be profitably applied to many non-relativistic quantum mechanical problems. In supersymmetric quantum mechanics (SUSYQM), one gets a better understanding of why certain potentials are analytically solvable. All solvable potentials have the property of shape invariance, which is realized through a relationship between the two supersymmetric partner potentials with a change of parameters related by translation. When extended to WKB theory, SUSYQM - inspired WKB quantization conditions (SWKB) reveal several interesting features: Unlike the standard WKB method, the leading order SWKB formula yields exact analytic expressions for the energy eigenvalues of all known shape invariant (SIP) potentials for which the change of parameters are of translational type. For spherically symmetric potentials, conventional Langer modification is not needed in the framework of SWKB theory. Furthermore, for non-exactly solvable cases, SWKB theory has so far predicted improved energy eigenvalues from the leading order as well as sub-leading orders as compared to those obtained from the corresponding WKB calculations.

It may then be natural for one to examine whether shape invariance and the exactness of the SWKB quantization formulae remain intact if the potential under study is generalized to higher dimensions. Dutt has studied the supersymmetric structure of the two-dimensional quantum disk billiard, of which the one-dimensional version, the infinite square-well potential, has been found to be shape-invariant. He has shown that although the shape invariance property is no longer valid in two dimensions, SWKB predictions for the energy eigenvalues are more accurate than the corresponding ones obtained from the WKB calculations.

Dutt has examined also the SIPs from the standpoint of periodic orbit theory. An exact trace formula for the quantum spectra of such potentials is derived. On the basis of this finding, he has presented a new derivation of the result that the lowest order SWKB quantization rule is exact.

Gangal, Anil

Anil Gangal together with Abhay Parvate has established conjugacy of calculus on fractals and ordinary calculus. This conjugacy provides a practical tool for solving fractal differential equations such as fractal time relaxation equation, fractal diffusion equation, equation of motion of a particle involving friction in a fractal medium, etc.

Kaushal, R. S.

In recent years, in the studies of theories of early universe the coloured objects like quarks, diquarks and gluons are found to play an important role, particularly in the context of stability studies of certain stellar objects. R. S. Kaushal with A.K. Sisodiya and his other collaborators has been investigating the role of multi-diquark interactions within the frame work of a polynomial field theory. In particular, using a generalized Pauli principle and the constituent quark model, the role of phi-4 and phi-6 - terms in the effective Lagrangian written for scalar field phi, is investigated. In another related work, in collaboration with D. Parashar and A.K. Sisodiya, Kaushal has proposed a quark- double diquark model for the newly discovered pentaquark baryons and tetraquark mesons as an extension of his 27 year old work on the quark-diquark model for the tri-quark baryons.

In several physical problems, particularly in the studies of population biology, the role of nonlinear terms in the diffusion equation has started penetrating in order to understand several newly discovered phenomena. Kaushal, in his recent work, has advanced the solitary wave solutions to a certain types of nonlinear diffusion-reaction (D-R) equations in one dimension. The mathematical contents of the associated non-Hermitian Hamiltonian with the linear counterpart of the D-R equation are investigated in a great detail.

Malik, Usha

It has been suggested by Usha Malik and her collaborators in an earlier publication that the high-Tc of a multi-component superconductor comes about due to multiple phonon exchanges between the electrons in it. So, the phonon propagator in the Cooper problem has been replaced by a phonon superpropagator. For this purpose, it is convenient to use Bethe-Salpeter formalism, because of the ease with which it allows temperature to be introduced. The analysis also gives a satisfactory explanation of the observed fact that the Tc's of alloys are universally higher than that of their constituents.

As a follow up of the above approach in superconductivity, the calculations of Tc's of some of the binary superconducting alloys are presented in the following scenarios: (a) the alloy is characterized by a single Debye temperature and (b) the alloy is characterized by two Debye temperatures.

The same approach has been followed to interpret the size effects (in the nano particle range) observed experimentally in high Tc oxide superconductors. The particle - size dependence of lattice constants plays a significant role in calculations of Tc. This feature, along with increase in Debye temperature and enhancement in electron density of states at Fermi level on reduction in size appears to have a strong hold on the Tc of multi component superconductors.

Pandita, P. N.

The idea of grand unification is one of the most compelling theoretical ideas that goes beyond the Standard Model (SM). In grand unified theories (GUT's), the SM gauge group $SU(3)\times SU(2)\times U(1)$ can be elegantly unified into a simple group. Moreover, the fermion content of the SM can be accommodated in irreducible representations of the unified gauge group. Also, one can understand the smallness of neutrino masses via the seesaw mechanism in some of the grand unified models like $SO(10)$. Since, supersymmetry is at present the only known framework in which the Higgs sector of the Standard Model is stable under radiative corrections, one must consider grand unified theories with underlying supersymmetry. In supersymmetric grand unified theories, the renormalization group flow of the gauge couplings leads to their unification at a very large scale.

P. N. Pandita, in collaboration with B. Ananthanarayan, has carried out a detailed analysis of the sfermion mass spectrum that arises in $SO(10)$ supersymmetric GUT. In supersymmetric $SO(10)$ grand unification, the unified gauge group can break to the Standard Model gauge group through different chains. The breaking of $SO(10)$ necessarily involves the reduction of the rank, and consequent generation of non-universal supersymmetry breaking scalar mass terms. By taking into account these non-universal contributions to the sfermion masses, a set of squark and slepton mass relations has been derived, which can help distinguish between the different chains through which the $SO(10)$ gauge group breaks to the SM gauge group. Thus, these sum rules can serve as a crucial test of the symmetry breaking pattern of the $SO(10)$ gauge group in the context of supersymmetric unification. The implications of these non-universal supersymmetry breaking scalar masses for the low energy phenomenology have been studied in detail.

Pandita, in collaboration with Katri Huitu, Jaari Laamanen and Sourov Roy, has carried out detailed investigations of lightest neutralino (a possible dark matter candidate) properties as well as an upper bound on its mass in a supersymmetric GUT based on $SU(5)$ gauge group. Such a grand unified theory can lead to non-universal gaugino masses at the unification scale. The phenomenological implications of these non-universal gaugino masses arising from a grand unified theory in the context of the Large Hadron Collider have been studied in detail.

Ramesh, Babu T.

The cross sections for two and three-photon ionization of hydrogen atom is evaluated by T. Ramesh Babu by performing the infinite summations over the complete set of atomic states including the continuum using the Dalgarno-Lewis metnod. Using this method, a convenient analytical expression is derived for Kramers-Heisenberg matrix element, describing the elastic scattering of photons by hydrogen atom. An analytical expression for the second-order AC Stark shift of the ground state of atomic hydrogen is also derived.

Verma, R. C.

The Standard Model of elementary particle and their interactions has been quite successful in explaining the electromagnetic and weak interactions in leptonic and semileptonic sector. However, hadronic processes have posed serious challenges to the model. Particularly, weak hadronic decay processes experience interference due to the less understood strong interactions. Quantum chromodynamics provides a reliable description of the strong interactions at high energy scale, but hadronization of quarks to form the hadron bound states introduces serious complications. Experimentally, now good amount of data exist for the weak hadronic decays involving s-wave hadrons. Consequently, theoretical efforts have been focused on charm and bottom hadrons emitting s-wave particles. However, these hadrons being heavy can also emit p-wave hadrons. Recently, these decays have also been observed experimentally, therefore, their theoretical investigations acquire significance.

Now more precise measurements of hyperon magnetic moments have become available, but there exist serious discrepancies between experimental and theoretical predictions. R. C. Verma has shown that a good agreement can be obtained for hyperon moments exploiting the concepts of effective quark mass and effective quark charge inside the baryons. He has first determined the effective quark masses from the charmed baryon masses by including spin-spin interaction caused by the exchange of gluons among the constituent quarks. Using the effective quark masses, he has calculated the moments by sandwiching the magnetic moment operator between charmed baryon flavour-spin wave functions. Similarly, he has also investigated quark charge screening effects on the charmed magnetic moments. The obtained values are expected to be tested in near future as serious efforts are underway to measure charmed baryon moments.

Theoretical progress on p-wave emitting weak decays of heavy hadrons has been rather slow. Initially, it was expected that these decays would be suppressed in comparison to the s-wave counterparts. However, the available experimental information on such decays of charmed meson, though meager, has already started showing discrepancy with such naive expectations. Since, charm and bottom hadrons are very heavy, they can decay through numerous channels emitting scalar and axial vector mesons, which Verma has studied. Using the QCD modified weak Hamiltonian based on the Standard Model, he has studied weak nonleptonic decays of bottom mesons emitting pseudoscalar and axial vector mesons using the factorization scheme, and calculated their branching ratios in Cabibbo favoured, Cabibbo suppressed, and Cabibbo doubly suppressed modes. He has also investigated two-body weak decays of charm baryons emitting $J_P =^+$ baryons and scalar mesons using the factorization scheme, and made first estimates for their decay rates, and it is hoped that these results would be helpful to experimentalists in their measurements.

Cluster Computing for Machine Learning

Ninan Sajeeth Philip

Santhom Cluster Project is a holistic approach to teaching and learning, in that the major emphasis is to the three aspects of learning, viz. (a) acquisition of Knowledge, (b) acquisition of Skill and (c) acquisition of Values. A survey in Technopark, the silicon valley in Kerala revealed that only 3 % of the students who pass out from the colleges in Kerala acquire the skill level required by the industries functioning there. While the state of Kerala is said to be hundred percent literate, this low level of “hit rate” indicate some serious drawback in the teaching and learning methodology adopted by the educational institutions in the state. Santhom Cluster Project is an experiment to identify talented students and to give them training in the missing aspects of learning with the aid of modern educational tools, led by N. Sajeeth Philip.

The test of the concept was the six node cluster building project done by five students and Sajeeth Philip at St. Thomas College in 2003. An extension of the project with 16 nodes was carried out at IUCAA in April 2004 by the same group. Both these projects were completely student oriented, in the sense that each member in the team felt their involvement in the project and recognised their contributions, whereby they gained self confidence and personal skill that supplemented their textual knowledge.

In October 2004, IUCAA donated 22 used computers, with special sanction from UGC for the cluster project at St. Thomas College. These machines were used in two phases of the Santhom Cluster Project. The first phase completed in December 2004. About twenty B.Sc. final year students actively participated in the first phase of the project. Starting from preparing the room by painting and wiring, they built the network and installed OS on the machines. The facility built by them is being used outside the working hours of the college by all interested students in the department to learn programing languages such as C and C++, in addition to other utilities and projects. A wide collection of self learning tutorials are made available on these machines, so that students may explore themselves the topics of their choice without waiting for classroom lecture hours. Evaluation procedures showed remarkable improvement in learning curves, ability to retain and recollect topics learned in the new environment as compared to conventional classroom learning.

The second phase of the Santhom Cluster Project started in January 2005 and is expecting completion by the end of March 2005. Six M.Sc. students, four from St. Thomas College and two from a nearby college work on this project. The aim is to develop OS support for low memory and low bandwidth clusters for massively parallel computing. A twelve node cluster is built with 10 Pentium 1 processors and two Celeron 2 GHz processors under this project. The Pentium 1 machines run at about 300MHz clock speeds with a memory of 32 MB, while the Celeron machines have 128 MB RAM each. None of the machines boots from local media; however, it is possible to have local hard disks for swap memory or provide local storage. Here again, every part of the project from assembling the machines, making network cables and clustering were all done by the students. The group was also able to modify the linux 2.4.27 vanilla kernel to run on as low as 16 MB RAM that now serve as the cluster OS on these systems. OpenMosix and LAM-MPI are installed on the cluster. Further optimisation of the code and benchmarking are being carried out. The facility is built following the GNU culture of the Free Software Foundation and efforts are made to document the entire project so that those who wish to experiment similar setups may copy them freely instead of reinventing the wheel.

Instrumentation

Dodia, Umesh

The CCD camera designed at IUCAA, compatible to SBIG ST-6 commercial camera, has been replicated at IUCAA by Umesh Dodia under UGC Minor research project, which will be very useful as a backend instrument to Bhavnagar University is Automated Photoelectric Telescope (APT) with the two stage stay at IUCAA. This has included making of CCD controller card, data grabber card, connection cables, related mechanical work, testing of controller with CCD head, familiarisation of softwares CCDOPS and AIP4WIN by taking images with CCD camera, construction of Low Level Light Sourse (L3S) for advanced testing of CCD camera, and Astronomical Image Processing for Windows (AIP4WIN). The results show that camera designed at IUCAA is a good instrument which can be produced at low cost about Rs. 30,000/-, which is possible under small projects like UGC minor research project.

No observational work could be carried out due to some logistic problems regarding Observatory. (It has taken about 2 years to shift the Observatory dome, which was damaged due to earthquake to the department building.)

(III) IUCAA-NCRA GRADUATE SCHOOL

Two IUCAA Research Scholars, Parampreet Singh (Guide: N.K. Dadhich) and Tirthankar Roy Choudhury (Guide: T. Padmanabhan) 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) Gravity at High Energies

Parampreet Singh

Understanding of the initial conditions of our universe is one of the frontier problems in current research. Standard model of cosmology fails to address the issues concerned with very early history of the universe, near and above Planckian energies, which is related with the breakdown of classical general relativity near big bang singularity. In this regime of gravity at high energies, there is an interface of gravity and quantum, and the correct description can only be provided by a theory of quantum gravity. It is expected that such a theory may also provide answers to some unsolved problems in standard model of cosmology, like that of dark energy, matter-antimatter asymmetry, etc. This thesis deals with investigations on the interface of gravity and quantum, and cosmological implications of candidate theories of quantum gravity. It is formatted in the following chapters.

Chapter 1 deals with an introduction to the problem of quantization of gravity and its motivations. The demand that a union of general relativity and quantum mechanics be self consistent and puts severe constraints restricting the possible approaches to the problem. Of these, the most prominent are the string theoretic approach based on ideas of particle physics and canonical quantization or the loop quantum gravity based on Einsteinian philosophy of spacetime. This chapter includes a discussion and comparison on these candidate theories. Apart from these mainstream approaches, we also discuss some aspects of interface of quantum and gravity like gravity induced quantum phase shifts. Though the latter does not aim to address the issues of quantum gravity, it never the less offers some useful insights on the subtle domain where quantum and gravity meet which is discussed in detail in Chapter 2.

Chapter 2 is based on the investigations related to the effect of gravitational field on the quantum phase shifts. It is well known that an extended body possessing multipole moments deviates from geodesic motion due to coupling of its multipole moments with the background gravitational field. The effect of gravitational field on monopole moment of neutrons has been empirically observed in interferometric experiments. However, in order to know the phase shift due to dipole and higher multipole couplings with background gravitational field, we must have an action principle formulation for dynamics of extended bodies in general relativity. This is so because, the action is directly observable as the phase shift of the wavefunction in the quantum theory. Dynamics of extended bodies possessing multipole moments in external gravitational field, like motion of planets, etc., is an important problem which captures the effect of non negligible extension of the body in comparison to the radius of curvature of the background field. The coupling of multipole moments to the curvature generates corrections to the geodesic equation, which were obtained earlier for the case of spinning particles and higher multipole moments. All these studies focused on obtaining corrections by using the conservation of stress energy tensor. However, the problem to obtain these corrections from an action principle remained unsolved for last 65 years. In this chapter, we would discuss an elegant action based procedure, which we have established for the first time. It can, in a very simple way compute the corrections to geodesic equation due to coupling of multipole moments *of any order* with the gravitational field and the resultant phase shifts. The new phase shifts may be measurable in future interferometry experiments.

Chapter 3 deals with string inspired braneworld scenarios with an emphasis on aspects of localization of gravity. In recent years there has been a lot of studies related to large extra dimensions and brane world scenarios motivated by string theories. In particular, Randall-Sundrum models with warped extra dimension have caught lot of attention. An important feature of these models is to show that extra dimension can be non compact and still gravity can be localized on the brane. This is accomplished through the effect of bulk curvature in the warp factor of the metric. One of the important problems in these scenarios is that of localization of gravity on the brane. This was established originally by Randall and Sundrum for the case of an anti de Sitter bulk with vanishing Weyl and a flat brane with a vanishing cosmological constant. An immediate question which arises in a more general setting is whether gravity is localized on the brane when Weyl curvature in the bulk is non vanishing. We study this problem for bulk spacetimes with non zero Weyl curvature in the bulk, in particular, for the five dimensional generalization of the Nariai spacetime and the Schwarzschild-AdS spacetime. In the former case, we show that a bound normalizable massless mode can not exist on the brane and thus, gravity can not be localized. The Schwarzschild-AdS bulk allows FRW cosmological branes and hence to understand localization of gravity in this case becomes an important issue, if bulk-brane scenarios have to be of any cosmological interest. The problem becomes difficult because of motion of brane, which makes difficult to impose boundary conditions. However, in a cosmological setting the important issue is whether conventional gravity is recovered on brane at late times of expansion of the universe when the brane is moving very slowly. This would mean that over time scales of interest brane can be treated as static. For such a case, we show that a massless graviton mode can be localized on the brane, provided the effective cosmological constant on the brane is non negative. Thus, for brane cosmology, a non-negative cosmological constant is a definite prediction.

In chapter 4, we study how large extra dimension immediately opens up a new avenue for studying cosmological consequences of such models and even confront the ideas with current astronomical observations like supernova and CMB. It is well known that warped brane world cosmologies do not predict new and distinct signatures from the standard cosmologies at low energies. Earlier studies in the field established that the brane corrections to Friedmann equation either die out at low redshifts or are severely constrained by the Big Bang nucleosynthesis. Thus, it becomes difficult to have any new low energy signature from the brane world cosmology. However, corrections to bulk-brane action motivated by stress tensor regularization generate modifications to the effective Friedmann equation, which gives distinct predictions for brane cosmologies from those of the standard cosmological model at low energies. Some of these corrections appear as surface term in the bulk-brane action and modify the curvature term, which amounts to a difference between the geometrical and dynamical curvature in FRW models. Such a model is distinct from the standard model of cosmology at low redshifts and thus, we can use astronomical observations to constrain it. We study fitting of this model with supernova Ia, position of peaks in CMB and quasar observations.

This chapter also deals with a related investigation of cosmological dynamics of a phantom field, which is inspired by string theory. Astrophysical observations like supernova Ia, have confirmed that our universe may be accelerating. This has become one of the corner stone issues of cosmology in recent years and many models have been proposed to explain this phenomena. Though the attempts are far from giving any physically reasonable explanation, there is an evolving consensus that this acceleration may be caused by some sort of dark energy composed of exotic matter which may have an equation of state less than -1. The only field theoretic possibility for such an equation of state is allowed through phantom scalar field which has negative kinetic energy. We study phantom scalar field in cosmological setting and use supernova Ia observations to constrain the model parameters.

Chapter 5 deals with some cosmological implications of another candidate theory of quantum gravity, the loop quantum gravity. It is a non-perturbative canonical quantization of gravity and one of the important questions it faces is related with its semi-classical limit. We study two approaches, one based on coherent states and the other on weave states. We discuss construction of coherent states for constrained systems and extensions of weave states for the Fermionic sector. For neutrinos, we discuss the way weave states introduce a new energy dependent scale and modifies the dispersion relation for different helicities. For massless neutrinos, this effect translates into a net neutrino asymmetry and we argue that this can be one of the physically viable mechanisms for generating matter-antimatter asymmetry in the universe after inflation. We also discuss construction of semi-classical wormhole solutions using coherent state technique.

We conclude with summary of results and future directions in Chapter 6.

Publications:

The work reported in this thesis is based on the following publications:

1. Parampreet Singh, and Naresh Dadhich, Non-conformally flat bulk spacetime and the 3-brane world, Phys. Lett. B **511**, 291 (2001); hep-th/0104174.

2. G. Date, and Parampreet Singh, Semi-classical States in the context of constrained cystems, quant-ph/0109127.

3. Parampreet Singh, and Naresh Dadhich, Localization of gravity in brane world cos-

mologies, Mod. Phys. Lett. A **18**, 983 (2003); hep-th/0204190.

4. Parampreet Singh, R. G. Vishwakarma, and Naresh Dadhich, Brane curvature and supernovae Ia observations, hep-th/0206193.

5. Parampreet Singh, and Naresh Dadhich, Localized gravity on FRW branes, hep-th/0208080.

6. R. G. Vishwakarma, and Parampreet Singh, Can brane cosmology with a vanishing Λ explain the observations ?, Class. Quant. Grav. **20**, 2033 (2003); astro-ph/0211285.

7. Jeeva Anandan, Naresh Dadhich, and Parampreet Singh, Action principle formulation for motion of extended bodies in general relativity, Phys. Rev. D **68**, 124014 (2003); gr-qc/0212130.

8. Gaetano Lambiase, and Parampreet Singh, Matter-antimatter asymmetry generated by Loop quantum gravity, Phys. Lett. B **565**, 27 (2003); gr-qc/0304051.

9. Jeeva Anandan, Naresh Dadhich, and Parampreet Singh, Action based approach to the dynamics of extended bodies in general relativity, *Honorable Mention in Gravity Research Foundation Essay Competition 2003,* Int. J. Mod. Phys. D **12**, 1651 (2003); gr-qc/0305063.

10. Parampreet Singh, M. Sami, and Naresh Dadhich, Cosmological dynamics of phantom field, Phys. Rev. D **68**, 023522 (2003); hep-th/0305110.

(ii) Physics of Structure Formation in the Universe

Tirthankar Roy Choudhury

In recent years, our understanding of the universe has been driven by tremendous progress in observational cosmology, which has revealed a great deal of information about the geometry, mass distribution and composition, and formation and evolution of structures of the universe. The observations of cosmic microwave background radiation, consisting of photons reaching us from the era when they decoupled from matter, have provided valuable information about the nature of our universe as it was about 10 billion years ago. The observations of distribution of matter over very large scales (say, ~ 10 Mpc), studied through galaxy surveys, spectra of distant quasars and other measurements have provided information about the formation and evolution of structures that we see today. The redshift-magnitude measurements of the high redshift supernovae have provided information about the geometry, and hence, the energy density of the universe. Current and near future observations of gravitationally lensed objects will help us constrain the cosmological parameters to a very high accuracy. The high accuracies in the measurement of most of the cosmological parameters helped the theoretical cosmologists to develop the so called "standard model" of cosmology – a model which is consistent with all the observations.

