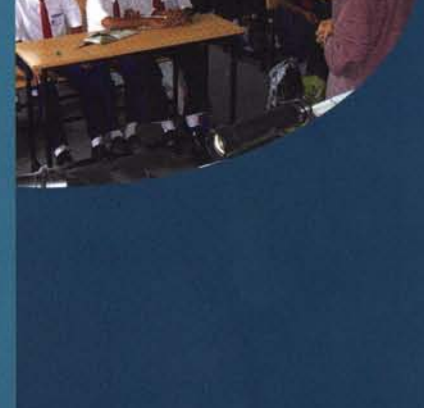
16th

Annual Report

2003 - 2004



IUCAA

Inter-University Centre for Astronomy and Astrophysics

(An Autonomous Institution of the University Grants Commission)

Cover Page :

The Muktangan Vidnyan Shodhika, 'Pulastya', a Science Exploratory for school students which has been inaugurated during the current year, and some of the activities.

INTER-UNIVERSITY CENTRE FOR ASTRONOMY AND ASTROPHYSICS

(An Autonomous Institution of the University Grants Commission)

Annual Report

(April 1, 2003 - March 31, 2004)

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HIGHLIGHTS OF 2003- 2004

This annual report covers the activities of IUCAA during its sixteenth year, April 2003 -March 2004. 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), 12 post-doctoral fellows and 18 research scholars. The core research programmes by these academics span a variety of areas in astronomy and astrophysics. These topics include quantum theory and gravity, classical gravity, gravitational waves, cosmology and structure formation, observational cosmology, cosmic microwave background radiation, active galactic nuclei, and quasar absorption system, high energy astrophysics, galaxy and interstellar medium, interstellar dust and extinction by non-spherical grains, stellar physics, solar physics, and instrumentation. These research activities are summarised in pages 17-76. The publications of the IUCAA members, numbering to about 65 in the current year are listed in pages 110 -112. IUCAA members also take part in pedagogical activities like lectures, seminars, popularisation of science, etc., the details of which are given in pages 119-122 of this Report.

The extended academic family of IUCAA consists of about 90 Visiting Associates, who have been active in several different fields of research. Pages 77-99 of this report highlights their research contributions spanning general relativity and gravitational waves, classical gravity, quantum cosmology, brane world and quintessence, cosmology and structure formation, galaxies and quasars, interstellar matter and star formation, X-ray binaries, compact and exotic stars, sun and the solar system, nonlinear dynamics, plasma physics, theoretical physics, observational astronomy and image analysis, radio astronomy, cluster computing for machine learning, and instrumentation. The resulting publications, numbering to about 120 are listed in pages 113-117 of this report.

A total of about 1643 man-days were spent by Visiting Associates at IUCAA during this year. In addition, IUCAA was acting as host to about 355 visitors through the year.

IUCAA conducts its graduate school jointly with the National Centre for Radio Astrophysics, Pune. Among the research scholars, four students have successfully defended their theses and obtained Ph.D. degrees from the University of Pune during the year 2003-2004. Summary of their theses appears in pages 100-109.

Apart from these activities, IUCAA conducts several workshops, schools and conferences each year, both at IUCAA and at different university campuses. During this year, there were 5 such events in IUCAA and 5 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 (19 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 142-144 of this Report.

IUCAA has plans for a 2-metre new technology telescope for optical astronomy. The first phase and the second phase of the mechanical integration were completed in May-June, 2003. This was to be followed by electrical cabling on the telescope, but the manufacturer of the telescope, Telescope Technologies Limited, UK, decided that the electrical work needed a major diversion in methodology from what was originally anticipated by them. It is expected that this work would start by June 2004, and the installation would be completed by early 2005.

CONTENTS

The Council and the Governing Board

The Council

President

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

Vice-President

V.N. Rajasekharan Pillai, (from April 30, 2003)
Vice-Chairperson,
University Grants Commission, New Delhi.