However, these observations have also left the theoretical cosmologists with some challenging issues. For example, we do not have any laboratory evidence for about 95 per cent of the matter component in the universe. About one third of these is a non-relativistic pressure-less fluid which does not interact with radiation, while the rest two-third is a negative pressure component. Similarly, we still do not have satisfactory models which describe the physics of the formation of baryonic structures, like galaxies, in the universe. In this thesis, we have addressed two key issues in this field, namely, (i) the formation of baryonic structures (Chapters 2–5), and (ii) the nature of dark matter and dark energy, and the limitations in determining their nature from observations (Chapter 6). Although tremendous progress has been achieved in studying the baryonic physics in the universe through numerical simulations, the computational cost has prevented us from achieving high enough numerical resolution so as to understand the physical processes in detail. In this regards, we have taken the approach of analytical and semi-analytical modelling, which do not have the problem of computational power. The analytical and semi-analytical models described in this thesis are found to match excellently with current observational data, and can be further compared with improved datasets expected in near future.

A chapter wise summary of the thesis is given below:

The first chapter reviews some of the basic concepts in cosmology and structure formation needed for the rest of the thesis. We have discussed very briefly the basic features of the standard model of cosmology. The standard model is studied in the framework of Einstein's general theory of relativity. The line element appropriate for an expanding universe, which is homogeneous and isotropic at large scales is given by the Friedmann metric. It describes the geometry of the smooth background universe, which is reviewed very briefly in this chapter. The observations indicate that the composition of the universe consists of normal matter (baryons), radiation, and two unknown components of dark matter and dark energy.

The formation of structures are believed to be because of the growth of small 'seed' perturbations (mainly dark matter and baryonic) via gravitational instability. We have described the evolution and statistics of these perturbations (both in dark matter and baryons) in the framework of linear as well as non-linear theory. The interaction of the baryons with the radiation cause tremendous difficulties in developing a non-linear theory for baryonic perturbations. A major part of the thesis is devoted to modelling these non-linearities. Finally, we have described the thermal history of the baryons and formation of baryonic structures in the universe. The neutral baryons fall into the potential wells created by the massive dark matter haloes. These baryons can form galaxies provided they are able to cool and fragment within the dark matter haloes. As the first stars form, the ultraviolet radiation emitted by them ionize the nearby low density baryons in the intergalactic medium – the process is called 'reionization'. We have discussed the current understanding of the basic physical processes leading to the reionization and the physical conditions in the diffuse intergalactic medium.

In Chapter 2, we introduce an approximation scheme for the non-linear baryonic mass density – the lognormal ansatz. Analytical derivations of the correlation function and the column density distribution for neutral hydrogen in the intergalactic medium (IGM) are presented, assuming that the baryonic mass density distribution in the IGM follows the lognormal ansatz. This ansatz was used earlier by Bi and Davidsen to perform one-dimensional simulations of lines of sight and analyse the properties of absorption systems. We have taken a completely analytical approach, which allows us to explore a wide region of the parameter space for our model. The analytical results have been compared with observations to constrain various cosmological and IGM parameters, whenever possible. Two kinds of correlation functions are defined : (i) along the line of sight (LOS); and (ii) across the transverse direction. We find that the effects on the LOS correlation owing to changes in cosmology and the slope of the equation of state of the IGM, γ are of the same order, which means that we cannot constrain both the parameters simultaneously. However, it is possible to constrain γ and its evolution using the observed LOS correlation function at different epochs provided that one knows the background cosmology. We suggest that the constraints on the evolution of γ obtained using the LOS correlation can be used as an independent tool to probe the reionization history of the universe. From the transverse correlation function, we obtain the excess probability, over random, of finding two neutral hydrogen overdense regions separated by an angle θ. We find that this excess probability is always less than 1 per cent for redshifts greater than 2. Our models also reproduce the observed column density distribution for neutral hydrogen, and the shape of the distribution depends on γ. Our calculations suggest that one can rule out $\gamma > 1.6$ for $z \simeq 2.31$ using the column density distribution. However, one cannot rule higher values of γ at higher redshifts.

In Chapter 3, we extend the analytical calculations of the previous chapter and perform one-dimensional semi-analytical simulations along the lines of sight to model the IGM. Since this procedure is computationally efficient in probing the parameter space – and reasonably accurate – we use it to recover the values of various parameters related to the IGM (for a fixed background cosmology) by comparing the model predictions with different observations. For the Λ cold dark matter model ($\Omega_m = 0.4$, $\Omega_\Lambda = 0.6$ and $h = 0.65$), we obtain, using statistics obtained from the transmitted flux, constraints on (i) the combination $f = (\Omega_B h^2)^2/J_{-12}$, where Ω_B is the baryonic density parameter and J_{-12} is the total photoionization rate in units of 10^{-12}s^{-1}, (ii) temperature T_0 corresponding to the mean density, and (iii) the slope γ of the effective equation of state of the IGM at a mean redshift $z \simeq 2.5$. We find that $0.8 < T_0/(10^4\text{K}) < 2.5$ and $1.3 < \gamma < 2.3$, while the constraint obtained on f is $0.020^2 < f < 0.032^2$. A reliable lower bound on J_{-12} can be used to put a lower bound on $\Omega_B h^2$, which can be compared with similar constraints obtained from big bang nucleosynthesis (BBN) and cosmic microwave background radiation (CMBR) studies. We find that if $J_{-12} > 1.2$, the lower bound on $\Omega_B h^2$ is in violation of the BBN value.

Chapter 4 deals with comparatively high density regions, namely, the damped Lyα systems (DLAs). The DLAs are identified with the lines having highest column densities in a typical observed absorption spectrum of a distant quasar. These high column density systems are important in understanding the baryonic structure formation, because they contain a fair amount of the neutral hydrogen in the universe at high redshifts. As a preliminary study for understanding these systems, a simple analytical model for estimating the fraction ($\Omega_{\rm gas}$) of matter in gaseous form within the collapsed dark matter (DM) haloes is presented. The model is developed using (i) the Press-Schechter formalism to estimate the fraction of baryons in DM haloes, and (ii) the observational estimates of the star formation rate at different redshifts. The prediction for $\Omega_{\rm gas}$ from the model is in broad agreement with the observed abundance of the damped Lyα systems. Furthermore, it can be used for estimating the circular velocities of the collapsed haloes at different redshifts, which could be compared with future observations.

In Chapter 5, we take our first step towards modelling the reionization. We explore the possibility of using the properties of gamma-ray bursts (GRBs) to probe the physical conditions in the epochs prior to reionization. The GRBs are among the brightest sources in the sky in any wavelength region. They are believed to originate due to collapse of very massive stars in the galaxies. In this chapter, the redshift distribution of GRBs is modelled using the Press-Schechter formalism with an assumption that they follow the cosmic star formation history. We reproduce the observed star formation rate obtained from galaxies in the redshift range $0 < z < 5$, as well as the redshift distribution of the GRBs inferred from the luminosity-variability correlation of the burst light curve. We show that the fraction of GRBs at high redshifts, the afterglows of which cannot be observed in R and I band owing to HI Gunn-Peterson optical depth can, at the most, account for *one third of the dark GRBs*. The observed redshift distribution of GRBs, with much less scatter than the one available today, can put stringent constraints on the epoch of reionization and the nature of gas cooling in the epochs prior to reionization.

Chapter 6 deals with issues related to the nature of dark matter and dark energy. Current cosmological observations strongly suggest the existence of two different kinds of energy densities dominating at small ($\lesssim 500$ Mpc) and large ($\gtrsim 1000$ Mpc) scales. The dark matter component, which dominates at small scales, contributes $\Omega_m \approx 0.35$ and has an equation of state $p = 0$, while the dark energy component, which dominates at large scales, contributes $\Omega_\Lambda \approx 0.65$ and has an equation of state $p \simeq -\rho$. The most obvious candidate for this dark energy is the cosmological constant (with the equation of state $w_X = p/\rho = -1$), which, however, raises several theoretical difficulties. This has led to models for dark energy component which evolves with time. We discuss certain questions related to the determination of the nature of dark energy component from observations of high redshift supernova. The main results of our analysis are: (i) Even if the precise value of w_X is known from observations, it is *not* possible to determine the nature of the unknown dark energy source using only kinematical and geometrical measurements. We have given explicit examples to show that different types of sources can give rise to a given w_X. (ii) It is usual to postulate weakly interacting massive particles (WIMPs) for the dark matter component and some form of scalar field or cosmological constant for the dark energy component. We explore the possibility of a scalar field with a Lagrangian $L = -V(\phi)\sqrt{1-\partial^i\phi\partial_i\phi}$ acting as *both* clustered dark matter and smoother dark energy, and having a scale-dependent equation of state. This model predicts a relation between the ratio $r = \rho_V/\rho_{\rm DM}$ of the energy densities of the two dark components and expansion rate n of the universe [with $a(t) \propto t^n$] in the form $n = (2/3)(1+r)$. For $r \approx 2$, we get $n \approx 2$ which is consistent with current supernova observations. (iii) It is well known that the full data set of supernova observations (which are currently available) strongly rule out models without dark energy. However, the high ($z > 0.25$) and low ($z < 0.25$) redshift data sets, individually, admit decelerating models with zero dark energy. This implies that any possible evolution in the absolute magnitude of the supernovae, if detected, might allow the decelerating models to be consistent with the data. This certainly appears ad-hoc; but one should compare the ad-hocness in these assumptions with the ad-hocness in introducing a dimensionless constant $\Lambda(G\hbar/c^3) \approx 10^{-123}$ in the physical system to explain the cosmological observations. (iv) The evolution of the dark energy component can be parametrized by its equation of state parameter $w_X(z)$. We have examined the possibility of constraining $w_X(z)$ by comparing theoretical models with supernova observations. In this regard, we have introduced two parameters, which can be obtained entirely from theory, to study the sensitivity of the luminosity distance on w_X. Using these two parameters, we have argued that although one can determine the present value of w_X accurately from the data, it is much more difficult to determine the evolution of w_X unambiguously.

Finally, the main conclusions of the thesis are summarized in Chapter 7. We have also commented on how some of the work described in the thesis can be extended further in near future.

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The thesis is mainly based on the following publications:

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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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T. Padmanabhan

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(b) Proceedings

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Vishwakarma, J. P., and S. Vishwakarma (2004) Analysis of cylindrical imploding shock waves with the rear flow-field isothermal, Proceedings of ISMAMS, **2**, 54.

(c) Proceedings (edited)

Iyer, Bala R., **V. C. Kuriakose** and C.V. Vishveshwara (2004) (eds): Proceedings of the Fifth International Conference on Gravitation and Cosmology (Indian Academy of Sciences, Bangalore), **63**, 643.

(d) Books

Ahsan, Zafar (Second Edition – 2004, Fourth Printing - July 2004, Fifth Printing - March 2005) Differential Equations and Their Applications, Prentice-Hall of India, New Delhi, Bestseller of the years 1999-2004.

Ahsan, Zafar and Nikhat Ahsan (2005) Mathematical Methods, Anamaya Publishers, New Delhi.

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Verma, R. C. (2004) Computer Simulation in Physics (based on Numerical Methods and FORTRAN), Anamaya Pub., N. Delhi.

(e) Supervision of Theses

Kaushal, R. S. (2004) A study of complex phase space approach to quantum mechanics and supersymmetric quantum mechanics, University of Delhi, Ph. D. Thesis of A. Parthasarathi.

Pandey, S. K. (2004) Multiwavelength Study of Dust Properties in early-type Galaxies, SRTM University, Nanded, Ph.D. thesis of M. K. Patil.

Pradhan, A. (2004) A study on cosmological models in general relativity, V. B. S. Purvanchal University, Jaunpur, Ph. D. thesis of Hare Ram Pandey.

Vishwakarma, J. P. (2004) A study of shock propagation in conducting and non-conducting fluids, D.D.U. Gorakhpur University, Gorakhpur, Ph. D. thesis of Subhash Vishwak

(V) PEDAGOGICAL ACTIVITIES

(a) IUCAA-NCRA Graduate School

S. Dhurandhar
Methods of Mathematical Physics I

A. Kembhavi
Electrodynamics and Radiative Processes I
Introduction to Astronomy and Astrophysics II

R. Misra
Electrodynamics and Radiative Pocesses II

T. Padmanabhan
Methods of Mathematical Physics II
Aspects of Quantum Field Theory (Topical course)

A. N. Ramaprakash
Astronomical Techniques I

R. Srianand
Interstellar medium
Galaxies: Structure, Dynamics and Evolution

T. Souradeep
Extragalactic Astronomy I

(b) University of Pune
M.Sc. (Physics)

N. Dadhich
General Relativity

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

Varun Sahni (jointly with N. Dadhich)
Cosmology

K. Subramanian
Astronomy and Astrophysics I (about 21 lectures)

M.Sc. (Space Science)

J. Bagchi
Radio Astronomy (theory classes + experimental sessions)

Ranjan Gupta
Astronomy and Astrophysics I (theory) (40 lectures)
Advanced Observational Astronomy (Part of the course 15 lectures)

(c) Supervision of Projects

J. Bagchi

Vaibhav N. Prakash (Dept. of Atmospheric and Space Sciences, University of Pune)
Relativistic effects in CGCG049-033: a giant, one-sided jet-like radio source

Satyajit Chavan (Dept. of Physiscs, Swami Ramanand Teerth Marathwada University, Nanded)
Training in radio astronomy, GMRT observations, AIPS, etc.(long term project 2005-2008).

Aliakbar Dariush (Shiraz University and Arsenjan Azad University, Iran)
The Wolf-Rayet galaxies

Pratik P. Lunavat, Sarvesh B. Devi and G. Ravi Kishore [B.E. (E & TC), Wadia Institute of Technology, Pune]
'Chaparral' and 'Cavity-backed Dipole' feed construction for 1400 MHz radio telescope application.

Nikhil Pawar (Dept. of Physics, Fergusson College, Pune)
A radio antenna for receiving decametric radio noise from Jupiter.

Anupriya Das (Dept. of Physics and Astrophysics, Delhi University)
Study of sub-cluster merger in Abell 3376 (VSP programme 2004).

Naresh Dadhich

Varghese Anto Chirayath (VSP 2004)
Blackholes

Prasun Dutta (VSP 204)
Brane world gravity

Vasundhara Vitthal Wadekar
Swapnil D. Gadhave
Sonali Ramdas Patil
Kashmira Suresh Patil
School Students' Summer Programme (Foucault's Pendulum)

Sanjeev Dhurandhar
for a batch of four school students

Trigonometry: applications to astronomy

Ajit Kembhavi

Anushyam Mohan, JNCASR, Bangalore,
Quasars

Ashutosh D., Shreyas N., Priyanka G., Ketan and Shipra B.,
Veermata Jijabai Technological Institute, Mumbai,
Web based user interfaces for astronomical data-sets.

Ranjeev Misra

Reshmi Behra (VSP 2004)
Power-spectra of X-ray binaries

Misha Hari and K. Souyma (M.Sc.)
Gamma-Ray Bursts

A.N. Ramaprakash

A. Shukla, Pune University
Polarization of T-Tauri Stars

A. D. Jayashankar and V. Sharma, GSM Engineering College, Pune, B. Tech.
Astronomical observation planning tool

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

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

Vaibhav Karkare (VSP - 2004)
Measurement of optical abberations from defocused images

T. Padmanabhan

Aseem Paranjpe, St. Xavier's College, Mumbai
Indian Academy of Sciences sponsord Summer Project
The gravitational action functional

Prasant Samantray (VSP - 2004)
De Sitter Spacetime in different coordinates

R. Srianand

Nidhi Mehta, Physics Dept., Pune University
Nitrogen abundance in DLAs, (M. Sc project)

Roopa Karmarkar, Wadia College,
M. Sc. Project.
Distribution of GRBs

K. Subramanian

R. Shankar (VSP - 2004)
Galactic dynamo

Tarun Souradeep

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

Ehsan Kourkchi (M.Sc., Sharif University of Technology, Iran)
CMB anisotropy in multiply connected universes

(d) Supervision of Theses

Naresh Dadhich (Guide)
Parampreet Singh
Gravity at High Energies

T. Padmanabhan (Guide)
Tirthankar Roy Choudhury
Physics of Structre Formation in the Universe

(VI) COLLOQUIA, SEMINARS, ETC.

(a) Colloquia

G. Rajasekaran: *Recent discoveries in neutrino physics*, July 9.

J. Maharana: *Unification of fundamental forces*, November 4.

G. Madhavan Nair: Indian space programme, December 27.

Apoorva Patel : *Languages of genetic information: Why do living organisms use 4 nucleotide bases and 20 amino acids?*, December 31.

Abhay Ashtekar: *Black holes in fundamental physics*, January 5.

Kishore Marathe: *Chern-Simons and string theory*, January 25.

Anand D. Karve: *Don't let textbooks interfere with your education*, March 14.

(b) Seminars

Firoza Sutaria: The XMM-Newton FOV of M74 and associated SNe SN2002ap, April 1.

Badri Krishnan: *Dynamical horizons and their properties*, April 13.

Badri Krishnan: *Searching for gravitational waves from pulsars using the Hough transform, April 15*.

Banibrata Mukhopadhyay: *Light-curve due to the hot-spot motion on the neutron star surface*, April 23.

Dipankar Maitra: *XTE observations of the 2003 outburst of the microquasar V4641 SQR*, June 3.

Sandip Trivedi: *An inflationary model in string theory*, June 7.

Richard Henriksen: *What is the dynamic state of dark matter halos, both young and old?*, June 22.

Arnab Rai Choudhuri: *Why do millisecond pulsars have weaker magnetic fields compared to ordinary pulsars?*, July 8.

Somak Raychaudhury: *The evolution of galaxies in small groups*, July 12.

Srinivas R. Kulkarni: *The central engines of gamma-ray bursts, x-ray flashes and supernovae*, July 20.

Susmita Chakravorty: *Compton drag model for gamma ray bursts*, July 30.

Gaurang Y. Mahajan: *The Casimir effect*, July 30.

Tapan Naskar: *Measurement strategies for the popularization measurement for brown dwarfs*, July 30.

Saumyadip Samui: *Reionization of the universe*, July 30.

Amrit L. Ahuja: *Study of pulsar dispersion measure*, August 5.

Hum Chand: *Probing the cosmological variation of fine-structure constant: Results based on VLT-UVES sample*, August 5.

Atul Deep: *Near infrared PICNIC imager : A progress report*, August 5.

Sanjit Mitra: *Efficient data analysis strategy for the detection of gravitational waves from inspiraling binaries : Chebyshev interpolation*, August 5.

Anand S. Sengupta: *Performance of the EHS pipeline on LIGO-S2 data*, August 5.

B.S. Sathyaprakash: *Gravitational wave observations : Current status and future prospects*, August 10.

Sivarani Thirupathi: *Discovery of an L Subdwarf and a lead rich star*, August 19.

Vijay Mohan: *Search for baryonic dark matter in the milky way*, August 30.

K. Narayan: Closed string tachyon condensation : Orbifold singularities, September 21.

Ujjaini Alam: *Is there supernova evidence for dark energy metamorphosis*?, October 11.

Biswajit Pandey: *Filaments in the universe*, October 12.

Tom Theuns: *The intergalactic medium at redshifts* 2-4, November 16.

Pradip Kumar Sahu: *Signature of quark deconfinement in neutron star*, November 25.

R. Ganapathy: *Meteorites and early solar system*, December 7.

Ashok Das: *Light-front field theories at finite temperature*, December 15.

Nikhil Padmanabhan: *The angular galaxy power spectrum from Z = 0.2 to 0.6 with the SDSS*, December 16.

Pankaj Jain: *Is there a preferred direction in the universe?*, December 23.

Gurbax Lakhina: *Relevance of research on historical geomagnetic storms to society*, January 6.

David Atkinson: *Quantum correlations and classical probability*, January 11.

Ashish Mahabal: *High-redshift quasars and science with Palomar-quest survey*, January 13.

Frank Verheest: *Linear and nonlinear wave phenomena in pair plasmas*, January 13.

D. Lynden-Bell: *Why accretion disks make jets*?, January 20.

E.P.J. van den Heuvel: *Evolution of x-ray binaries*, January 21.

Banibrata Mukhopadhyay: *Hydrodynamic induced turbulence in accretion disks: Study of energy growth*, January 24.

Sudip Bhattacharyya: *Surface atomic spectral lines from weakly magnetized rotating neutron stars*, January 27.

M. Elvis: *Quasar wind: the fourth element*, January 28.

G. Fabbiano: *Chandra observations of merging galaxies*, January 28.

Subhabrata Majumdar: *Probing our universe with the Sunyaev-Zel'dovich effect*, February 3.

Swara Ravindranath: *Morphological evolution of galaxies: Probing the assembly of the Hubble sequence*, Feburary 11.

Francis Bernardeau: *Multi-field inflation(s)*, February 23.

Emmanuel Rollinde: *The density structure around quasars inferred from Lyman-alpha optical depth statistics, March 24.*

(c) Neem Seminars

Parampreet Singh: *Discussion on Triality between inflation, cyclic and phantom cosmologies*, May 13.

Sandeep Sahijpal: *Some recent results in X-ray flaring and the origin of the solar system*, May 14.

Ujjal Debnath: *Gravitational dust collapse with cosmological constant*, May 27.

Subenoy Chakraborty: *The role of anisotropy and inhomogeneity in Lematire-Tolman-Bondi collapse*, May 28.

Sanjay K. Pandey: *Probing LSS at high redshifts using HI emissions*, June 7.

S.N. Hasan; *From Nbody1 to Nbody6 : The growth of an industry*, June 8.

Naresh Dadhich: *Probing the universality of gravitation*, June 15.

Daksh Lohiya: *Softening Deuterium constraints in early universe cosmology*, June 17.

Lalan Prasad: *Nanoflares as a plausible coronal heating agent*, June 23.

Abhay Ashtekar: *The puzzle of information loss*, December 30.

(d) IDG Talks

R. Srianand: *The z= 10 galaxy: Implications*, April 2

Amrit Lal Ahuja: *Association of coronal mass ejections with solar flares*, April 16.

Ujjaini Alam: *Latest results from high redhsift supernovae*, April 30.

Amir Hajian: *Beating cosmic variance*, May 7.

Atul Deep: *Magnification of type Ia supernovae with SDSS*, September 24.

Anand S. Sengupta: *Upper limits on gravitational wave signals based on loudest events*, October 8.

Abhishek Rawat: *X-ray properties of Lyman break* *galaxies in the Great Observatories Origins Deep Survey*, October 29.

Hum Chand: *The transverse proximity effect: A probe to the environment, anisotropy, and megayear variability of QSOs*, November 5.

Sanjit Mitra: *Universal limits on computation*, November 19.

R. Srianand: *A large neutral fraction of cosmic hydrogen a billion year after the big bang*, December 3.

Emmanuel Rollinde: *Cosmic star formation, reionization, and constraints on global chemical evolution*, December 17.

(VII) TALKS AT IUCAA WORKSHOPS OR AT OTHER INSTITUTIONS

(a) Seminars, Colloquia and Lectures

Ujjaini Alam

Is there supernova evidence for dark energy metamorphosis? International Conference on General Relativity and Gravitation (GR-17) Dublin, Ireland, July 18-23.

Dark energy deciphering dark energy: Parameter estimation from present and future data, XIII Meeting of the Indian Association for General Relativity and Gravitation, Jaipur, December 7-10.

Joydeep Bagchi

Astrophysics of 21 cm hydrogen line, IUCAA-NCRA Summer School/VSRP/VSP, May 31 and June 1.

Naresh Dadhich

Universalization as a physical guiding principle, 11th Regional Conference on Mathematical Physics, Institute for Studies in Theoretical Physics and Mathematics, Tehran, Iran, May 3.

Universalization as a physical guiding principle, University of Kerman, Iran, May 7.

Black holes and Spacetime singularities, IUCAA-NCRA Summer School/VSRP/VSP, May 24 and 25.

Probing universality of gravitation, IUCAA, Pune, June 15.

Probing universality (of Gravity) University of Portsmouth, Portsmouth, United Kingdom, July 13.

Probing Universality (of Gravity) , Queen Mary College, United Kingdom, July 17.

A volume integral quantifier for Anec violations in traversible wormhole spacetimes, International Conference on General Relativity, Dublin, Ireland, July 20.

Probing universality (of Gravity), University of Oxford, July 24.

Why Einstein? Jamia Millia Islamia, Delhi, August 25.

Probing universality, IUCAA Reference Centre, Delhi University, August 25.

Gravitation, University of Hyderabad, September 5-18.

Thoughts on gravity, Workshop on Strings and Cosmology at IUCAA, October 27.

Why Einstein? Workshop on Cosmology, Department of Physics, Ramnarain Ruia College, Matunga, Mumbai, November 18.

Why Einstein? University of Allahabad, November 20.

Gravity: Mother of all, Department of Physics, Scottish Church College, Kolkata, January 3.

Why Einstein? Department of Physics, Mangalore University, Mangalore, January 11.

Gravity: Mother of Forces, National Seminar on Gravity and Light at the Department of Physics, Cochin University of Science and Technology, Cochin, January 14.

Universalization as a Physical Guiding , National Seminar on "Gravity and Light", Department of Physics, Cochin University of Science and Technology, Cochin, January 15.

Why Einstein? Kumaun University, Nainital, February 21.

A Unified View of the Basic Forces of Nature, Kumaun University, Nainital, February 22.

Why Einstein? IIIT, Hyderabad, February 25.

Why There are only Four Basic Forces? Department of Astronomy, Osmania University, Hyderabad, February 26.

Why Einstein? Maharishi Karve Stree Shikshan Sanstha's Cummins College of Engineering for Women, Pune, March 10.

Sanjeev Dhurandhar

Gravitational Wave Observation: The Dawn, Perspectives in particle physics, gravity and cosmology conference, PRL, Ahmedabad, April 2.

Efficient extraction of inspiral signals from interferometric noise: Chebyschev interpolation, LSC meeting, Hanford, US, August 19.

Gravitational Waves: Recent Perspectives, 23rd IAGRG conference, Jaipur, December 7.

Time-Delay Interferometry for LISA, TAMA Symposium and Winter School, Osaka City University, Osaka, Japan, February 18.

Algebraic structures underlying LISA data analysis, Observatoire de la Cote D'Azur, Nice, France, June 10.

The Extended Hierarchical Search for Inspiraling Binaries, Caltech, U.S.A., August 31.

Efficient search for inspiraling binary signals using Chebyschev interpolation, Osaka University, Osaka, Japan, February 21.

Ranjan Gupta

Artificial Neural Networks in Astronomy, IUCAA/NCRA Summer School VSRP/VSP lecture on May 28.

Use of Small Telescopes and back-end instrumentation for teaching and research, University of Mauritius, May 31.

Recent studies of industrial pollution and its modeling, Dr. Babasaheb Ambedkar Technological University, Lonere, June 14.

Artificial Neural Networks and it's application to astronomical spectra, B.R. Ambedkar Bihar University, Muzaffarpur, November 1.

Dust models and calculations, Workshop on Interstellar Medium, Bangalore University, Bangalore, December 6-10.

A near-IR stellar spectral library in the H-band using the Mt. Abu Telescope, Symposium on Infrared and Optical Astronomy at Mt. Abu Observatory: The past decade and the future, December 15-17.

Theoretical modeling efforts of light scattering by non-spherical grains and Plans of a laboratory setup, Kobe University, Japan, March 9.

Amir Hajian

Statistical Isotropy of CMB from WMAP Data, University of Oxford, UK. March 05.

Rotational Symmetries of CMB Statistics and the Shape of Our Universe, IPM School on Cosmology and High-z Universe, Qeshm Island, Persian Gulf, Iran, January 05.

A Bipolar Power Spectrum Analysis of CMB, IAP, Paris, September.

Statistical Isotropy of CMB and the Shape of Our Universe, ICTP, Trieste, September.

Rotational Symmetries of the CMB Sky, Univ. Milano Bicocca, Milan, September.

Priya Hasan

Near Infrared Photometry of Young Star Clusters, TIFR, Mumbai, May 25

Near Infrared Photometry of Young Star Clusters, Mt Abu Symposium, PRL, Ahmedabad, December 16.

Ajit Kembhavi

Virtual Observatories, IIA, Bangalore, April 19.

Virtual Observatories, 11th Regional Conference of Mathematical Physics & IPM Spring Conference, Iran, May 3.

VO tools developed by the VO-I Project, International Virtual Observatory Alliance Interoperability Workshop, Cambridge, USA, May 25.

The VOPlot tools & Software developed by the VO-I Project, International Virtual Observatory Alliance Interoperability Workshop, Cambridge, USA, May 26.

The VOPlot tools & Software developed by the VO-I Project, Johns Hopkins University, SDSS Group, June 1.

Quasars & Super-massive Black Holes, IUCAA-NCRA Summer School/VSRP/VSP, June 10 and 11.

Virtual Observatory, Vth Rencontres Du Vietnam on New Views on the Universe, Vietnam, August 10.

The UGC-Infonet a New Paradigm for the Universities, Dr. Babasaheb Ambedkar Marathwada University, Aurangabad, September 16.

The UGC-Infonet Initiative, Vice-Chancellors' Meet, Margao, Goa, September 25.

Galaxies-near & far, IAGRG Conference & Symposium on Recent Trends in General Relativity, Cosmology & Astrophysics, Department of Mathematics, University of Rajasthan, Jaipur, December 7.

Lenticular & other galaxies, A Symposium on Infrared & optical Astronomy, Mount Abu Observatory: The Past Decade & the Future at PRL, Ahmedabad, December 15.

The Black Hole at the centre of the Milky Way Galaxy, Jadavpur University, Kolkata, December 22.

Statistics in Astronomy, National Seminar on Statistics in Natural, Social & Biological Sciences, Calcutta University, December 23.

UGC-Infonet Engine, Indo-UK Conference on Information Technology on Education and Learning, Le Meredien, Pune, February 17.

Virtual Observatories, Harish-Chandra Research Institute, Allahabad, February 21.

Fundamental Correlations in Galaxies, Harish-Chandra Research Institute, Allahabad, February 22.

Numerical analysis & software for teachers of commerce & finance, Academic Staff College, University of Mumbai, March 21.

Ranjeev Misra

Radiative Processes and Accretion Disks, ASTROSAT Workshop, BARC, Mumbai. May.

Radiative Processes, Two lectures for Summer School, IUCAA, Pune, June.

The non-linear behavior of GRS 1915+105, Spectra & Timing of Accreting X-Ray Binaries TIFR, Mumbai, January 17-21.

The non-linear behavior of GRS 1915+105, Raman Research Institute,Bangalore, March.

Accretion disks around black holes, Indian Institute of Science,Bangalore, March.

Sanjit Mitra

Introduction to Gravity Waves, IUCAA-NCRA Introductory Summer School on Astronomy and Astrophysics, IUCAA, Pune, June 7.

Universal Limits on Computation, IUCAA-NCRA Informal Discussion Group Meeting, IUCAA, Pune, November 19.

CMB Power Spectrum Estimation using Noncircular Beams, XVI DAE High Energy Physics Symposium, SINP, Kolkata, December 1.

Efficient data analysis strategy for the detection of Gravitational Waves from inspiraling binaries: Chebyshev Interpolation, 23rd Conference of the IAGRG, University of Rajasthan, Jaipur, December 8.

J. V. Narlikar

Impact of physics, chemistry and biology, Guha Research Conference, Kodaikanal, December 3.

Theory of relativity from a historical perspective, Indian Association for General Relativity and Gravitation (IAGRG), Department of Mathematics, University of Rajasthan, Jaipur, December 9.

Special relativity and faster than light motion (Workshop on 100 years of Einstein's Relativity), IUCAA, Pune, January 2.

Relativity and faster than light motion (a lecture delivered during the International Conference organized by the Indian Planetary Society to celebrate the Albert Einstein's Theories Centenary Year), Mumbai, January 8.

Science as an aid towards value education (National Seminar on Philosophy and Science of Value Education in the Context of Modern India organized by the Ramakrishna Mission Institute of Culture), Kolkata, January 22.

T. Padmanabhan

Wild Thoughts on Dark Energy, The Quest for a Concordance Cosmology and Beyond, Institute of Astronomy, Cambridge, July 6.

Gravity and the Thermodynamics of Horizons, Melbourne University, September 10.

Cosmological Constant - The Weight of the Vacuum, Melbourne University, September 22.

Precision Cosmology - The New Era, Miegunyah fellowship Public Lecture, Melbourne University, October 7.

Cosmology - An overview, Workshop on Strings and Cosmology, IUCAA, Pune, October 27.

Dark Energy and Cosmology: Overview, DAE Symposium on High Energy Physics, Saha Institute of Nuclear Physics, Kolkata, December 1.

The quantum vacuum-much ado about nothing, Astronomical Society of India, Nainital, February 22.

A. N. Ramaprakash

Optical Astronomy Techniques : IUCAA-NCRA Summer School/ VSRP/VSP June 7 - 9.

Laboratory and Sky Experiments Training : IIUCAA-NCRA Summer School/ VSRP/VSP, June 10.

Varun Sahni

Dark Energy, Workshop on Strings and Cosmology, IUCAA, Pune, India October 27 - Nov 1.

Cosmological Surprises from Braneworld models of Dark Energy, 14th Workshop on General Relativity and Gravitation), Yukawa Institute for Theoretical Physics, Kyoto, Japan, Nov 29 - Dec 3.

The mysterious nature of dark energy, 11th Regional Conference on Mathematical Physics, Tehran, Iran, May 3-6.

Dark Matter and dark Energy, IUCAA-NCRA Summer School/ VSRP/VSP June 10 -11.

Why is the Universe accelerating? Institute of Physics, Federal University of Rio de Janeiro, Brasil August.

M. Sami

Joining the Two Ends, FTAG, Sikkim, February.

Recent Trends in Cosmology, Jamia Millia Islamia, New Delhi, June 1.

Gauge Invariant Formulation of Cosmological Perturbations, (workshop on Strings and Cosmology), IUCAA, Pune, October. (2 lectures).

Problems and Prospects of Quintessential Inflation, 23rd IAGRG meeting, Jaipur, December.

Quintessential inflation, (workshop on Theoretical high energy physics, Roorkee (India), March 16 - 20.

Cosmological relevance of scaling solutions, Delhi University, March 18 –19.

Role of accelerated expansion in the dynamical history of our Universe in the Challenges of theoretical physics, Jamia Millia Islamia, New Delhi, March 16.

Rita Sinha

Cosmological Parameter Estimation - A Bayesian Approach, Jamia Millia Islamia, New Delhi, June16.

Cosmological Parameter Estimation for CMBR, IUCAA Reference Centre, Physics Department, University of Delhi, Delhi, July 23.

Monte Carlo Approach in Study of Hypernuclear Interactions, Cosmological Parameter Estimation, School of Physical Sciences, Jawaharlal Nehru University (JNU), New Delhi, November 5.

Estimating Cosmological Parameters from CMBR, 23rd IAGRG Conference and Recent Trends in General Relativity, Cosmology and Astrophysics, Jaipur, December 8.

Tarun Souradeep

Statistical isotropy of CMB anisotropy, Japanese workshop on General Relativity and Gravitation (JGRG-14), Kyoto, Japan, December 1.

Primordial power spectrum from WMAP, Yukawa Institute for Theoretical Physics, Kyoto, Japan, November 24.

Early Universe from the Cosmic Microwave Background Anisotropy, (review talk at the Strings and Cosmology meeting) in IUCAA, October 28.
Primordial power spectrum from WMAP, (International meeting COSMO-04), Toronto, Canada, September 17—21,2004.

Statistical Isotropy of CMB maps: A Bipolar Spherical Harmonic analysis, International meeting COSMO-04, Toronto, Canada, September 17—21.

CMB anisotropy from WMAP under scrutiny, TIFR, Mumbai, August 19.

Statistical Isotropy of CMB maps: A Bipolar SH Analysis, 20th IAP Colloquium: CMB Physics & Observations, Paris, France, July 2.

Combing the CMB Anisotropy on large scales, CITA, Toronto, Canada, June 21.

Milking the large angle CMB Anisotropy, Department of Physics, University of Pennsylvania, June 16.

Statistical Isotropy of the CMB anisotropy, Department of Astrophysical Sciences, Princeton University, June 15.

R. Srianand

Do constants vary with time, Colloquium given in IAP Paris, June.

Probing the variation of fine-structure constants using QSO absorption lines, ICTP, Trieste, September.

On the variation of fine-stucture constant, Workshop on Strings and Cosmology, IUCAA, Pune, October.

Physical conditions in proto-galaxies, a talk given in IAU symposium held in SHAO, Shanghai, China, March 17.

K. Subramanian

Nonlinear restrictions on the galactic dynamo, Leiden workshop on Magnetic Fields in Galaxies, Leiden, The Netherlands, July.

Wrapping up summary, Leiden workshop on Magnetic Fields in Galaxies, Leiden, The Netherlands, July.

Primordial magnetic fields and cosmic microwave background anisotropies, Astronomy Colloquium, Max-

Planck Institute for Radio Astronomy, Bonn, Germany, July.

Magnetic helicity and its flux, Programme on Magnetohydrodynamics of Stellar Interiors Isaac Newton Institute for Mathematical Sciences, Cambridge, UK, October.

Primordial magnetic fields and cosmic microwave background anisotropies, Institute for Gravitation, University of Portsmouth, UK, November.

Magnetic helicity fluxes in nonlinear turbulent dynamos, Leeds meeting on "Stellar dynamos", University of Leeds, UK, December.

P. Subramanian

Space weather and Communications, Jagannath Institute of Technology and Management, Orissa, March 5.

(b) Lecture Courses

S. V. Dhurandhar

General Relativity and Gravitational Waves Physics Dept., Gauhati University, October 4 - 6 (4 lectures).

Special and General Relativity and Gravitational Waves, Tezpur University, October 7 - 16 (12 lectures)

Ranjan Gupta

Basics of Observations and small telescope: Workshop on Astrophysics for college Teachers and Researchers, Department of Physics, Kumaun University, Nainital, October 25-29. (4 talks)

Ajit Kembhavi

Stellar Structure & Evolution, Workshop on Astrophysics for college Teachers & Researchers, Kumaun University, Nainital, October 25-26. (3 talks)

Galaxies, Workshop on Cosmology, Ramnarain Ruia College, Mumbai, November 17-19. (3 talks)

Stars - Introduction, Workshop on Observational Astronomy with Small Telescopes, V.R. College, Nellore, January 31-February 1. (3 talks)

J. V. Narlikar

Cosmology, Department of Physics, Ramnarain Ruia College, Mumbai, November 17-18 (3 lectures).

Relativity and cosmology (the students from the Mumbai University) at IUCAA, Pune, February 14-19 (6 lectures).

Cosmology from the sidelines (lectures to the Junior Research Scholars at IUCAA, Pune, March 1, 3, 8, 10, 15 (5 lectures).

Cosmology from sidelines, Harish-Chandra Research Institute, Allahabad, March 17, 18, 21, 22 (4 lectures)

T. Padmanabhan

Gravitation, IUCAA-NCRA Summer School/ VSRP/VSP May 19 - 21 (4 lectures)

Varun Sahni

Dark Energy , XIth Brazilian School on *Cosmology and Gravitation*, Mangaratiba, Brazil, July 26-August 4. (4 lectures)

R. Srianand

Diffuse matter in space, VSRP/VSP 2004, IUCAA. (5 lectures)

K. Subramnaian

Cosmology and structure formation, Summer School/ VSRP/ VSP programme, IUCAA. (4 lectures)

(VIII) SCIENTIFIC MEETINGS AND OTHER EVENTS

Inauguration of IUCAA Muktangan Vidnyan Shodhika

The IUCAA Muktangan Vidnyan Shodhika (MVS), the latest offering of IUCAA to the young minds curious about science, was inaugurated by Professor Yash Pal on June 12, 2004. The exploratorium is intended essentially for school children and will act as a focal point for them to have fun with science by actually doing experiments and investigating scientific principles. The exploratory was built from a handsome donation from Smt. Sunitabai Deshpande [wife of Pu.La. Deshpande] and partial funding support from the Marathi NRI organization in the USA called Maharashtra Foundation. The building has been named "Pulastya" (which is the name of one of the stars of the Saptarshi constellation), in memory of Pu-La.

The Exploratorium comprises of a small auditorium, where lectures, demonstration of experiments/slide shows, etc. can be held. It also has a Laboratory, Computer Centre, and a Library concentrating at present on Astronomy, Physics and Mathematics. On the day of the inauguration, there were lectures by Professor Yash Pal, as well as Professor Dinesh Thakur (University of Michigan) and Professor Milind Watve (Garware College, Pune) on the theme of "Fun of Doing Science".

The IUCAA Muktangan Vidnyan Shodhika inaugurated by Professor Yash Pal

Professor Yash Pal in conversation with the students

Professor Yash Pal looking through the microscope

Introductory Summer School on Astronomy and Astrophysics

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

The Department of Science and Technology sponsored Introductory Summer School on Astronomy and Astrophysics was held jointly by IUCAA and NCRA from May 17 to June 18, 2004. Thirty five students (final year bachelor and pre-final year masters) of science, engineering and mathematics streams from different colleges and universities spread across the country were selected for the school from an unusually large 350 applications. This year, the summer school also turned international with applications received from Bangladesh and USA. A masters student from Bangladesh University of Science and Technology also attended the school.

During the morning sessions of the school, there were several introductory courses covering topics in astronomy, astrophysics, gravitation, cosmology, etc. which were offered by faculty members of IUCAA and NCRA. The post-lunch sessions were set apart for talks on exciting areas of research and development in A&A. The speakers of these sessions were drawn from experts in the fields both from the local resource pool, as well as from other institutes in the country. Each school participant was also assigned an academic staff member of IUCAA/NCRA, with whom (s)he did a reading project. During the last week of the school, all the participants gave 20 minute presentations on their respective projects.

Facilities like library, internet access, xeroxing, etc. were provided to the students during their stay. A trip was also organized to visit the IUCAA Observatory and GMRT. Additionally, films on space research related subjects were screened during weekends.

The school was coordinated jointly by A. N. Ramaprakash (IUCAA) and D. J. Saikia (NCRA).

School Students' Summer Programme

Since 1993, IUCAA has been conducting summer programme for school students of Pune to give scientifically inclined students, a glimpse on doing science. The programme was conducted for six weeks for students of VIII and IX standards. Each week, a new batch of 30 students was invited to work on a project at IUCAA from Monday to Friday. Groups of four to six students were attached to individual guides. The programme has no set syllabus or course guidelines. The students and the guide work out their own schedule for the week. The students were given access to the IUCAA library. On the last day of the programme, that is on Friday, every student is asked to submit a report on the work carried out during the week.

This year's School Students Summer Programme was held from April 19 to May 28, 2004. The venue of the programme was the newly constructed Pulastya building of Muktangan Vidnayan Shodhika (see the report of its inaugural programme in this issue of Khagol). We try to introduce a new element in this programme when possible. This year the students' presentation was carried out in the lecture hall of Pulastya. For the students, who gave the presentation, it was their first experience.

Students carried out various projects under the supervision of Amrit L. Ahuja, V. Chellathurai, N. K. Dadhich, Sanjeev Dhurandhar, Arvind Gupta, Ranjan Gupta , T. Padmanabhan, Arvind Paranjpye, A.N. Ramaprakash, Sanjit Mitra, Arvind C. Ranade, R. Srianand, Kandaswamy Subramanian, Prasad Subramanian and Arun V. Thampan.