Members

R.P. Bambah, (till June 18, 2003)
(Chairperson, Governing Board)
1275, Sector 19-B, Chandigarh.

N. Mukunda, (from June 19, 2003)
(Chairperson, Governing Board)
Centre for Theoretical Studies,
Indian Institute of Science, Bangalore.

Arnab Rai Choudhuri,
Indian Institute of Science, Bangalore.

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

Deepak Dhar,
Tata Institute of Fundamental Research,
Mumbai.

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

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

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

R. R. Pandey,
Vice-Chancellor,
D.D.U., Gorakhpur University.

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

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

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

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

Lakshman Chaturvedi,
Department of Physics,
Banaras Hindu University, Varanasi.

Ramanath Cowsik,
Director,
Indian Institute of Astrophysics, Bangalore.

K. Kasturirangan,
Secretary to the Government of India,
Department of Space, Bangalore.

T. Padmanabhan,
IUCAA, Pune.

K.N. Pathak,
Vice-Chancellor,
Panjab University, Chandigarh.

M.S. Thimmappa,
Vice-Chancellor,
Bangalore University, Bangalore.

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

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.

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

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

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

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

Member Secretary

N.K. Dadhich, (from July 4, 2003)
Director, IUCAA, Pune.

J.V. Narlikar, (till July 3, 2003)
Director, IUCAA, Pune.

The Governing Board

Chairperson

R.P. Bambah, Chandigarh, (till June 18, 2003)
N. Mukunda, Bangalore, (from June 19, 2003)

Members
A.S. Kolaskar
Rajaram Nityananda
Ved Prakash

The following members served on the Governing Board till December 31, 2003.

Lakshman Chaturvedi
Ramanath Cowsik
T. Padmanabhan
K.N. Pathak
M. S. Thimmappa

The following members have been inducted in the Governing Board during this year.

Shishir K. Dube
Ashok Kumar Gupta
Kota Harinarayana
A.K. Kembhavi
G.K. Mehta
G. Rajasekaran
C.V. Vishveshwara

Member Secretary

N.K. Dadhich (from July 4, 2003)
J.V. Narlikar (till July 3, 2003)

Honorary Fellows

Geoffrey Burbidge,
University of California, CASS, USA.

E. Margaret Burbidge,
University of California, CASS, USA.

A. Hewish,
University of Cambridge, UK.

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

Yash Pal,
New Delhi.

A.K. Raychaudhuri,
Kolkata.

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

P.C. Vaidya,
Gujarat University, Ahmedabad.

Visiting Professor

Russell Cannon,
Anglo Australian Observatory, Australia.

Statutory Committees

The Scientific Advisory Committee (SAC)

J.V. Narlikar (Convener) (till July 3, 2003)
Director, IUCAA, Pune.

N.K. Dadhich (Convener) (from July 4, 2003)
Director, IUCAA, Pune

U. C. Joshi,
Physical Research Laboratory, Ahmedabad.

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

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

The following members served on the SAC till December 31, 2003.

S. Rai Choudhury,
University of Delhi.

E.P.J. van den Heuvel,
University of Amsterdam, The Netherlands.

Pushpa Khare,
Utkal University, Bhubaneswar.

N. Mukunda,
Indian Institute of Science, Bangalore.

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

Bernard F. Schutz,
Max-Planck Institute for Gravitation Physics, Germany.

The following members have been inducted into the SAC from January 1, 2004.

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

Rohini Godbole,
Indian Institute of Science, Bangalore.

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

S.K. Pandey,
Pt. Ravishankar Shukla University, Raipur.

Ashoke Sen,
Harish-Chandra Research Institute, Allahabad.

Users' Committee

N.K. Dadhich, (Chairperson) (from July 4, 2003)
Director, IUCAA, Pune.