During the week, they participated in various common activities. Arvind Gupta conducted a scientific toy making activity for them, Vinaya Kulkarni conducted guided tour of the Science Park and scientific movie appreciation, and Arvind Paranjpye carried out a general question answer session, observing spectrum using a spectroscope and coordinated the programme.

Transit of Venus 2004

The rare event of the transit of Venus took place on June 8, 2004. The last transit of Venus from the earth was seen in 1882, nearly 122 years ago. Thus, this rare planetary alignment grabbed the attention of members of scientific community, public as well as media. IUCAA's 14 inch, 9 inch and a 6 inch telescopes were tracing the Venus, seen as a small black dot on the disc of the Sun. Moving with an angular speed of 3.2 arc minutes per hour, the Venus took about 6.2 hours to cross the disc of the Sun. The disc of the Venus made the first contact with the solar disc at 10:43:29 hrs and it left the solar disc totally at 16:55:59 hrs. Vinaya Kulkarni, Madhura Gokhale, Abhra Ray, Hrishikesh Kulkarni, and Nilesh Puntambekar recorded a movie of the ingress, black drop effect, transit and egress using a web camera attached to the 14 inch telescope.

ZEE News, Star News, Aaj-Tak, and Sahara television channels interviewed A. N. Ramaprakash, Varun Sahni, S.K. Pandey, Ajit Kembhavi, Vinaya Kulkarni, Abhra Ray (M.Sc. Space Science student, Pune University), and Nilesh Puntambekar (Sky Watchers' Association, Pune) on the various aspects of the transit phenomenon. The Zee News was giving live telecast of the views of IUCAA members and the preparations of the transit viewing at IUCAA for two days prior to the event and also on the day of the transit. The Star News gave live telecasts of members of IUCAA on the details of the rare phenomenon of the transit on the day of the event.

Arrangements were made at IUCAA Science Park area to show the transit of Venus to the members of public. The solar image through telescope was projected on a screen. Around 1500 people visited IUCAA to view the transit.

Arvind Paranjpye anchored Vigyan Prasar film - *Khoj Khagoliya Ikai Ki* (in search of astronomical unit) a film on the Transit of Veus, in which he explained how to and how not to observe the transit. The film was shot at IUCAA and was directed by Deepak Varma (for Vigyan Prasar). The jury of the CEC-UGC (Consortium for Educational Communication and University Grants Commission) festical has awarded the film a citation for best programme for teachers. CEC-UGC festival is for films/programmes with educational values and they invite entries from organisations and independent producers.

The various phases of the transit of Venus

Film on Trnsit of venus received citation of best programme for teachers

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 17-July 2, 2004. Eight students participated in this programme. The participants attended about 50 lectures dealing with wide variety of topics in Astronomy and Astrophysics, given by the members of NCRA and IUCAA. Each student also did a project with one of the faculty members of IUCAA during this period. The main purpose of this programme is to pre-select the eligible students to Ph.D. Programme. K. Subramanian was the faculty coordinator of this programme.

International Virtual Observatory Alliance (IVOA) Interoperability Meeting and Small Projects Meeting

Speakers getting ready for their talks

The Interoperability (IO) meeting of the International Virtual Observatory Alliance (IVOA) took place in IUCAA during September 27 -29, 2004. The meeting was jointly organised by IUCAA and Persistent Systems Private Limited (PSPL), Pune, who are partners in the Virtual Observatory-India (VO-I) project, which is partially funded by the Ministry of Information and Communications Technology. The IO meetings are held about twice a year in important Virtual Observatory centres in different countries, and their aim is to provide a platform for discussion, planning and collaboration between people working in different Virtual Observatories. The Working Groups (WG) of the IVOA, which were represented in the meeting were Registry, Uniform Content Descriptors, Data Model, Data Access Layer, Virtual Observatory Query Language, Grid and Web services and Global Grid Forum. One or more sessions of each WG were held during the meeting, with a number of presentations being made in each session. There were a small number of plenary talks, summarizing all the discussions. Working papers emerging from the sessions will be posted on the IVOA website. These will provide directions for further development in the concerned areas.

Participants of the IVOA meetings

A Small Projects Meeting of the IVOA took place at IUCAA during September 30 - October 1, 2004, following the Interoperability meeting. The aim of these meetings is to provide a forum for the relatively small Virtual Observatory projects in the Asia-Pacific region to discuss the work undertaken by them, the products made ready and plans for the future. The first such meeting was held in Beijing in November 2003 and the meeting at IUCAA has been the second one in the planned series. The specific aim of the meeting at IUCAA was to bring together Observing Facilities, which have been recently completed or will be ready in the near future, and people working on VO related projects. From India, there were presentations on the Himalaya Chandra Telescope (HCT), The TAUVEX Mission and projects undertaken by VO-I. There were also presentations by VO projects from Australia, China and Japan and plenary talks and discussion sessions on science from the VO and the progress of VO from development to deployment.

A public lecture by Francoise Genova, Observatoire de Strasbourg, Strasbourg was organised at the Chandrashekhar Auditorium, IUCAA and another one by Peter Quinn, European Southern Observatory, Munich, in the Devang Mehta Auditorium at PSPL. About fifty astronomers and software engineers from abroad, and a similar number from India attended both the IVOA meetings. A.K. Kembhavi was the coordinator of these meetings.

Workshop on Astrophysics for College Teachers and Researchers

A five-day workshop on “Astrophysics for College Teachers and Researchers” was conducted successfully at the Department of Physics., Kumaun University, Nainital, during October 25-29, 2004. It was attended by fourteen teachers and researchers from remote parts of Uttaranchal and UP, six from Aryabhatta Research Institute of Observational Sciences (ARIES), and fifteen local participants including teachers and researchers from other disciplines of the Kumaun University.

The Workshop was inaugurated by the Vice Chancellor, R.C. Pant of Kumaun University, Nainital on October 25, 2004. The speakers and the topics were as follows:
A.K. Kembhavi (IUCAA) on *Stellar atmospheres, internal structure, energy balance, and spectra of stars;* Ram Sagar (ARIES) on (i) *Star clusters with particular reference to galactic clusters* and (ii) *New technology telescopes*; M.C. Pande (ARIES) on *Magnetohydrodynamics*; L.M. Saha (Zakir Husain College, New Delhi) on *Sun and the solar system*; Kavita Pandey (Kumaun University) on *Solar neutrino problem*; Suchi Bisht (Kumaun University) on *Particle physics and how its laws could be applied to the understanding of universe in a few minutes after the bing bang*; Rajmal Jain (PRL) on (i) *Dynamic sun,* (ii) *Instrumentation* and (iii) *Data analysis of the observations by the SOXS mission*; Wahab Uddin (ARIES) on *Details of the contribution of ARIES solar astronomers in observation*; Seema Bisht (Kumaun University) on *Solar flares and prominences*; and Ranjan Gupta (IUCAA) on *Small telescopes and their back end instrumentation*. In addition, Ajit Kembhavi delivered a popular talk on *Virtual Observatories Data Base.*

The coordinators of the workshop were Kavita Pandey (Kumaun University) and Ranjan Gupta (IUCAA).

Participants of the Workshop on Astrophysics for College Teachers and Researchers

Workshop on Strings and Cosmology

Participants of the Workshop on Strings and Cosmology

An attempt was made to start a dialogue between the practitioners of strings and cosmology through a workshop organised at IUCAA during October 27 - November 1, 2004. About 25 active workers from either side came together and meeting had good review as well as technical talks. The format was discussion intensive, as there was enough free time for informal discussions. It was a wonderful and refreshing experience for the participants. The idea was for cosmologists to open up to developments in quantum gravity as well as for string theorists to address cosmologically meaningful questions. It was unfortunate that the loops remained under represented, because many of the loopy people were out of the country at that time.

Going by the overall enthusiasm, it has been proposed that such dialogue should continue at a regular frequency. The coordinators of the meeting were N.K. Dadhich and M. Sami.

Workshop on Interstellar Medium

Participants and Lecturers of the Workshop on Interstellar Medium

A five-day workshop on "Interstellar Medium" was held in the Department of Physics, Bangalore University during December 6-10, 2004. It was also noted that interestingly, the year 2004 happened to be the centenary year of the discovery of interstellar medium!

The workshop was inaugurated by the Vice Chancellor of Bangalore University, M.S. Thimmappa on December 6, 2004. The speakers and the topics were as follows:

M.N. Anandaram (Bangalore University) on *Review of the essential astrophysical concepts*; Jayant Murthy (IIA) on (i) Characteristics of spectral lines and (ii) *Analysis of space mission data*; D.C.V. Mallik (IIA) on (i) *Evidences for ISM* and (ii) *Heating and cooling processes*; K.S. Dwarakanath (RRI) on *H21 cm line in the study of ISM*; R. Srianand (IUCAA) on *ISM at high redshifts*; H.C. Bhatt (IIA) on *Dust and star formation in ISM*; G. Srinivasan (RRI) on *Super novae and their influence on ISM*; Yashwant Gupta (NCRA-TIFR) on *The study of ISM through radio astronomy*; Ranjan Gupta (IUCAA) on *Models of dust*; C. Sivaram (IIA) on *Chemical and biological processes taking place in ISM*.

The coordinators were: R. Srianand from IUCAA and B.A. Kagali from Bangalore University.

W orkshop on Astronomy with Small Telescopes

Participants and Lecturers of the Workshop on Observational Astronomy with Small Telescopes

A five days Workshop on *Observational Astronomy with Small Telescopes* was held at Department of Physics, V.R. College, Nellore, during January 31 to February 4, 2005. The workshop was inaugurated by Ajit Kembhavi. Speakers and topics were as follows:

Ajit Kembhavi (IUCAA) on Light of Stars; Vijay Mohan (Visiting Scientist, IUCAA) on Data Analysis Techniques in Astronomy; S. K. Pandey (Pt. Ravi Shankar Shukla University, Raipur) on Observational Projects with Small Telescopes and R. Ramakrishna Reddy (S.K. University, Anantapur) on Stellar Spectroscopy.

Vijay Mohan took special sessions on 'Hands-on Training on Data Analysis' and Arvind Paranjpye carried on 'Hands-on Training on Photoelectric Photometry Observations' for selected participants and followed by subsequent sessions on data analysis.

There were 33 registered participants, of which 29 were from the different parts of the country.

A. N. Ramaprakash (IUCAA), S.K. Pandey (Pt. Ravi Shankar Shukla University, Raipur), and P. Sudhakara Reddy (V.R. College, Nellore) coordinated the workshop.

W orkshop on High Performance Computing

Participants of the Workshop on High Performance Computing

A training workshop on High Performance Computing (HPC) was held in IUCAA from Oct.~5-9, 2004. The workshop was a joint venture with members of CDAC Pune. CDAC members conducted the HPC course along the lines of their regular HPC programs and also made available teaching manpower and the course material. The workshop scheduled many hands-on sessions to allow participant to work on the HPC facilities both at IUCAA and CDAC, Pune round the clock. The workshop also featured inspiring seminars by prominent scientists who use HPC in very different fields. There were talks on upcoming trends like grid computing and of the near future possibilities in HPC. There was a live compute cluster building demonstration by IUCAA associate, Sajeeth Phillip and a presentation by Redhat on available and upcoming linux clustering tools.

The prime motive was to generate users for the HPC facilities in IUCAA and CDAC. There were over 60 participants from all over India who benefited from this workshop. A large number of computers were set up that allowed all participants to work simultaneously. Typically, CDAC training courses are costly and inaccessible to the university sector. Being an IUCAA activity allowed free participation from the University sector. The workshop was successful in creating users from the University sector. This was perhaps the first serious joint venture between IUCAA and CDAC and strongly appreciated by Directors of CDAC.

The workshop was coordinated by Tarun Souradeep and IUCAA HPC team members, Sarah Ponthratnam, Rita Sinha, Sunu Engineer, Sanjit Mitra and Anand Sengupta. Dr. Sundar Rajan and Dr. V.C. V. Rao led the CDAC team. Administrative support was provided by Manjiri Mahabal & Swati Gujar and system administration team of IUCAA set up and ably managed the large computer laboratory set up for the meeting.

Public Outreach Programme

Muktangan Vidnyan Shodhika

Three times a week about 50 children from one particular school come to the centre and spend 4 hours making toys that spin, fly, whistle, jump, and hop. They make "action" toys, for all children are attracted to dynamic toys. Children learn to fold a dozen different caps using old newspapers. They learn geometry by paper folding making the rotating hexa-flexagon using an old photocopy paper!

At slightly higher level students of St. Mira's College for Girls, Reshma Lalwani and Hritul Madge (IInd year Junior College) visited the Exploratorium for two weeks to study and to design a Sundial for their college. Priyadarshini S. Bangale, first year student of Electronics and Telecommunication of MGM College Nanded, did a project on The Study of Solar Limb Darkening. Three final year students of Cummins college of Engineering, Pune, Bakul Purohit, Parchee Bahulekar and Sonali Deshmukh, fabricated a Coelostat for the Solar observatory of the Exploratorium.

SLt Kanand Bhagwat and Slt Nikhil Kane (trainee officers at the Faculty of Training Project, Electrical Technology School, INS Valsura, Jamnagar) did a project on Data logger for photoelectric photometer.

The school students at the Space UK exhibition

Space UK Exhibition

A SpaceUK exhibition on the solar system and its exploration, was kept open at IUCAA for the people during August 1- 8, 2004. The exhibition has been commissioned by British Council. The United Kingdom has played an important role in the solar system missions, both by developing spacecraft and instrumentation and by interpreting the results. The SpaceUK exhibition highlighted on those missions and the future UK led exploratory missions to the Moon, a comet, Mars, Venus and Saturn as well.

The exhibition looked at the key missions regarding solar system exploration and described some of the challenges that scientists and engineers face in designing a spacecraft. With striking graphics and a walk-through tunnel display, SpaceUK delved into the science behind the missions and the questions that will be answered about the planets, comets and asteroids. A scaled down model of the solar system hung on a stand gave an idea of comparative sizes of the planets and the Sun, and the distances in the solar system.

Everyday, screening of The IUCAA Story, Taryanchi Jeevangatha I & II (Life cycle of stars), Powers of Ten was also done one after the other during the day time, and during August 2-7 every evening, a popular talk or a scientific film was arranged at the Chandrasekhar Auditorium. Pandit Vidyasagar, from the Department of Physics, Pune University (Brain: Known and Unknown), Murali Sastry from National Chemical Laboratory (Nanoscience and the Next Industrial Revolution), and Tarun Souradeep from IUCAA (Unravelling Our Universe) gave popular talks.

In spite of heavy rains, students, amateurs and enthusiasts turned up in thousands to view the exhibition. Many of the curious students took out their notebooks to take down the information about various missions. Apart from the information content, viewers found the exhibition in the form of tunnel display very impressive.

The exhibition was in India till November 2004. It was inaugurated at the Goa Science Centre on July12, 2004. After Pune, the exhibition moved on to Mumbai, Vadodara, Gandhinagar, Delhi, Bhopal, Kurukshetra and Kolkata.

National Science Day

The National Science Day was celebrated at IUCAA during February 27-28, 2005. On Sunday, February 27, the Centre was opened to the general public, so that they may acquaint themselves with the research done at IUCAA and appreciate scientific temper and methodology. On Monday, the 28th, science related competitions, which were designed to test the exploratory and imaginative skills of the participants, were held for high school students.

The Open House for Public

A large number of people from all age groups and different professional backgrounds visited IUCAA on Sunday, February 27. The visitors viewed several posters describing the basics of Astronomy and Astrophysics and the fundamental research done at IUCAA. They interacted with IUCAA members who demystified the technical details of the research activities. A kiosk was also set up where individuals could ask questions or doubts they may have about astronomy, directly to astronomers, like Professor J.V. Narlikar. Short interactive lectures were held in different topics including one about career prospects in Astronomy for those aspiring to become Asronomers. A public talk, which explained the importance of this year's Nobel prize in physics, in non-technical language, was presented in the evening. Demonstrations of how the atmosphere affects astronomical observations and how Radio Telescopes work were set up as examples of how astrophysical research is undertaken. The visitors were shown how a model of the robotic Mars explorer, Rover, could be controlled by a computer. Science documentaries on interesting scientific topics were shown. Actual samples of meteorites (i.e., rocks from space which can be older than the earth) were exhibited.

Visitors were encouraged to get hands on experience of science using several do-it-yourself experiments set up in the recently inaugurated Muktangan Vidnyan Shodhika, which is a unique centre that facilitates school students to learn about science in a free and fun atmosphere. These experiments were designed and presented by students of Rewachand Bhojwani School. Students (Kshitija Deshpande, Rohit Belapurkar and Rahul Sangole) from Pune Institute of Engineering and Technology, Maharashtra Institute of Technology and Pune Vidyarthi Grihas College of Engineering and Technology respectively, displayed an airship which they had designed and made. A computer was set up by NIIT, Delhi which allowed people to self learn about computers. A popular place was the IUCAA science park, where there are several interactive outdoor exhibits, each one designed to explain a scientific principle.

Inter-School Competitions

Several schools were invited to take part in the inter-school science competitions held on Monday, February 28, at IUCAA. Fifty five schools participated by sending a team of five students each. Drawing and Essay competitions were held with topics suitably chosen to enable the students to exhibit their scientific knowledge as well as a fertile imagination. 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, as well as their ability to solve puzzles. The students and their teachers were introduced to the making of scientific toys with common cheap materials, that would enable young minds to learn and be excited about scientific inquiry.

A great deal of planning and administration was necessary for the smooth execution of the celebrations of the National Science Day, which was possible because of the active participation by all the members of IUCAA. IUCAA thanks the volunteers from Sky Watchers Association of Pune for helping with the National Science Day celebration.

Sky Watch Program

In the evening of Monday 28th, a sky watch programme was organized. The IUCAA's six-inch telescope was used by the people to see various aspects of the night sky, including Jupiter, Moon and the Orion Nebula.

Lecture Demonstration

Since 1993 IUCAA has been organizing lecture demonstration programme for the students of class VIII to X. This programme has been very popular and successful.

During the period of the report, 6 lectures were organised which were attended by about 6000 students.

Lectures for High School Students (Classes VIII - X)

[Every speaker delivered lecture in Marathi and then in English]

Arvind Paranjpye
Be an Amateur Scientist, July 10

A. L. Ahuja
Nine Wonderful Planets, August 14

M. Prakash
How to Study Maths Effectively?, October 9

C. K. Desai
Electromagnetic Induction, December 12

Pradeep Gothoskar
The Story of Red-Green-Blue, January 8

Jayant Narlikar
Cosmic Illusions, February 12

The experiments being explained to the visitors during the National Science Day

Students at the Essay Competition

The Quiz-winiing team holding the trophy

Public lectures

Pandit Vidyasagar, Dept. of Physics, Pune University
Brain : Known & Unknown, August 2

Murali Sastry, National Chemical Laboratory,
Nanoscience and the next industrial revolution, August 5

Tarun Souradeep
Unraveling Our Universe, August 6

Peter Kalmus
The Forces of Nature, October 8
(In association with the British Council, Mumbai)

Roddam Narsimha
A Love of Flow, December 29

Pervez Hoodbhoy
Why Scientific Revolution Didn't Happen in Our Part of the World?, January 19
(With presiding remarks by Jayant Narlikar)

Special Relativity Centenary Meeting

A one day Lecture series for the undergraduate and junior college students was organized to commemorate the launch of the International Year of Physics, on January 2

The speakers and their topics:

Abhay Ashtekar (Director of the Center for Gravitational Physics and Geometry, Penn State University,USA)
Space and Time: From Antiquity to Einstein and Beyond

Donald Lynden-Bell (Professor of Astrophysics at the University of Cambridge, UK)
The Relativity of Rotation: Before and After Einstein

Gavin Wraith (Emeritus Reader, Department of Mathematics, University of Sussex, UK)
Ideas of Space and Observability

Jayant Narlikar (Professor Emeritus, Inter-University Centre for Astronomy and Astrophysics, India)
Special Relativity and Faster than Light Motion

Results of various competitions

Drawing Competition

1st Prize: Mayura M. Datar, Jnana Probodhini Prashala, Pune.

2nd Prize: Nikita A. Bhate, Symbiosis Secondary School.

3rd Prize : Soundarya Sunder Pawar, Judson High School.

Honorable Mention

Mayur Valmik Ladkat, Shri Fattechand Jain Vidyalaya.

Meeta Vishwas Kurundkar, Muktangan English School.

Essay Competition (Marathi Medium)

1st Prize : Snehal Nilkanth Chavan, P.E.S. Girls' High School.

2nd Prize : Vallabh Sanjay Joshi, M. S. S. High School.

Honorable Mention

Nirmitee Vinod Watve, Ahilyadevi High School for Girls.

Essay Competition (English Medium)

1st Prize : Prachi Ashok Joshi, Abhinava Vidyalay English Medium School.

No essay was adjudged for the award of second prize.

Honorable Mention

Leah Thomas, St. Joseph High School, Pashan

Quiz Competition

1st Prize

Abhishek Hemantkumar Dang, Aniket Rajendra Inamdar, and Kedar Sanjay Jumde from Jnana Prabodhini Navnagar Vidyalaya.

2nd Prize

Priya Rajendra Sidhaye, Tanay Milind Deshpande and Adwait Jayant Gandhe from Abhinava Vidyalay English Medium School.

3rd Prize

Swetava Tapash Ganguli, Shreyas Ganesh Patankar and Ameya Pramod Phalake from Vidya Bhavan High School.

The following two schools were also qualified for the final round of the quiz competition.

Kendriya Vidyalaya, Southern Command : Mayur Ghawat, Tarun and Sanjeev Suresh *and*

N.M.V. High School: Chetan Ajay Doifode, Ameya Sushil Savare and Girish Shrinivas Vaidya.

Popular Talks and Articles by the IUCAA Faculty

a) Popular Talks

Naresh Dadhich

(2004) Riding on the Shoulders of Giants (a lecture delivered at Gorakhpur University), April 19.

Universalization as a Physical Guiding Principle (a general talk delivered to the science students) Gorakhpur University, April 19

Black Hole and Space-Time Singularities (a lecture delivered to the VSP students in IUCAA,) May 24

Universality of Gravity, Homi Bhabha Centre for Science Education, Mumbai, June 14.

Why Einstein? Maharashtra Institute of Technology, Pune, July 31.

Why Einstein? Mathematics department of Abasaheb Garware College, Pune, August 17.

Science: Method and Vision, Institution of Electronics and Telecommunication Engineers, Pune, August 30.

From the Shoulders of Giants, Veermata Jijabai Technological Institute, Matunga, Mumbai, September 2.

Vaigyanik Drishti Aur Samajik Paripeksha delivered at Jawahar Planetarium, Allahabad, November 19.

Why Einstein?, Motilal Nehru National Institute of Technology, Allahabad, November 20.

From the Shoulders of Giants, students of Central School, Bhopal, November 22.

Science: Method and Vision, Regional Institute of Education, Bhopal, November 22.

From the Shoulders of Giants, students of Central School, Indore, November 23.

Science : Method and Vision Institution of Engineers (India), Pune, November 29).

Why Einstein? International Conference organized by the Indian Planetary Society to celebrate the Albery Einstein's theories Centenary Year, Mumbai, January 9.

Why Einstein? B.M. Birla Science Centre, Hyderabad, February 25.

S. V. Dhurandhar

The Story of Gravity, lecture at Darang College, Tejpur on October 11.

Gravity, on the occasion of the Science day programme at IUCAA, February 27.

Ranjan Gupta

Astronomical Observatories — New Telescopes in India and Abroad, Dept. of Physics, Jamia Millia Islamia University, New Delhi October 26.

Priya Hasan

Galaxies and AGN at a seminar on Women in Science, Birla Planetarium, Hyderabad, November 19.

Birth and Life of Stars Aurora College, Hyderabad, December 16.

Ajit Kembhavi

Stars, Summer Camp in Science at Chinmaya Vidyalaya, Hubli, April 21.

The Virtual Observatory, Panjim, Goa, Sept. 23.

Black Holes, M.B. Govt., P.G. College, Haldwani, Oct. 27.

Binary Stars- Astronomy and Physics, Nehru Planetarium, Allahabad, Febuary 22.

Careers in Astronomy & Astrophysics, Science Day, IUCAA, Pune, February 27.

Einstein's Gravity and Black Holes, Science Day, Agarkar Research Institute, Pune, February 28.

J. V. Narlikar

Cosmic illusions (a talk delivered at the Science Festival in Genoa, Italy), November 4

From black clouds to black holes (a talk delivered at the Science Festival in Genoa, Italy,) November 7.

The Culture of Science (C.D. Deshmukh Memorial Lecture delivered at the India International Centre, New Delhi,) January 14.

Vidnyanprasarachi Garaj (A need of science popularization)(in Marathi) (a lecture organized by the Vidnyanvahini, Pune,) January 16.

Modern cosmology from a historical perspective (a lecture delivered under the 'Bengal Science Lectures' Series' organized by the Government of West Bengal at the Rabindra Sadan Auditorium, Kolkata,) January 20.

Cosmic illusions (a lecture delivered on the occasion of the Foundation Day of the National Institute of Oceanography, Goa,) January 28.

Paragrahavarchi jeevshrusti (Extra-terrestrial life)(in Marathi) (a lecture delivered during the Amateur Astronomers' Meet 2005, Goa,) January 29.

Kya bramhand mein hum akale hein (Are we alone in the universe?) (in Hindi) (Second Baburao Pimpalapure Memorial Lecture, Sagar,) February 5.

Badalti duniya mein Hindustan (The role of India in a changing world)(in Hindi)(a lecture under Aaj Ka Bharat Lecture Series, Bhopal,) February 7.

Cosmic illusions (a lecture delivered under Saturday Lecture Demonstration Porgramme at IUCAA, Pune,) February 12.

Antaralatil drushtibrahm (Cosmic illusions)(in Marathi) (a lecture delivered under Saturday Lecture Demonstration Programme at IUCAA,) February 12.

The search for extraterrestrial life (a lecture delivered at the Cummins College of Engineering for Women, Pune,) March 11.

Scientific temper and its relevance in modern India (a lecture delivered at the Deccan College, Pune,) March 11.

Prithvi ke bahar jeevasrishti ki khoj ke prayas (Search for extraterrestrial life)(in Hindi) (a public lecture delivered at the Jawahar Planetarium, Allahabad,) March 19.

T. Padmanabhan

Dark Energy: the Cosmological Challenge of the Millennium, (Science Day Public Lecture, TIFR, Mumbai), February 28.

Nobel Prize in Physics, (National Chemical Laboratory, Pune), November 5.

Nobel Prize in Physics - 2004, (IUCAA Science Day), February 27.

Understanding our Universe, (Homi Babha Centre for Science Education (HBCSE),Mumbai), December 22.

Special Relativity and Gravity, (International Conference on Einstein's Theories, The Indian Planetary Society, Mumbai), January 8.

A. N. Ramaprakash

Technological Challenges in Astronomy : National Technology Day Lecture, May 11.

How far can we see, How faint can we see : SpaceUK Exhibition, Nehru Science Centre, Mumbai, August 17.

Tarun Souradeep

On a cosmic discovery trail?, sponsored by the British Council, Nehru Planetarium, Mumbai, Aug. 18.

Unraveling our Universe, IUCAA, Pune, August 6.

K. Subramanian

Travelling through time, IUCAA Science day, February 27.

b) Popular Articles

Dadhich N. (2004) Indian Science Experiment, (Economic and Political Weekly, May 22)

Amir Hajian, "Story of the Creation", Scientific Magazine of Embassy of Islamic Republic of Iran, New Delhi, April 2004.

Ajit Kembhavi

Electronic Subscriptions for Indian Universities. Informatics Newsletter, January 2005. Page 3.

Kembhavi, Ajit, Information and Computer technology for the Universities. EduComm Asia, Vol 10, No. 2, Page 2.

Kembhavi, Ajit, International year of Physics 2005. In Marathi. daily Sakal (Saptarang), Jan 9, page 5.

J. V. Narlikar

(2004) Creating successful scientific institutions, (Ideas that have Worked, 99) -

(2004) Science journalism in India and abroad, (Science Reporter, December)

- (2004) Salad days, (Souvenir, 43) (Article published on the occasion of the 70th Annual Meeting of the Indian Academy of Sciences, Bangalore at the Banaras Hindu University Varanasi.)

- (2005) Beautiful mind : A 100 years since Einstein launched himself, (Times of India, January 1)

- (2005) Time-keeping in special relativity, (Virat Surya, January, 49)

- (2005) Diaryspeak of how a Puneite became Senior Wrangler in imperial England, (The Indian Express, Pune Newsline, February 8)

- (2005) The culture of science, (India International Centre Quarterly, 156)

- (2004) Ujavya sondecha Ganapati (in Marathi)[Ganesha with right handed trunk], (Marathi Katha : Visave Shatak, 415)

- (2005) Vaidnyanik drustikon (in Marathi)[Scientific outlook], (Vidnyanvahini, 89)

c) Radio/TV Programmes

Naresh Dadhich

IUCAA Sanstha Ek Parichay (in Marathi) - An interview to All India Radio, Pune, in the programme entitled, "BAHURANGI MAHARASHTRA", June 5

J. V. Narlikar

Akashdarshan, Akashwani, Pune, January 16, February 13, March 13, 2005

Interview for Horizon, All India Radio, Kolkata, January 26.

d) Science Popularisation

J. V. Narlikar

(i) Participation in question-answer programmes on key channels on television.

(ii) Occassional talks and interviews on All India Radio and on TV, listed under (d)

(iii) Writing of popular articles in newspapers and magazines, listed under `Popular Articles'.

FACILITIES

(I) Computer Centre

The IUCAA Computer Centre continues to provide state-of-the-art computing facility to users from IUCAA as well as IUCAA associates and visitors from the universities and institutions in India and abroad.

Increased use of laptop computers and increase in worker mobility have fueled the demand for wireless networks. Till recently, the technology was slow, expensive and reserved for mobile situations or hostile environments where cabling was impractical or impossible. With the maturing of industry standards and the deployment of lightweight wireless networking hardware across a broad market section, wireless technology has come of age. In IUCAA, wireless internet connectivity is available in several locations including the Computer Centre, Library, Bhaskara III, Conference Hall and A3 Seminar Room. The access points from 3 COM are used to provide wireless connectivity. The coverage it offers is 100 meters and the protocol supported is 802.11g i.e., 54 Mpbs shared. This facility is being extensively used during international conferences.

The Cisco Long-Reach Ethernet solution meets the demands of high bandwidth applications, while leveraging the existing copper wiring infrastructures (telephone connections). Using this technology, internet connection has been provided to Muktangan Science Exploratorium, Takshashila VIP flatlets and IUCAA housing colony. The devices used are Cisco catalyst 2950 Long-Reach Ethernet switches, POTS splitter and CPE (Customer Premise equipment). This facility offers true ethernet connectivity over existing telephone lines. It also delivers fast, reliable connections without recurring costs.

Lately, internet users have been increasingly subjected to email abuses such as viruses, worms, spam and other unwanted email content that have penetrated Internet. As a preventive measure against such email abuses, ERNET, our Internet Service Provider (ISP), has provided an email gateway which uses "Symantec Mail Security for SMTP" at all its ERNET Centres. This software combines virus protection, spam prevention and content filtering for email messages to maintain email integrity and enhance email security. Apart from having the Mail Security software at the ISP level, "openprotect" software is being used to scan emails to check for spam and viruses at daakghar, the IUCAA email server. This is a linux based cost effective server side software, which offers protection against virus, spam and dangerous content.

The Computing facility continues to extend technical support to visitors, project students and associates of IUCAA.

(II) Library and Publications

During the period under review, the IUCAA library added 955 books and 450 bound volumes to its existing collection, thereby, taking the total collection to 20,037. The library subscribes to 129 journals.

The library is also planning to acquire a cdrom mirroring server, which would essentially include instructional aids, demonstrations of physics experiments, astronomy films, etc. on DVD and VCD format, which would increase the usage of the cdrom collection.

The IUCAA library has also benefited in terms of access to additional e-journals published by American Institute of Physics, Institute of Physics, Springer, etc. in Astronomy, Astrophysics and related areas. This has been provided by UGC Infonet Consortia programme for e-subscriptions, initiated by INFLIBNET, Ahmedabad, under the guidance of the Chairman, UGC.

The IUCAA library is an active member of the Forum for Resource Sharing in Astronomy (FORSA), which comprises of ten institutes in which, Astronomy and Astrophysics is a major research area. A meeting of the FORSA members was organized at the National Centre for Radio Astrophysics (NCRA) library, Pune during July 26-27, 2004. The members presented new initiatives taken up in their workplace and discussed the possibilities of forming consortia for journals published by American Institute of Physics/American Physical Society, Nature online, World Scientific, etc.

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

Over the last year the laboratory has been substantially involved with the installation of IUCAA telescope, the details of which are reported as a separate section below. Another main project which is currently underway in the laboratory is the development of Near-IR PICNIC Imager (NIPI).

It was reported last year that work was in progress for testing the attenuation achieved by the baffle arrangment for UVIT, a payload being built for the ASTROSAT mission. This work has progressed considerably now, with a prototype baffle being manufactured and tested in the laboratory. Tests for understanding the behaviour of photon-counting CMOS detectors for UVIT also are continuing.

Another development has been the completion of testing of the USB-based data acquisition system on Windows platform for the CMOS detector array controllers. Tests of the Linux version of this is soon to start. With this technology, data from the array controllers can be downloaded to a PC through a standard USB port, thereby, eliminating the need for solutions depending on frame grabbers, etc.

(IV) The IUCAA Telescope

Electrical integration of the IUCAA telescope started in July 2004, with the arrival of a team of engineers at site from Telescope Technologies Ltd, Liverpool, UK, the manufacturers of the telescope. Installation and testing of the electrical system was completed by September, which was followed by installation of the top-end assembly which carries the secondary mirror and the focussing mechanism. Safety interlock installation and a limited amount of software integration allowed the telescope to achieve movement under pendant control. The primary mirror was then installed in early December and engineering first light through an eyepiece and the autoguider CCD deployed at field centre was achieved by December 10, 2004 (see Figures 22 and 23).

Further system integration work started in early January 2005, after the Christmas, New Year break for TTL engineers. Alignment of the telescope optics, installation of axis encoders, fine tuning of the servo controls for pointing and tracking, integration of the enclosure control system (which was developed at IUCAA) with the telecope control system, etc. were carried out during this phase of the work. Although by mid-February 2005, considerable progress was achieved with system integration, further work was delayed by an unfortunate failure of the Cassegrain rotation system. This lead to an eight week delay in the installation work when the Cassegrain motors were returned to the UK, problem investigated and a solution found. Due to the onset of monsoon in early June, it is expected that the final commissioning of the telescope will occur only after the weather turns suitable for on-sky tests.

Meanwhile, the primary instrument for the telescope (IUCAA Faint Object Camera and Spectrograph - IFOSC) and the calibration unit was transferred from the laboratory to the observatory in March 2005. The instrument has been now mechanically and electrically integrated at the direct Cassegrain port of the telescope. Initial optical tests have been carried out and the full commissioning of the instrument will be undertaken once the telescope is operational.

Details of the development of a second instrument for the telescope which works at near-IR wavelengths have been discussed elsewhere in this report. A direct imaging CCD camera system is also being procured, which will be used on one of the Cassegrain side ports of the telescope. This liquid nitrogen cooled CCD camera will offer the capability for high spatial sampling observations in the UBVRI wavelength bands. Initial exploratory work also has started to identify a suitable second generation instrument for the telescope. A strong candidate instrument being considered is a near-IR imager cum spectrograph.

The need for having a mirror coating plant had been recognized early on in the project. After detailed literature survey and inputs from other observatories, a set of specifications had been arrived at, for a mirror coating plant for the telescope. Technical proposals received from suppliers are being studied at the time of writing this report. It is planned to have the mirror coating plant commissioned so as to be ready for use by mid 2006.

(V) Virtual Observatory

A virtual observatory (VO) makes possible the storage of vast quantities of astronomical data, which can be retrieved over the internet and used by astronomers, wherever they may be located in the world. Virtual observatories have become indispensable tools in a situation where vast quantities of data at different wavelengths are produced every night by major observatories on the Earth and in space. Data obtained at different wavelengths requires quite different techniques or analysis and expertise which takes a long while to develop. However, the modern astronomer needs to take a multi wavelength approach to the study of astronomical objects, and it is necessary to have computational tools and resources for meeting this requirement.

A network of virtual observatories, each with large data mirrors in one domain or 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 project is a collaboration between IUCAA and Persistent Systems Pvt. Ltd. (PSPL), which is a major software development company in Pune, with expertise in data mining and related areas. The project is funded by the Ministry of Communication and Information Technology (MCIT) and PSPL. The hardware platform for the project is located at IUCAA, while the software development is undertaken in close collaboration at PSPL and IUCAA. VO-I has developed

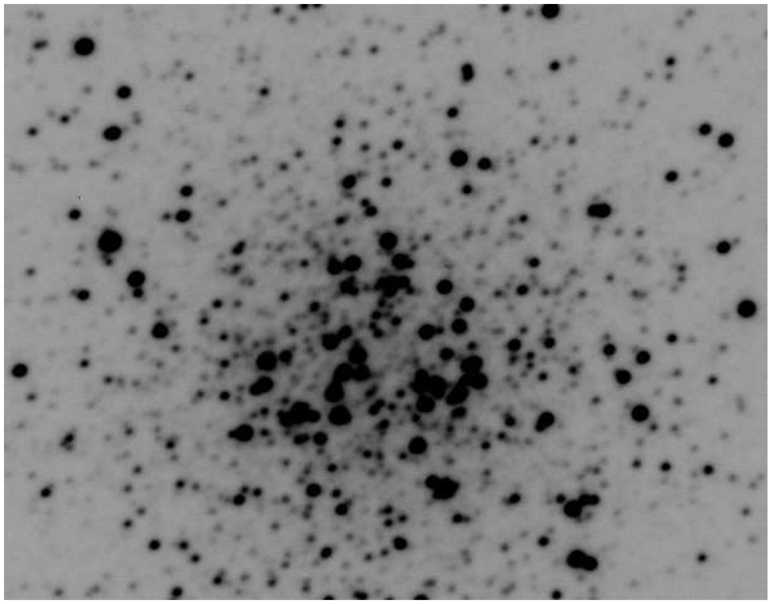

Figure 22: Globular cluster M53. Exposure time is 25s, Field is about 225" x 180", pixel scale is about 0.22" per pixel and the FWHM of stars is about 1.2"

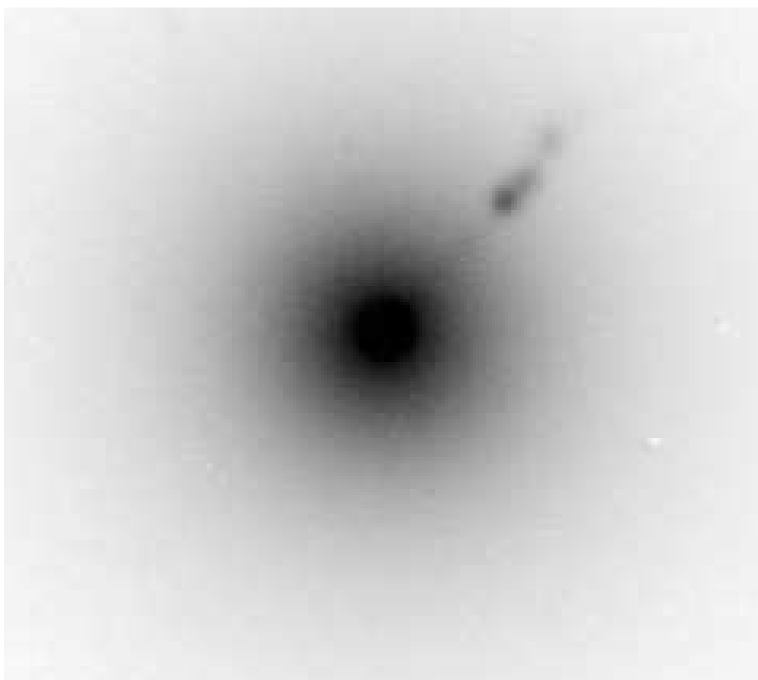

Figure 23: Giant Elliptical Galaxy M87(Virgo A) about 60 Mly away. 240s exposure of the central 220" x 180" field. Scale is about 0.22" per pixel. Individual knots in the 8000 light year long optical jet are clearly seen.

several tools, which have found wide acceptance in the international virtual observatory community, and have been used in making new and exciting scientific discoveries, including black holes in galaxies and rare kinds of stars.

The projects undertaken by 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

(Sky-Atlas). It has been integrated in many Astronomical Data Archives such as VizieR, Hubble Space Telescope Archive , OpenSkyQuery Portal. VOPlot lets astronomers do complex plotting, visualization and statistics completely online, without having to down load the data, and without having to issue any commands as VOPlot is completely event-driven. It is developed using Java Technologies. VOPlot was developed in collaboration with Centre de Donnes astronomiques de Strasbourg, France. Over the last several months, development of 3-D version of VOPlot has been completed, and much work has been done in integrating it with the statistical package VOStat.

2) Data Archival System : The Data Archival System is designed to archive the data that is generated from the Himalayan Chandra Telescope (HCT, Hanle). The telescope observations are output as FITS (Flexible Image Transport System) format, a standard for representing images and spectra. The FITS contain a number of headers, which give relevant information about the observation(s). These headers are parsed and then loaded into a queryable database. The database is accessible using a web-based front-end. Users can query the database for fields such as object name, observer, date, etc. The system takes into account different users, their privileges, database design, administrative functions for handling the data, etc. It is developed using JSP, MySQL Technologies. The system was developed in collaboration with Indian Institute of Astrophysics (IIA), Bangalore.

3) Streaming and Non-Streaming VOTable Parsers : VOTable is a standard adopted by the International Virtual Observatory Alliance (IVOA). It is a XML (eXtensible Markup Language) based system of representing astronomical catalogue data as XML offers various advantages in transporting data over the world wide web. The Streaming and Non-Streaming VOTable Parsers are C++ libraries, which parse the XML-based VOTable and carry out raw VOTable processing. This is of immense use to the IVOA community and people working on VOTable applications. Libraries are available for Windows 95/98/2000/XP and Linux operating systems. New versions of the parsers which are consistent with the latest version of VOTable have been developed.

4) Data Interface Tool (DIT) : The Data Interface Tool is designed to create a data retrieval and analysis package for Astronomical Catalogues. It creates an astronomer friendly interface for constructing a query with various constraints to retrieve the catalogue-data. The results can then be analyzed by using VOPlot, retrieving images and spectra from remote image servers using Aladin, SpecView (A spectrum viewer). It is developed using Java and MySQL technologies. A prototype is ready, and extensive development will be made in the next phase (VOI-TNG).

A very successful International Virtual Observatory Alliance (IVOA) Interoperability meeting was organized in IUCAA during September, 2004. The meeting was attended by about 50 participants from abroad and a similar number from India, and was very useful in setting up new projects and collaborations. The VO-I team includes Ajit Kembhavi, Sarah Ponrathnam and Jayant Gupchup at IUCAA, and T.M. Vijayaraman, Amey Navelkar, Sonali Kale, Jagruti Pandya, Nilesh Urunkar and Archis Kulkarni at PSPL. On the scientific side, T. Sivarani, a visitor at IUCAA has used virtual observatory tools to discover only the third L-type subdwarf dome in the galaxy using the Sloan survey. C.S. Stalin, who is a post-doctoral fellow on the VO-I project has been using the tools to find close pairs of Quasars from the Sloan survey on the 2DF survey.