J. V. Narlikar, (Chairperson) (till July 3, 2003)
Director, IUCAA, Pune.

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

N. Unnikrishnan Nair,
Vice-Chancellor,
Cochin University of Science and Technology,
Kochi.

The following members served on the Users' Committee till December 31, 2003

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

Somenath Chakrabarty,
Department of Physics,
University of Kalyani.

Bharat Oza,
Vice-Chancellor,
Bhavnagar University.

R. Ramakrishna Reddy,
Sri Krishnadevaraya University, Anantapur.

The following members have been inducted in the Users' Committee from January 1, 2004

Narayan Banerjee,
Jadavpur University, Kolkata.

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

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

T. Padmanabhan,
IUCAA, Pune.

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

The Academic Programmes Committee

N.K. Dadhich (Chairperson) (from July 4, 2003)
J.V. Narlikar (Chairperson) (till July 3, 2003)
T. Padmanabhan (Convener)
S.V. Dhurandhar
Ranjan Gupta
A. K. Kembhavi
A.N. Ramaprakash
Varun Sahni
Tarun Souradeep
R. Srianand
K. Subramanian
S. N. Tandon

The Standing Committee for Administration

N.K. Dadhich (Chairperson) (from July 4, 2003)
J.V. Narlikar (Chairperson) (till July 3, 2003)
K.C. Nair (Member Secretary) (from August 4, 2003)
S. Shankar (Member Secretary) (till August 3, 2003)
A.K. Kembhavi
T. Padmanabhan

The Finance Committee

R.P. Bambah (Chairperson) (till June 18, 2003)
N. Mukunda (Chairperson) (from June 19, 2003)
P. Agarwal (from December 18, 2003)
L. Chaturvedi
R. Nityananda
T. Padmanabhan
Ved Prakash
N.K. Dadhich (from July 4, 2003)
J.V. Narlikar (till July 3, 2003)
K.C. Nair (Non-Member Secretary) (from August 4, 2003)
S. Shankar (Non- Member Secretary) (till August 3, 2003)

Members of IUCAA

Academic

J.V. Narlikar (Director) (Retired on July 18, 2003)
N.K. Dadhich (Director) (from July 19, 2003)
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 (from July 19, 2003)

Scientific and Technical

T.D. Agarkar
N.U. Bawdekar
S.S. Bhujbal
M.P. Burse
V. Chellathurai
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
S. Ponrathnam
V.K. Rai
H.K. Sahu
S. Sankara Narayanan (till June 13, 2003)
Y. R. Thakare (from February 16, 2004)

Administrative and Support

K. C. Nair (Senior Administrative Officer)
(from August 4, 2003)
N.V. Abhyankar
V.P. Barve
S.K. Dalvi
S.L. Gaikwad
B.R. Gorkha
B S. Goswami
S.B. Gujar
R.S. Jadhav
B.B. Jagade
S.M. Jogalekar
S.N. Khadilkar
S.B. Kuriakose
N.S. Magdum
M.A. Mahabal
S. G. Mirkute
E.M. Modak
K.B. Munuswamy
R.D. Pardeshi
R.V. Parmar
B.R. Rao
M.S. Sahasrabudhe
V.A. Samak
S.S. Samuel
B.V. Sawant
S. Shankar (SAO till August 3, 2003)
D.R. Shinde
V. R. Surve
D.M. Susainathan
A.A. Syed
S.R. Tarphe
S.K. Waghole
K.P. Wavhal

Post-Doctoral Fellows

A. Bhattacharya (till August 1, 2003)
P. Chakraborty
H. K. Jassal
B. Mukhopadhyay (till April 16, 2003)
R. Nayak (till October 1, 2003)
S. Ray (from October 3, 2003)
E. Rollinde (from November 20, 2003)
S. Sahay (till July 31, 2003)
G. Sarkar (from January 28, 2004)
P. Subramanian
R.G. Vishwakarma (till September 12, 2003)
R.S. Yadav (from July 9, 2003)