(VI) The IUCAA Radio-Physics Training and Educational Facility

IUCAA is setting up a novel *'Radio-Physics Training and Educational Facility'* with technical collaboration of neighbouring National Center for Radio Astrophysics (NCRA). During 2004-05, significant progress was made by *J. Bagchi* and collaborators M.R. Sankararaman and M.N. Karthikeyan (NCRA), towards final design of the radio telescope, and test and calibration of instruments, meant for this radio astronomy based educational and training laboratory.
The main observational facility will be a 5-meter Radio Telescope 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 beginning 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. Work has started for setting up the first Parabolic dish antenna of 5 meter diameter.

This should allow observations of Sun, 6.6 GHz Methanol masers, and detection of strong extragalactic radio sources. This 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.

They have performed calibration of instruments in the GMRT laboratory and also done actual astronomical observations with a prototype 4-

meter parabolic dish antenna located at the GMRT observatory. The main aim was to test the performance of the radio astronomy instruments, demonstrate through sky observations that the required sensitivities can be achieved, and use this data as a benchmark for the performance expected from the planned 5-meter radio telescope. All these experiments were done with an active participation of science and engineering students from Pune and SRTM university, Nanded. A brief summary of the interesting new results obtained from these laboratory and astronomical observations are as follows:

• The hydrogen-line spectrometer frequency scale was calibrated using a precision Rubidium frequency standard synchronised with a GPS clock. The 10 MHz master signal derived from the Rubidium oscillator was given to the input of a frequency synthesiser for generating the exact rest frequency of hydrogen spin-flip transition - i.e. 1420.405752 MHz. A correction factor for zero-point shift was derived which was applied for accurate frequency/velocity calibration of our 21cm hydrogen line observations of cold galactic neutral hydrogen clouds.

• The hydrogen-line spectrometer temperature scale was calibrated using observations of several regions of galactic plane containing IAU recommended standard regions. Two standard calibrators (S8 in Orion and S7 in Perseus) led to excellent quality 21 cm spectral line observations as shown in the Figure 24. The quality of the 21cm spectral line observations were found to be extremely good. Both sources - one with a simple line profile (S8 region), and other having complex multiple lines (S7 region) - could be detected with $S/N > 35$ in 0.3 seconds intergration per channel. Comparison of the results with much larger, professional grade telescope observations showed excellent match in term of line-shape, velocity structure and spectral width.

• 21cm radio continuum observation of the Sun were also done. By fast scanning the antenna over the Sun, many solar traces were obtained. From these traces a value of 3.8^0 for the half-power Beam Width (FWHM) of 4-m radio dish was obtained, which is in accord with diffraction theory if one assumes some degree of illumination taper due to specific design of the feed-horn. They also obtained relative calibration of power level obtained from the Sun with a noise-cal diode source injected at the input of the radio receiver. The antenna temperature provided by the Sun on the observing day was ≈ 1366 K.

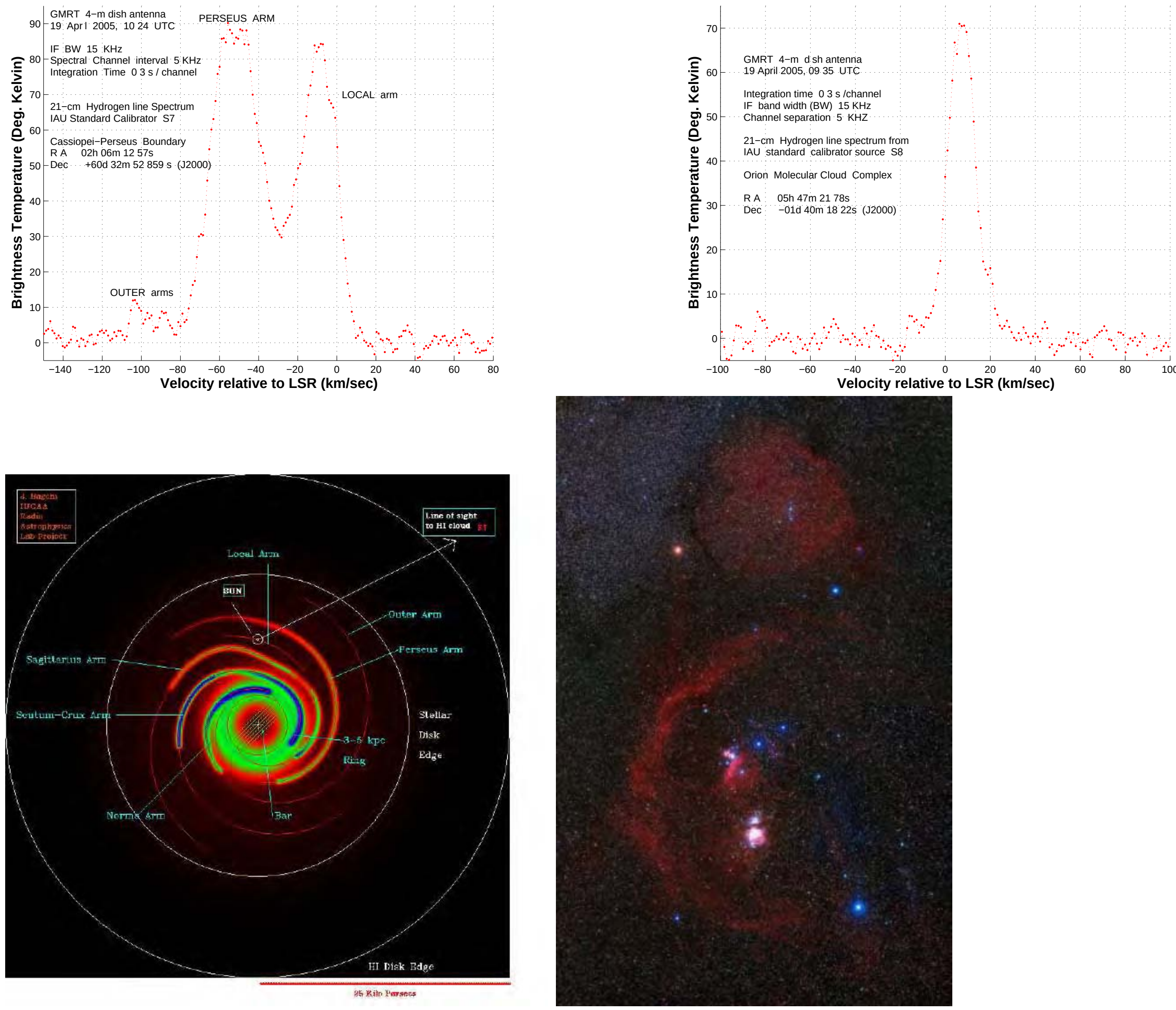

Figure 24: **Upper left**: 21cm hydrogen line spectrum showing several blue-shifted lines detected from the direction of IAU calibrator source S7 in Perseus. The brightest line with peak temperature $T_B = 90 \pm 5\ K$ and $V_{LSR} \approx -55$ km/sec (in blue-shift) is located in the Perseus arm, and the spectral lines near $V_{LSR} \approx$ -10 to 10 km/sec originate within local arm and other low velocity hydrogen clouds close to Sun. V_{LSR} is velocity relative to local standard of rest. Couple of lower column density, high velocity clouds in the region of $V_{LSR} \approx$ -80 to -120 km/sec originate in sparser outer galactic arms beyond the Perseus arm. **Lower left**: A schematic drawing of Milky Way depicting this geometry is shown. **Upper right**: A red-shifted hydrogen line with peak brightness temperature $T_B = 72 \pm 5\ K$ detected from the direction of IAU calibrator source S8 in Orion molecular cloud. **Lower right**: Optical picture of Orion Molecular cloud complex near the *Barnard's Loop* which contains hydrogen line standard calibrator source S8. Region S8 is located within the red circle which is approximately the FOV of the 4-m radio telescope used for observation. Data obtained at the GMRT observatory on 19 April 2005 by radio astronomy students with the IUCAA 21cm hydrogen line spectrometer and 4-m radio telescope.

IUCAA REFERENCE CENTRES (IRCs)

[1] Delhi University
(Coordinator: T.R. Seshadri)

IRC has become a centre where several students, faculty and visitors interact. The facilities are used by them to varying degrees for their publication. Due to the extensive renovation work of the buildings, there was a space constraint and hence, there was some restriction in the activities. This will be sorted out soon and full fledged activities will start.

[2] Pt. Ravishankar Shukla University, Raipur
(Coordinator: S. K. Pandey)

M Sc students use the IRC facilities for preparation/ presentation of weekly seminars organized by the department. Final year M.Sc. students, who offer A&A as their specialization used IRC facilities(internet and library) to carry out their project work. The number of students who opt for A&A as the specialization is almost 50% of the student strength in M.Sc.

Another 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. This has been quite successful.

Dynamical modeling of elliptical galaxies was carried out by D. K. Chakraborty and his research students. Chakraborty, though formally retired from the University service in July 2004, is still with the department as an honorary professor. Besides regular teaching, he is continuing his research work of elliptical galaxies. Two new students, namely, Arun Kumar Singh and Firdous have joined D.K. Chakraborty for their doctoral work.

Multi-wavelength surface photometry of early-type galaxies carried out by S. K. Pandey and his research students as a part of collaboration with A. K. Kembhavi and people from other institutes/observatories. The main objective of the research programme is to study properties of dust in extragalactic environment to see how different are they from those of the dust in our own galaxy, and also to examine relationship of dust with other forms of ISM in these galaxies. Laxmikant Chaware and very recently S. Kulkarni have joined S .K. Pandey for their doctoral work and intend to work in this area.

Photometric/spectroscopic study of chromospherically active stars, well known as well as suspected ones being carried out by S. K. Pandey and his research students, ,namely Sudhanshu Barway and Laxmikant Chaware, to examine the short-term as well as long-term light variation in these stars.

[3] North Bengal University, Siliguri
(Coordinator: S. Mukherjee)

National Science Day was celebrated jointly with the Department of Physics, North Bengal University, with a day-long programme on February 28, 2005. A group of about 120 students, which includes post-graduate as well as under-graduate students from different colleges and about 20 college/university teachers participated in the programme. There were three popular talks by experts from SINP, Kolkata and U.K., science quiz and (sit-in) essay competitions. The programmes were well-received by the students.

A two day seminar for college teachers and students of neighbouring colleges was held at Sikkim Manipal Institute of Technology, at Majitar, Sikkim, with academic support from IRC in March 2005.

A seminar to celebrate the centenary of Einstein's papers was held at Raiganj University College, Raiganj, on March 19, 2005, in collaboration with SINP, Kolkata. Programmes included popular talks, demonstration lectures and science quiz competition. About one hundred students and twenty teachers participated in these programmes.

[4] Cochin University of Science and Technology, Kochi
(Coordinator: V.C. Kuriakose)

The national Seminar on Gravity and Light was mainly intended for post-graduate students, and a large number of students from neighbouring colleges participated in the programme. Post graduate students also participate in the IRC colloquia. Series of lectures on Quantum Field Theory in Curved Spacetime and Nonlinear Dynamics have been arranged for the benefit of research scholars and postgraduate students.

[5] Jadavpur University, Kolkata
(Joint Coordinators: Narayan Banerjee and Asit Banerjee)

Asit Banerjee delivered a talk in the Mathematics Department, Jadavpur University on March 3.
Narayan Banerjee participated in the programme for high school students in Baharampur, Murshidabad on 18.2.05 (in connection with the Year of Scientific Awareness, 2004).

[6] D.D.U. Gorakhpur University
(Coordinator: D.C. Srivastava)

Viewing of Saturn at its closest approach on January 13, 2005 and few days thereafter through 3" refractor telescope was arranged as part of public outreach programme. The faculty members, research scholars, M.Sc. students and general public participated in this activity.

Visitors at the various IUCAA Reference Centres

The following members visited the various centres for various purposes like giving lectures, discussions, collaborations, use of library and computer facilities and their stay extended for varying durations.

Delhi University

Diptiman Sen (IISc., Bangalore), Rohini Godbole (IISc., Bangalore), Sushan Konar (IIT, Kharagpur), Naresh Dadhich (IUCAA, Pune), Sanjay Pandey (L.B.S. P.G. College, Gonda), Rita Sinha (IUCAA, Pune), Aalok Pandya (Jaipur), Ranjan Gupta, (IUCAA, Pune), G. Rajasekharan, (IMSc., Pune), Abhijit Saha (NOAO, USA, T. Padmanabhan (IUCAA, Pune) and Archan Mazumdar (S N Bose Centre).

Pt. Ravishankar Shukla University, Raipur

M. K. Patil (S.R.T.M. Univ.), Saibal Ray (Barasat Govt. College) and Rabin Chhetri (Sikkim Govt. College).

North Bengal University, Siliguri

B. Bhattacharrjee (Gauhati University) , R. Chhetri (Sikkim Govt. College, Gangtok), Vivek Chhetri (Sikkim Govt. college, Gangtok), Renuka Dutta (Bethun College, Kolkata), J. P. Thakur (Sikkim Manipal Inst. of Technology, Majitar, Sikkim), J. Mandal (Mathabhanga College, Coochbehar), K. Bhattarjee (P. D. Women's College, Jalpaiguri), P. Sarkar (Alipurduar College, Jalpaiguri), D. K. Sarkar (Dinhata College, Coochbehar) (, S. D. Maharaj (Univ. of Kwazulu, Natal, South Africa), S. K. Ghosh (A. C. College Jalpaiguri), R. Sharma (St. Joseph's College, Darjeeling), A. Bhaduri (Kurseong College, Darjeeling), C. Basu (Raiganj Univ. College, Uttar Dinajpur) , S. Prasad (Bangabasi College, Kolkata), G. Singh (Canisius College, Buffalo, N.Y., USA) and R. Tikekar (Sardar Patel Univ., Gujarat).

Cochin University of Science and Technology, Kochi

Ninan Sajeeth Philip (St. Thomas College, Kozhencherry), T.M. Krishnan Marar (ISRO Satellite Centre, Bangalore), G.C. Anupama (Indian Institute of Astrophysics, Bangalore), N. Dadhich (IUCAA, Pune) and T.R.Govindarajan (IMSc, Chennai).

Jadavpur University, Kolkata

Sayan Kar (IIT, Kharagpur), Somnath Bharadwaj (IIT, Kharagpur), Ajit Kembhavi (IUCAA, Pune) and Ramesh Tikekar (Sardar Patel Univ.).

Seminars/Talks/Colloquia delivered at the various IUCAA Reference Centres

Delhi University:

Rohini Godbole: *Physics as the Next Linear Collider*, July 21
Rita Sinha : *Cosmological Parameter Estimation for CMBR*, July 23
Diptiman Sen: *Conductance of Quantum Wires*, July 28
Sushan Konar: *Magnetic Fields of Pulsars - New Horizons*, August 9
Naresh Dadhich: *Probing Universality*, August 25
M. Yuasa: *Supplementation of Adjusted Values to Imperfect Data Based on Principal Component Analysis*, October 20
G. Rajasekharan: *Recent Discoveries in Neutrino Physics*, November 16
Abhijit Saha: *The Large Synoptic Survey Telescope*, November 30
T. Padmanabhan: *Dark Energy - Current Status*, December

Pt. Ravishankar Shukla University, Raipur

H. M. Antia: *Solar Physics* (three lectures), Jan 20-21.
S.K. Pandey – Radio talk/interview on *Solar Oscillations and Internal structure of the Sun* (in Hindi), December 3.

North Bengal University, Siliguri

A. Beesham: *Biography of Einstein: the Annas mirabilis 1905*, January 3
S. D. Maharaj : *Relativistic Anisotropic Solutions*, January 4
P. N. Ghosh : *New Resonance in Rb Hyperfine Spectra*, January 4
P. Majumdar: *Fluctuations, Brownian motion and Black Hole Entropy*, January 4;
S. Raha: Brownian Motion a Hundred Years Later: Applications in Quark-Gluon Plasma, January 4;
Ranabir Dutta : The Nano Kelvin Physics of Bose-Einstein Condensation, January 5;
A. Ghosh: Black hole in Quantum Geometry, January 3;
P. S. Majumdar: *Black hole Entropy from LQG*, January 4 S. Chakraborty: *Dense stellar Plasma in Strong Magnetic Field*, January 5
B. Butta: *History of the Development of Einstein's General Theory of Relativity (1907-1916)*, January 5
Renuka Dutta: *The Remarkable Correspondence Between Einstein and Levi-Civita in Connection with Development of Gravitational Theory*, January 5
A. Abbas: Theory of Relativity and Current Ideas on the Origin of the Universe, January 3
U. Abbas: *From Brownian Motion to the Random Walk Model and the Large Scale Structure of the Universe*, January 5
N. Banerjee: *Present Acceleration of the Universe*, January 5
S. Mukherjee: *Maximum Mass of Compact Stars*, January 4
S. K. Ghosal: *Paradoxical Twins in Classical and Relativistic Worlds*, January 5
K. K. Nandi: *Volume Integral Theorem for Exotic Matter*, January 4
G. Singh: *Liquid-Gas Phase Transition Through Projectile Fragmentation at Relativistic Energy*, February 10
R. Tikekar: *Cosmology*, March 23 and 25.

Cochin University of Science and Technology, Kochi

Saumia P.S.: *Quasinormal Modes of Blackholes*, July 29
T.M. Krishnan Marar: *Gamma-ray Bursts –The big Explosion from the Early Universe*, August 17
M. Sabir: *Theory of Strong Interaction*, October 28
G.C. Anupama: *Observational Astronomy Facility in India*, January 8
K.P. Ravindranathan Kartha: *Sugars, Are They Only Just Sweet?*, February 2
Ushamani: *Polymers in Holography*, February 8.

Jadavpur University, Kolkata

A. K. Raychaudhuri: *Rotating Universe without singularity and without time like lines*, April 13
Sayan Kar: *Warped bulk-brane dynamics*, Sept. 13-14
Somnath Bharadwaj: *Large scale structure formation in the universe*, September 13-15
Ajit Kembhavi: *Supermassive black hole in the center of the galaxy*, December 22
Ramesh Tikekar: *Geometry and dense stars*, March 22.

D.D.U. Gorakhpur University

N. K. Dadhich: *Universalization as a Physical Guiding Principle*, April 19
Ajoy Ghatak: *Understanding Basic Quantum Mechanics on a PC*, January 29.

The Sixteenth IUCAA Foundation Day Lecture

A Love of Flow

RODDAM NARASIMHA
Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore

Abstract

You look up at the sky, and see a lovely cloud; you look down, and may see lovely ripples on a rivulet (or river). On a hot summer afternoon you see dancing dust devils; on a cold winter evening you can see smoke rising lazily from a chulah, and hang up there as if it has given up. You peer at a telescope, and see intense supersonic jets, or vast whirling galaxies; you measure in a wind tunnel, and sense powerful tornadoes behind an aircraft wing. The universe is full of fluid that flows in crazy, beautiful or fearsome ways. In our machines and in the lab, as in terrestrial nature, one sees this amazing diversity in the flow of such a simple liquid like water or a simple gas like air. What is it that makes fluid flows so rich, so complex - some times so highly ordered that their patterns can adorn a saree border, sometimes so chaotic as to defy analysis? Do the same laws govern all that extraordinary variety? We begin with a picture gallery of a number of visible or visualized flows, and consider which ones we understand and which ones we do not, which ones we can compute and which ones we cannot; and it will be argued that behind those all-too-common but lovely flows lie deep problems in physics and mathematics that still remain mysteries.

Almost anywhere we look we see a fluid flow: air, water, smoke, steam, oil or something. And the diversity of the flows we see, even with our unaided eyes, is astonishing. You look up at the sky, and may see striking clouds - white, pretty and fluffy against a perfectly blue sky, or black and threatening against a gray one. You look down at the ground, and may see a wonderful medley of ripples, whirlpools, jumps or bores on a tiny rivulet of water - or on a mighty river. On a hot summer afternoon you can see dust devils - suddenly twisting themselves into shape picking up all kinds of loose dirt, and darting wildly around for some seconds before they flop out. On a cool winter evening you can see warm smoke rising lazily from a *chulah* out in the open, and hang up there a few metres above ground with no energy left to push into the cooler, heavier air above. You can go to Jog and keep gazing at the four waterfalls there -majestic, awesome, graceful and so different from each other although they are all making the same leap.

With the power of modern instrumentation the range of what we can see goes up enormously. If you peer at a telescope, or the pictures it takes, we can see swirling nebulae whose sizes are measured in light years. If you have a microscope you can see minute organisms (like spermatozoa, for example) darting

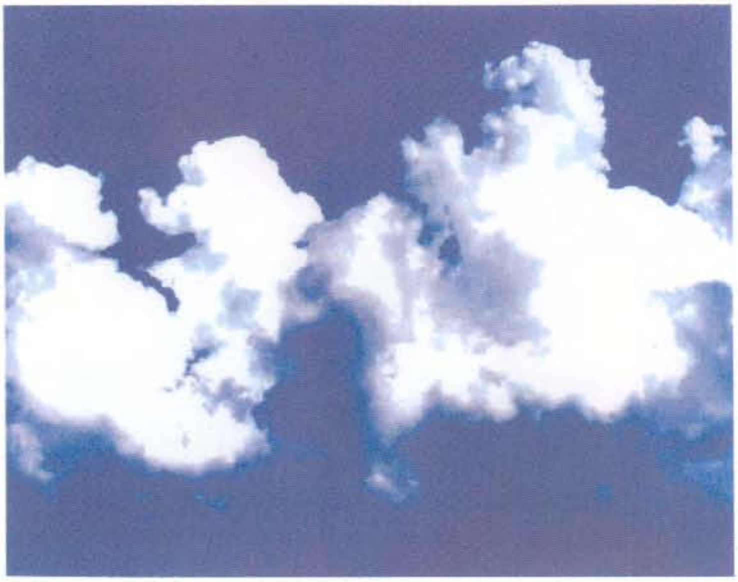

Figure 1a: Wind and Wave at Awa-Naruto by Hiroshige Utagawa (1797-1858). From Ogawa (1980?)

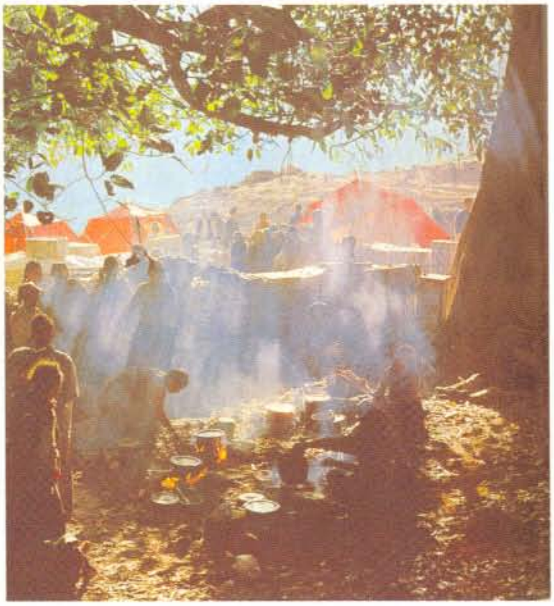

Figure 1b: Smoke rising lazily from the chulhas as trekking group prepares breakfast early in the morning

Figure 1d: Jupiter's famous red spot (12 000 km across). Note the instabilities and structures with a wide range of scales. From Voyager 1

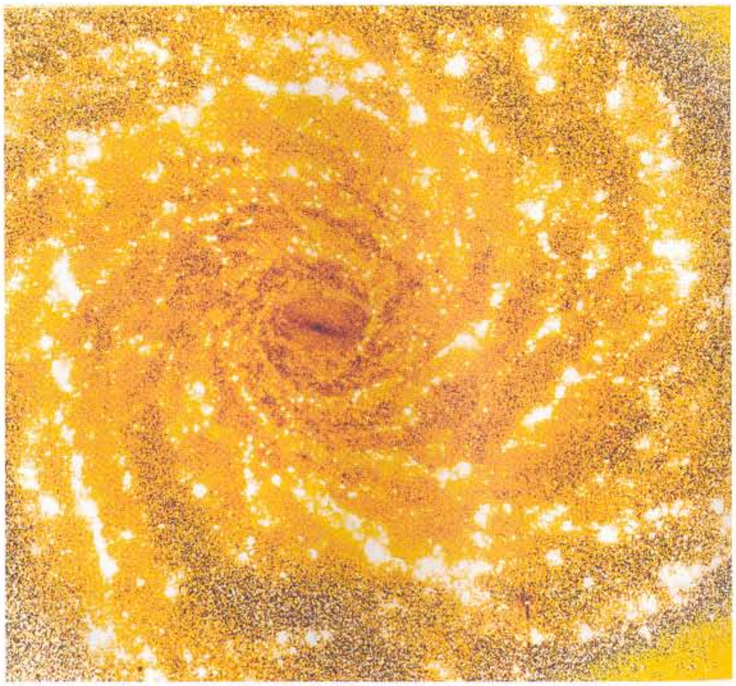

Figure 1e: Spiral galaxy in Eridanus, 108 light years from Earth, 2 105 light years in diameter

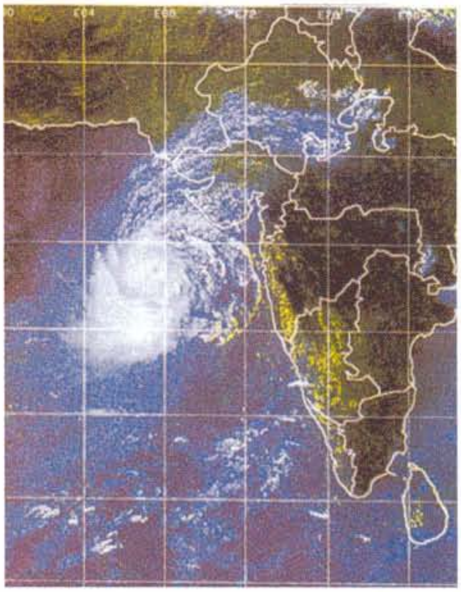

Figure 1g: A cyclone off the coast of Gujarat, captured by INSAT (8 June 1998).

here and there in the surrounding medium. If you can inject smoke and shine laser beams you can see powerful vortices that would otherwise be invisible in air, such as those that trail behind aircraft. From satellites, we can see cyclones that can wreak havoc. And there can be terrible tsunamis of the kind we experienced in south and south-east Asia just a few days ago (December 26). I have put together a collection of some flow pictures of this kind in Figure 1 - I hope you will agree that they can be crazy, beautiful and fearsome in turn. (A wonderful album compiled by Van Dyke has many others.)

One can go on endlessly like this. This diversity of fluid motion has fascinated man for thousands of years. The *Yōga-Vāsiṣṭha* (written perhaps around +6 or 7 c.) uses fluid flow metaphors extensively, and compares the complexity of the human mind with that of flowing water:

As water displays itself richly	dhārā-kaṇ -ōrmi-phēna-śrīr.
In current, wave, foam and spray,	yathạ samlakṣyatē.'mbhasah, |
So does the mind exhibit	tathā vicitra-vibhavā
A strange, splendid diversity.	nānāt". ēyam hi cētasah . ||

(3:110.48)

Elsewhere, the author sings of the beauty of a whirlpool in swaying water (*ālōla-salil'-āvarta-sundarī*). And, as if in illustration of *Vāsiṣṭha* poetry, the Japanese painter Hiroshige Utagawa (1797-1858) catches its essential spirit in a lovely print of *Wind and Wave* (Figure 2). In renaissance Europe, Leonardo da Vinci (1452-1519), who combined within himself the hands and eyes of an engineer as well as an artist, drew wonderfully faithful pictures of vortices in turbulent water flow.

Do we *understand* these diverse flows? How many of them can be described by a convincing theory? How many can be computed? After all (as you physicists will often ask), isn't the flow of fluids a 'classical' subject, whose governing laws

Figure 2: Wind and Wave at Awa-Naruto by Hiroshige Utagawa (1797-1858). From Ogawa (1980?).

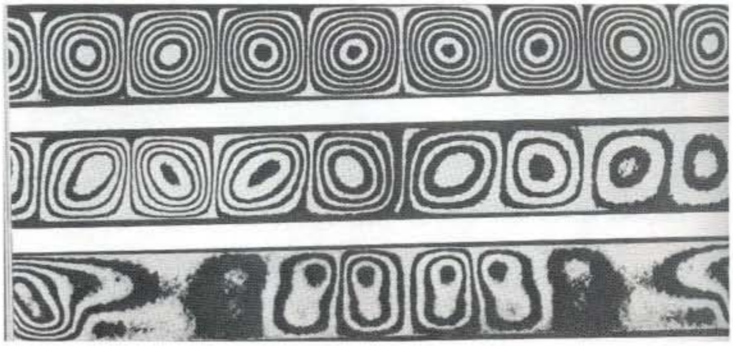

Figure 3: Rayleigh-Benard flow between two plates of which the lower one is heated. Top panel shows steady pattern of rolls just past onset of instability at a critical value of the Rayleigh number. Lower panels show flow at successively higher values of Rayleigh number, flow being quite chaotic in bottom panel (Oertel & Kirchartz 1979, Oertel 1982)

were set down in the first half of the 19th century? It may be interesting to put together an album of pretty flow pictures (you will continue), but are there new things to discover? (Answer: yes.) Why do people (like me) spend a life-time investigating fluid flow problems, pursuing the rather esoteric discipline of 'fluid dynamics'?

It is my intention in this lecture to try and answer these questions. But before offering answers, we need to look at those flows and grasp their nature a little better.

One of the most striking features of many fluid flows that has fascinated all observers - ancient and modern - is the strange mix of order and chaos that is their characteristic. At one extreme, a flow can be incredibly well-ordered. For example, consider the case of what is called Rayleigh-Benard convection between two large horizontal plates, the lower one of which is warmer than the upper. If the temperature difference between the plates is sufficiently small there is no flow at all, and heat is transported from the lower to the upper plate through thermal conduction in the enclosed fluid - which might just as well have been a solid, it would have made no difference. But as the temperature difference exceeds a critical value, the fluid suddenly overturns into motion, in a row of highly organized rolls (Figure 3), or, if the upper surface is free, into a pattern of hexagonal cells as seen from the top. Those rolls can be so steady in time and so repeatable in space that they could well decorate a saree border. As the temperature difference increases, the rolls get distorted and begin to sway and list, and eventually break down into chaotic motion, as we see in the bottom panels of Figure 3. (But, as we shall see shortly, that apparently chaotic motion may well contain hidden order.)

Saree-border type organization may also be seen in a variety of other situations - most famously in the flow in the wake of a circular cylinder. (By the principle of Galilean invariance, the relative flow is the same whether the cylinder moves in still fluid or the fluid flows past a cylinder at rest; so we shall use either frame interchangeably.) In this case, as a critical velocity is exceeded the flow

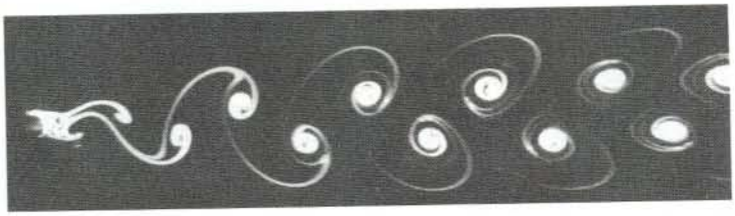

Figure 4: Another 'saree border' pattern, this time Karman vortices shed by a circular cylinder at a Reynolds number of 105. Visualization by electrolytic precipitation in water (Taneda 1988)

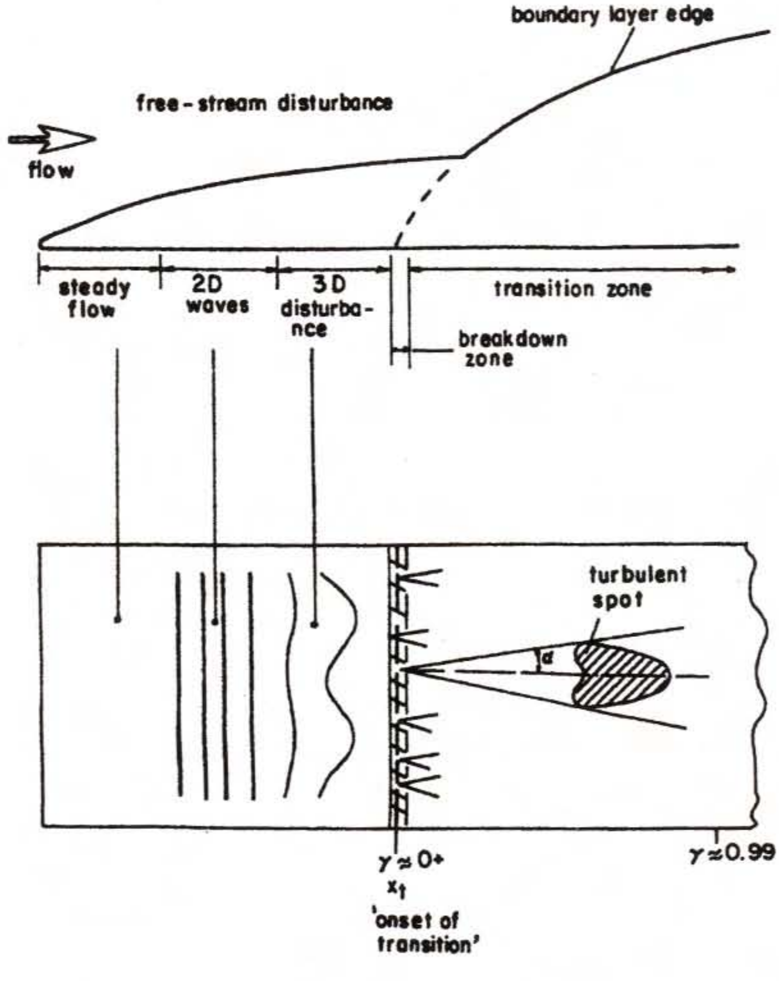

Figure 5: Transition to turbulence in boundary layer flow past a flat plate. Beyond onset of transition the boundary layer becomes much thicker. Before onset of transition flow goes through a sequence of a stable regime, two-dimensional instability and three-dimensional disturbances, ending in a short nonlinear breakdown zone. Turbulent spots are formed at breakdown, and propagate and grow through an intermittent zone till the flow is covered by spots and is turbulent full time (Dey & Narasimha 1989).

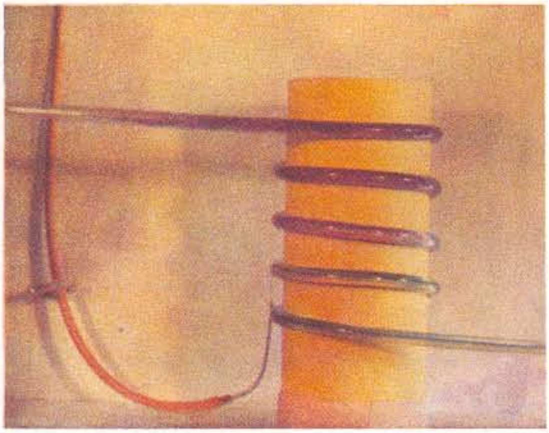

Figure 6: Reverse transition. Flow goes from turbulent to laminar in the coiled tube: it is turbulent as it enters at the top (red dye diffuses across tube). Green dye injected at fourth coil does not diffuse, showing flow is laminar

in the wake spontaneously breaks into two parallel rows of staggered vortices - clockwise in one row, anti-clockwise in the other (Figure 4), forming what is called a Karman vortex street. (We often 'hear' those vortices when power lines sing in wind; the Greeks even had an 'aeolian' harp, whose strings were resonantly 'plucked' by natural wind.) As the velocity is increased further, the Karman vortex street breaks down into apparent chaos, but again, it turns out, with hidden order in it.

In these and other cases, the appearance of order actually marks the onset of an instability. And the critical condition that sparks this onset is given not so much by a temperature difference or flow velocity, which may be specific to a particular apparatus and fluid, as (much more generally) by an appropriate non-dimensional number, - the Rayleigh number in convection, the Reynolds number in flow past bodies.

I myself have long been interested in flow past surfaces, such as an aircraft wing. What happens here in a simple and rather idealized situation is illustrated in Figure 5. At a critical distance from the leading edge (more precisely a Reynolds number based on that distance) instability waves can appear in the flow, and grow downstream; eventually they break down into islands of chaos called turbulent spots, which themselves grow and propagate downstream till the flow becomes 'fully turbulent'.

What I have described above is the phenomenon of flow transition - from laminar flow (no disorder) to turbulent flow (apparently complete disorder). Such a transition occurs in virtually every known flow type, often through one or more intermediate stages of instability of one kind or another. In some flows transition is abrupt or 'hard', in others it can be gradual and slow ('soft'). It can even be both: spots can appear suddenly, but full-time turbulence emerges slowly as spots need time to grow before they cover the surface. If the non-dimensional parameter governing the flow, like a local flow Reynolds number, varies in space (as in Figure 5) or in time (as it does in the upper reaches of our lungs especially if we are breathing hard, say after jogging), the transitional sequence from laminar to turbulent flow may occur in space or in time (or in both).

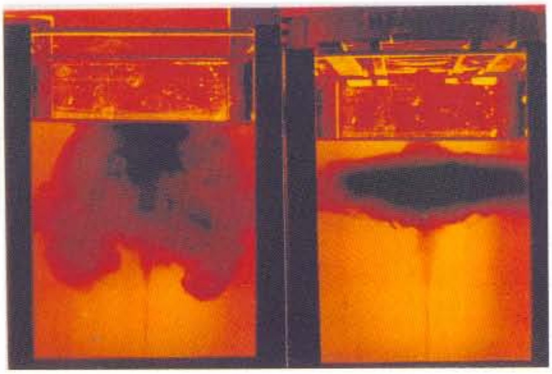

Figure 7: Stable density gradient can kill turbulence. (Left) Jet of dyed fluid discharging into a water tank. Point of transition is located where jet suddenly spreads at larger angle. If the experiment were to continue the whole tank would be red in a short while. (Right) Water at the top of the tank is rendered warm by switching on the heater above the tank. Now turbulence in the jet is killed and the jet fluid spreads out in a cloud. You can notice both transition to turbulence and relaminarization in this flow (P R Viswanath et al. 1978)

Under certain conditions (e.g., if the local Reynolds number *decreases* downstream) a turbulent flow can revert to a laminar state (as indeed happens in our lungs). This *reverse* transition from disorder to order does not violate the second law of thermodynamics, because the flows we are discussing are open systems. Some instances of such relaminarization are illustrated in Figure 6. You can sometimes see it in the evening sky, when a cloud, bubbling up from the ground, seems all of a sudden to lose its rough edges and bulges out into a smooth bump. This happens when the cloud hits what is called an 'inversion', a situation where the temperature locally *increases* with height, rather than decreasing as it most commonly does - and converts its turbulent energy to gravitational. This is similar to the *chulah* smoke mentioned earlier, and one of the pictures in Figure 6 is a laboratory simulation of this effect.

We recently discovered, to our astonishment, that as many as six such transitions - back and forth between laminar and turbulent flow - can occur in a narrow strip around the leading edge of the kind of swept wing that is typical of modern civilian passenger aircraft (such as Boeing and Airbus make). Figure 7 shows how wildly the output from hot-film sensors stuck on the surface of such a wing can vary from one sensor to the next, under conditions typical of take-off or landing.

I have talked loosely of transition from order to disorder or the other way round, but this is slightly misleading because (as I have been hinting) that fully turbulent flow is often *not* completely disordered. Instantaneous pictures of simple turbulent mixing layers, i.e., the flow at the interface between two streams moving at different velocities - showed dramatic evidence of unsuspected spatial organization into large-scale vortices (Figure 8), of which there had been hardly any hint in the numerous local measurements that had earlier been made in the same flows. These Brown-Roshko vortices (so called after their discoverers) are no longer strictly periodic, nor are they identical to each other. (So they are okay for modernist saree borders.) The turbulence reveals itself in the jitter and variability that characterize these vortices, and in the disordered motion

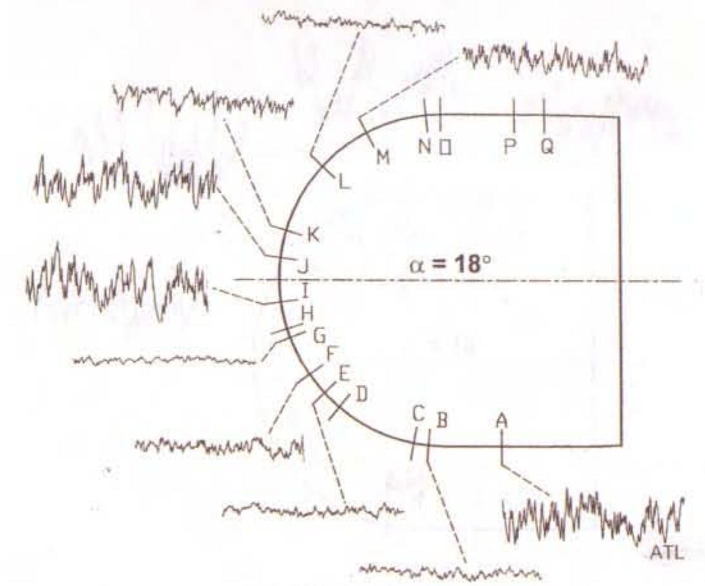

Figure 8: Typical leading edge of a swept wing of the kind common in large transport aircraft. Traces shown are from hot film gauges stuck on the surface of a wing at an angle of attack characteristic of landing or take-off. In this wind tunnel model wind is blowing from left, and a streamline attaches to the wing surface at station C. To the right of C fluctuation levels go up rapidly indicating transition to turbulence. Going clockwise from C signals increase at F showing an inclination towards turbulence, drop at G indicating relaminarization, grow explosively into turbulence once again at I and J, are quenched at L and grow again beyond it. We can therefore see six transitions (Narasimha 2004)

Figure 9: Flow in a turbulent mixing layer created by a faster stream of fluid at the top going over a slower stream at the bottom. The large scale coherent structures seen here are vortices (Brown & Roshko 1974; Narasimha & Kailas 1999).

at smaller scales, but even what is called fully turbulent flow often contains coherent structures of organized motion within itself.

Let us look at a less obvious example. Figure 9 shows the cross-section of a jet illuminated by a sheet of laser light. (We can think of it as a slice of flow issuing towards this sheet of paper from a circular orifice well below.) The fluid coming out of the orifice is dyed, so the picture shows how this jet fluid is mingling and mixing with the ambient fluid drawn into the jet. The raw image on the left - with false colouring indicating dye concentration - is what we normally associate with fully turbulent flow. (Notice by the way all those thin structures in the picture.) The image on the right is a wavelet transform - a spatial filter that eliminates both smoother and sharper variations than a specified scale. At the scale chosen, we found that a lobed ring-like structure pops out, presumably representing a wobbly, azimuthally unstable vortex ring. At much smaller scales the wavelet transform looks random.

We have no theories that can handle these mixed order-disorder phenomena well. But we do believe that the basic laws governing fluid motion are known. They are consequences of Newton's laws of motion and his concept of viscosity. The laws are best written down in the formalism of a continuous field, along the lines that Leonhard Euler introduced in 1755 - nearly 250 years ago. For an incompressible viscous fluid of density ρ and viscosity μ, the flow is governed by the equations of conservation of mass and momentum,

$$\text{div} \ \ \mathbf{u} = 0 \qquad (1)$$

and

$$\rho \frac{d\mathbf{u}}{dt} \equiv \rho \left(\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u}.grad) \, \mathbf{u} \right) = -\text{grad} \ \ p + \mu \, \nabla^2 \, \mathbf{u} + \mathbf{F} \qquad (2)$$

where $\mathbf{u} = \mathbf{u}(\mathbf{x}, t)$ is the (vector) velocity field, dependent on the position vector $\mathbf{x}$ and time $t, p = p(\mathbf{x}, t)$ is the pressure field, and $\mathbf{F} = \mathbf{F}(\mathbf{x}, t)$ is a body force (per unit volume of fluid).

Note the presence in the equations of the quadratically nonlinear term $\mathbf{u}.\text{grad}\mathbf{u}$. This nonlinear term is the crux of the problems of fluid dynamics; if it had not been there the subject would legitimately have become 'classical' by now. It is only in the 20th century that fluid dynamicists began slowly learning how to handle the non-linearity, but the learning process is far from over. The first shot here was fired by Ludwig Prandtl exactly a hundred years ago, so I should say a few words about it in this centenary year. In 1904 this remarkable engineer read a paper at the 3rd International Congress of Mathematics held at Heidelberg, and showed how, in the limit of large Reynolds numbers, the equations could be made manageable without sacrificing nonlinearity. His approach can be summarized in the recipe, 'Divide, conquer and unify'. The first big step was to realize that the flow could be divided into different *regions*: let us call them, in the simplest cases, inner and outer (assuming there are only two such regions). The corresponding inner and outer *equations*, each the limiting form of the governing equation in its respective region, are separately conquered, i.e., solved, yielding inner and outer *solutions*. By cleverly specifying their boundary conditions, these separate solutions are then 'unified' into a composite solution, which was later shown to be asymptotic to the exact solution *everywhere* in the large Reynolds limit.

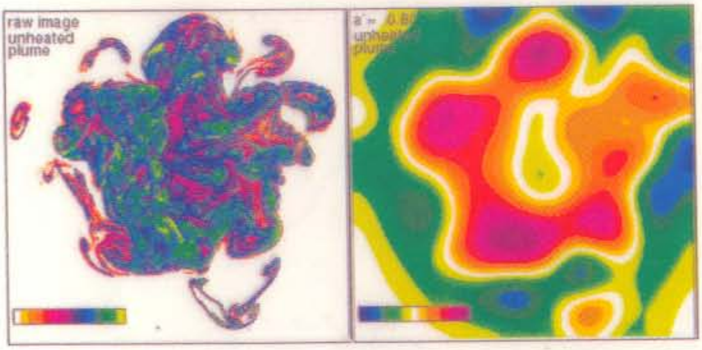

Figure 10: Wavelets can reveal order in apparent chaos. (Left) Cross-section of a jet which can be thought of as issuing from an orifice somewhere well below the page. Colour contours indicate dye concentration in a false coloured image. (Right) Two-dimensional wavelet transform reveals a wobbly ring hidden in the image at the left - presumably part of a large scale coherent structure in the jet (Narasimha et al. 2002)

Prandtl posed the problem for the flow past an aligned flat plate, which was trivial in 19th century Eulerian (*inviscid*) hydrodynamics ($\mu = 0$), but was fundamental to the new fluid dynamics he was creating. By an ingenious mixture of extensive visual observation (in a \$ 40 water channel), mathematical approximation and numerical calculation, he produced an answer for the drag or resistance of the plate that in principle solved the classical d'Alembert paradox (of no resistance in a non-viscous fluid). In the process of solving this special problem, however, Prandtl did many other things. He showed how, at high Re, fluid flows tend to fold or squash into layers; he invented what later became the more formal method of matched asymptotic expansions for handling singular perturbation problems; by example he brought to an end the war between ancient hydraulics and 19th century hydrodynamics, which till then had scorned each other (hydraulics was dismissed as a science of variable constants, hydrodynamics as the mathematics of dry water); and, in the process, he founded modern fluid dynamics, giving it the tools by which many of the earlier 'paradoxes' that had plagued the subject could be resolved one by one.

Thanks to that modern fluid dynamics we now know a lot about many fluid flows - enough to build aircraft traveling at Mach 3 or carrying nearly a thousand passengers (the A380 can take upto 873 people including crew), to make rockets that can shoot us to the moon and bring us back, to predict weather a few days in advance, to manage flows so as to enhance or diminish heat transfer between a solid surface and a fluid or to promote or suppress mixing between two fluids. But we still do not *understand* the central problem of turbulent flows, which remains fundamentally unsolved. As the word appears repeatedly in this talk, I should explain what I mean by *understanding* a phenomenon. In the first place, it implies that there is a quantitative explanation that is derived from accepted first principles - e.g., the Navier-Stokes equations - if necessary by exploiting reasonable approximations using well-tested methods, but not appealing to additional experimental data. Related to this is a second kind of explanation, consistent with the first but possibly qualitative, where the phenomenon in question may be shown to emerge from others which are already understood. If the physics underlying the phenomenon is utterly new, it is nat-

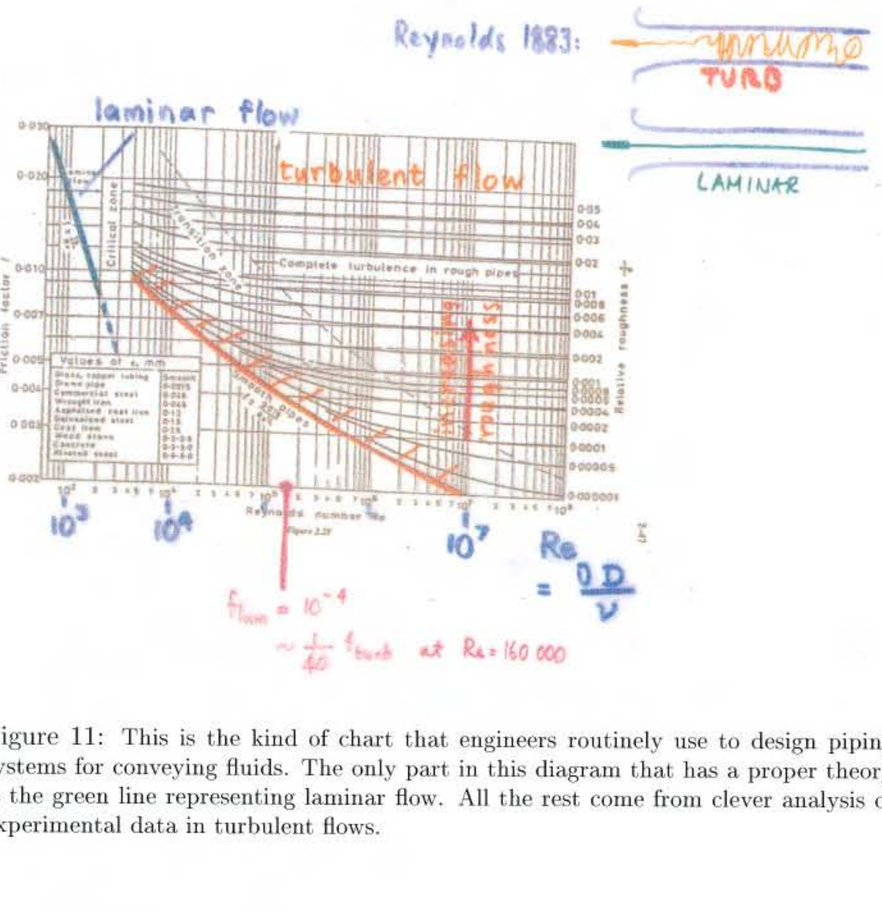

Figure 11: This is the kind of chart that engineers routinely use to design piping systems for conveying fluids. The only part in this diagram that has a proper theory is the green line representing laminar flow. All the rest come from clever analysis of experimental data in turbulent flows.

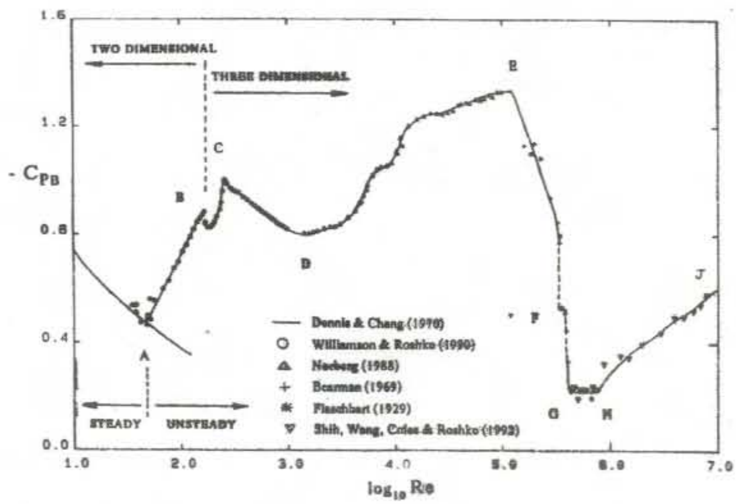

Figure 12: Variations of a base pressure coefficient on a circular cylinder with increasing Reynolds number. Ordinate is a non-dimensional version of the pressure at the back of the cylinder. Some flow regimes are also marked on the diagram. Variety of kinks in diagram appear to be genuine. Diagram suggests that the transition regime in the flow past a circular cylinder can be very prolonged (Roshko)

ural that understanding in the above sense will emerge only slowly. To illustrate the bizarre situation in fluid dynamics, consider the common plumbing problem of estimating the pressure loss suffered by water flowing through a pipe. Man has been pushing water through pipes and channels for thousands of years; our ancestors did that already very well in the Indus Valley civilization of some 4000 years ago. Thousands of engineers make confident and successful designs using data codified into diagrams of the type shown in Figure 10. But it is only the green line in the diagram, representing laminar flow, that is 'understood'. The rest *is* known, by a mix of testing and ingenious heuristic argument about turbulent flow, but not really *understood.* To highlight this extraordinary situation, let me note that there is a new analysis of turbulent pipe flow that claims that some of the results of the kind shown in Figure 10 can be wrong by as much as 60% at extremely high Reynolds numbers. This new analysis is not yet either confirmed or refuted.

This has been the enduring mystery of fluid flows: its governing laws are known, nevertheless even everyday phenomena, seen by our eyes all the time, cannot always be explained solely from those laws. Richard Feynman called turbulent flow 'the greatest puzzle of classical physics'. But the adjective 'classical' should be carefully interpreted, for 'classical' is often equated with 'understood', i.e., intellectually dead. This, of course, is far from being the case with regard to turbulent flows. I think it would be more accurate to say that Newtonian mechanics has turned out to be full of deep, unresolved, some times even unsuspected mysteries (in spite of having been dubbed as 'classical' with the advent of relativity and quantum mechanics). One such phenomenon, unsuspected till some forty years ago, is deterministic chaos. This forces together two concepts - of necessity and chance, of law and accident, or (in Upanishadic terms) of *niyati* and *yadṛcchā* - concepts that had earlier been thought of as two competing, mutually incompatible views of the nature of the universe. The discovery

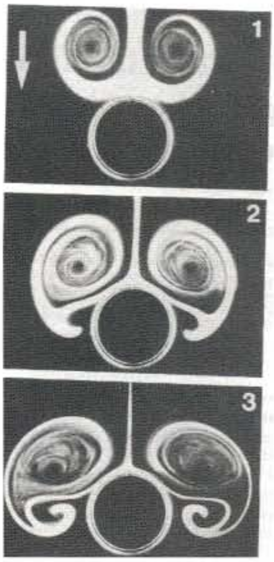

Figure 13: Pictures taken by injecting smoke into the flow created when a pair of vortices descends on a circular cylinder and folds into layers and spirals. The pictures are taken at 40 ms intervals at a Reynolds number of 1500 (Yamada et al. 1988)

that paradigmatically deterministic Newtonian systems can behave in ways that appear random has had such a profound effect on our thinking that Sir James Lighthill, occupant of the same prestigious Lucasian chair that Newton had held some 300 years earlier in Cambridge, felt compelled to say in 1986:

> We [i.e., the community of scientists pursuing classical mechanics] collectively wish to apologize for having misled the general educated public by spreading ideas about the determinism of systems satisfying Newton's laws of motion that, after 1960, were to be proved incorrect.

And chaos has now been detected in such exemplars of the alleged 'clockwork' of the universe as the planetary system, the pendulum and the elastic string. Einstein famously said that he did not believe in a God who played dice, but would he have believed in a Newtonian God who played deterministic nonlinear games whose outcomes would be effectively indistinguishable from the results of playing dice?

Incidentally, that Newtonian chaos is not unrelated to the turbulence of fluid flow - chaos is generic turbulence, so to speak, that may be encountered in non-fluid dynamical systems as well. Indeed, a key advance in the emergence of the concept of chaos was the study of a highly idealized form of convective weather - going one or two nonlinear steps beyond the saree-border pattern of Figure 3. That study, undertaken in the early 1960s by the American meteorologist E.N. Lorenz, showed how convection can become erratic, explained why weather is unpredictable beyond a certain time horizon, showed the relation of these properties to those of some simple nonlinear maps, and visually displayed, for the first time, the mathematical object that later came to be called a strange attractor. This theory of chaos has certainly solved the philosophical problem

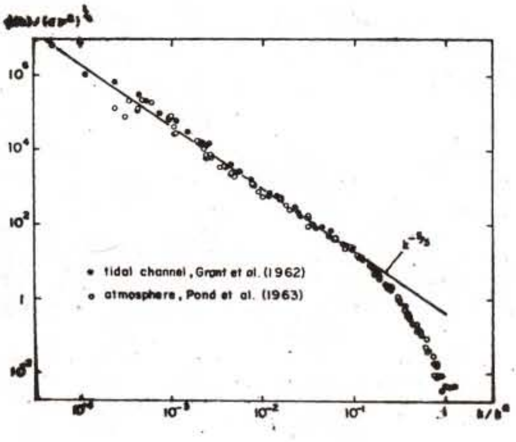

Figure 14: Kolmogorov scaling of the spectrum of turbulent velocity fluctuations. Data from atmosphere and ocean collapse into one curve, which follows the Kolmogoro k-5/3 law over three decades in wave number.

of how turbulence can emerge out of the Navier-Stokes equations. But it has unfortunately not otherwise been of great help in understanding or predicting turbulent flows for the simple reason that the number of degrees of freedom in a flow diverges as the Reynolds number increases.

I believe it was John von Neumann who came closest to seeing the true nature of the fundamental problem of fluid dynamics. He first of all realized that

> From the point of view of theoretical physics, turbulence is the first clear-cut instance calling for a new form of statistical mechanics.

He then went on to say

> The impact of an adequate theory of turbulence on certain very important parts of pure mathematics may be even greater [than on fluid dynamics].

Von Neumann thought that there was some hope to 'break the deadlock by extensive but well-planned computational efforts'; and this was one of the reasons that he got so deeply involved in the development of computer technology. But computing solutions of the Navier-Stokes equations is more like doing experiments (- only they are numerical, instead of physical), and will not automatically provide understanding. In any case, even on the most powerful computers available in the world today, we cannot reach Reynolds numbers higher than of order 10^4. To see that we still have a long way to go, look at Figure 11, which is a collection of data compiled by Anatol Roshko on the pressure at the back (more precisely rear stagnation point) of the same kind of cylinder that sheds Karman vortices at lower Reynolds numbers. First of all, note that the scatter in the data is surprisingly small. Now, how can the pressure on a body whose cross-section is a perfect Platonic circle vary with Reynolds number in such a non-simple way? (Could that crazy variation be a set of signatures of the many transitions that keep occurring as the flow folds into complex layers?) Who would dare to guess (based on that data) what happens to the pressure in the limit as the Reynolds number R tends to infinity? Or, to put it in equivalent terms, how is it that even at $R^{-1} = 10^{-7}$, we clearly cannot be sure we are close to the limit $R^{-1} \Rightarrow 0$? (There must be a discontinuity at $R^{-1} = 0$, showing the limit is singular.) And, to cap it all, even on the most powerful computers in the world today, we are not even half-way past the abscissa in the diagram. So you can see how far we are from final solutions.

That the problem is basically mathematical is at last being more widely recognized, for two problems on the Navier-Stokes equations are among the seven million-dollar prize problems posed by the Clay Foundation - along with the Riemann hypothesis and the Poincaré conjecture. That I feel is the right company for turbulence, and shows why fluid dynamics continues to be such an enduring challenge.

But, while waiting for mathematical paradise, there is a great deal that fluid dynamicists can do and have done about these problems. Engineers, of course, cannot always wait for understanding (: as the great electrical engineer Oliver Heaviside pointed out, we do not stop eating just because we do not understand digestion). But engineers would love a good theory - it would cut development costs dramatically (I can hear some of you saying ugh!). In the absence of a theory, one engineering way is to treat each flow on its merits, and make handbooks or catalogues with diagrams like Figure 10 (using physical or computational experiments) - or their more modern computerised equivalents. But I think a great deal more can be done.

First of all, I believe there are two keys to *appreciating* fluid flows, i.e., to getting an intuitive feel for their structure (which is still far short of *predicting* them from first principles). The two keys, I propose, are

INSTABILITY, NONLINEARITY.

As we have already seen, fluid flows tend naturally to instability under most conditions, barring the mildest (very low Reynolds or Rayleigh numbers, for example). The nature of the instability depends on the particular flow type (jet, boundary layer, convection, rotation, etc.), and can vary widely from flow to flow. That is, instability is general, but its character is flow-specific. This tendency to crumple into instability, enabling small disturbances to grow, can be the first step leading to chaos and turbulence. It is no wonder therefore that instability has been seen as a central issue by some of the biggest names in physics and fluid dynamics: Sommerfeld, Rayleigh, Heisenberg, Chandrasekhar - and most relentlessly and successfully by Prandtl and his pupils and by G.I. Taylor. But the final stages of transition, ending up in breakdown, are essentially nonlinear, and not yet understood.

That leads to nonlinearity, which has several effects. The first, strangely, is to fix order. By this I mean that a linear instability mode which has started growing can have its amplitude limited by nonlinear saturation, producing the *stable* order of which we saw several illustrations earlier (e.g., convective rolls, Karman vortices), without necessarily changing the *mode* much.

The second effect of nonlinearity is to fold the flow into layers, as first analysed by Prandtl in the simple case of flow past a flat plate. But as thin layers fold into even thinner ones (see e.g. Figure 12), there is a cascade in scales. And there can be layers within layers! Of course, the folding and squashing can result not only in sheets, but scrolls, filaments, shocks and various other types of singularities.

Thirdly, nonlinearity can generate chaos - as we have already described.

And, by a combination of all these mechanisms nonlinearity can produce strange mixtures of chaos and order over a wide range of scales - the *vicitra-vibhavā of the Vāsiṣṭha.*

To these two pillars of intelligent thinking about fluid flows, we should perhaps add a third,

SCALING AND MATCHING,

which is a way of reasoning about length and time *scales* in the flow. This is important for several reasons. First of all, fluid flows have a wide range of scales (because of the layer-making property discussed above). Secondly, scaling arguments help us to separate the more nearly universal features of a flow from those that are less so. Thirdly, a successful scaling argument helps us to condense vast quantities of experimental data into manageable *patterns.* For example, if the scales characterizing wake flows are known, then all wakes become *instances* of a universal wake, i.e., all of them collapse into universal functions and numbers in appropriately scaled variables. (Of course, these functions and numbers cannot still be *predicted*, and usually have to be found from physical or numerical experiments.)

One of the most celebrated of such scaling arguments is due to Kolmogorov (although the fundamental core of the argument had been used earlier in turbulent channel flow by Clark Millikan - at least that is the way I see it). Kolmogorov analysed the spectrum of turbulence, which he considered as determined by an energy cascade from large scales in the motion to small scales (rather as the crushing of coal leaves us with pieces of various sizes - from a few big lumps to a lot of fine dust). He proposed that the 'small eddies' (high wave numbers) are universal and depend only on the viscosity and energy dissipation, and the large eddies are flow-specific and inviscid. Crucially, he further postulated that there is a range of intermediate scales over which both scaling arguments are valid, i.e., they are matchable. This led to the prediction that, over that range of intermediate scales, the spectrum should be proportional to $k^{-5/3}$ (where k is the wave number). This should be true in *any* flow - whether it is a jet stream in the atmosphere, tidal flow in the oceans, or the boundary layer on an aircraft wing. Figure 12 shows how successful the argument is.

I have vastly oversimplified the reasoning here, and must hasten to caution you that universality may not be as common as it is sometimes thought to be. Kolmogorov himself felt compelled to revise his argument nearly twenty years after he first put it forward. Nevertheless, the organizing power of a successful scaling argument is enormous, its chief attraction being that it is minimalist in the hypotheses it makes (unlike in the vast industry that churns out basically *ad hoc* turbulence models, for example). But then, we cannot prove when (or even whether) such scaling arguments follow from the Navier-Stokes equations, and, even if the arguments are valid, the corresponding universal numbers and functions have, of course, to be determined from experiment of one kind or other.

Such scaling arguments have been used very widely - some times with success, at other times in controversy. They can be seen as simple applications of a kind of group theory, the centre-piece of the argument being a postulate on what the relevant group is.

What engineers often do today is use any tool or method that will help: theory of course, whenever it is available, testing, computing, simulation, scaling arguments and, increasingly, mathematical modelling. This modelling has to be distinguished from making direct appeal solely to first principles (e.g., Navier-Stokes). Instead, essentially new equations are devised, taking inspiration from but abandoning equivalence to the Navier-Stokes equations. Ingenuity lies in inventing equations that give the engineer the reduced information he wants, like the pipe data of Figure 10. Such models can be at many different levels - from codification into charts or tables like Figure 10, through ordinary differential equations for each flow type (boundary layers, jets, etc.), all the way to systems of nonlinear partial differential equations (for mean quantities) expected to be useful for wide classes of flows. Although none of them is spectacularly successful, many of these models are useful - sufficiently so that there is a minor industry across the world generating, testing and applying such models to a vast variety of fluid flow problems - from making better aircraft wings to estimating how pollutants disperse to forecasting weather or ocean state.

So I hope, you may see in some small way why some of us love exploring fluid flows: they can be beautiful, crazy, fearsome, important; a challenge whether you want to stare at nature's free displays, or visualize flows in the laboratory, or measure them with great precision, or control them so that they do your bidding; a happy hunting ground if you want to match your skills - of any kind - to try and unravel their secrets and to add to the great deal that is known; but, in essence, still beyond any mathematics or computers invented by man; still out there, so to speak, taunting us to see if we can *understand*, as we claim to know the basic laws.

If you also feel taunted by those flows, welcome to the fluid dynamicists' club!