Research Scholars

A.L. Ahuja
U. Alam
S. Chakravorty (from August 1, 2003)
H. Chand
T. Roy Choudhury (till November 5, 2003)
A. Deep
Amir Hajian Forushani
G. Mahajan (from August 4, 2003)
S. Mitra
T. Naskar (from August 1, 2003)
Ali Reza Rafiee
K. Ramu (from August 4 , 2003 till January 2, 2004)
A. Rawat
S. Samui (from August 1, 2003)
A. A. Sengupta
Arman Shafieloo
J.V. Sheth
P. Singh

Project and Contractual Appointments

M. S. Kharade
(Project Officer, ERNET Project)

V. Kulkarni
(Scientific/Technical Assistant-I,
Public Outreach Programme)

V. Raskar (Assistant, Public Outreach Programme)

The following members were in IUCAA for part of this year.

M. D'sa
(Quasi Steady-State Cosmology Project)

K. James
(System Administrator, ERNET Project)

The following members have been inducted in IUCAA during this year.

N. S. Bhujbal (System Administrative Assistant)

A.P. Chordia (System Engineer)

M.B. Ghule (Steno-Typist, CEC Project)

J.A. Gupchup
(Project Officer, Virtual Observatory)

S.T. Koshti
(Project Scientist, DST Project)

P. Kulkarni
(Project Officer, Virtual Observatory)

P.L. Shekade (System Engineer)

Part time Consultants

S. S. Bodas (Medical Services)

Visiting Members of IUCAA

Visiting Associates

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

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

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

Bindu A. Bambah,
Centre for Advanced Study in Mathematics,
Panjab University, Chandigarh.

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

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

S.K. Banerjee,
Department of Mathematics,
Mody College of Engineering and
Technology, Lakshmangarh.

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

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

Satyabrata Biswas,
Department of Physics,
University of Kalyani.

S. Chakrabarty,
Department of Physics,
University of Kalyani.

D.K. Chakraborty,
School of Studies in Physics,
Pt. Ravishankar Shukla University, Raipur.

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

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

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

Tanuka Chatterjee (Kanjilal),
Department of Mathematics,
Shibpur D.B. College, Howrah.

S. Chaudhuri,
Department of Physics,
Gushkara Mahavidyalaya, Burdwan.

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

M.K. Das,
Institute of Information and Communication,
University of Delhi, South Campus.

Jishnu Dey,
Department of Physics,
Maulana Azad College, Kolkata.

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

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

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

S. G. Ghosh,
Department of Mathematics,
Birla Institute of Technology and Science, Pilani.

A.K. Goyal,
Department of Physics and Astrophysics,
Hans Raj College, Delhi.

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

P.P. Hallan,
Department of Mathematics,
Zakir Husain College, New Delhi.

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

S.N. Hasan,
Department of Astronomy,
Osmania University, Hyderabad.

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

K. Indulekha,
School of Pure and Applied Physics,
Mahatma Gandhi University, Kottayam.

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

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

K. Jotania,
Department of Physics,
M.N. College, Visnagar.

R.S. Kaushal,
Department of Physics and Astrophysics,
University of Delhi.

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

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

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

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

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

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

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

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

Yogesh Kumar Mathur,
Department of Physics and Astrophysics,
University of Delhi.

A. K. Mittal,
Department of Physics,
University of Allahabad.

Kalyan K. Mondal,
Department of Physics,
Raja Peary Mohan College, Hooghly.

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

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

U. Narain,
Astrophysics Research Group,
Meerut College.

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

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

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

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

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

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

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

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

S.K. Popalghat,
Department of Physics,
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.

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

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

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

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

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

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 2003

Anil Ch. Borah,
Physics Department,
Assam University, Silchar.

K. N. Iyer,
Department of Physics,
Saurashtra University, Rajkot.

Bijan Modak,
Department of Physics,
University of Kalyani.

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

S.K. Srivastava,
Department of Mathematics,
North Easern Hill University, Shillong.

From July 2003...

Badruddin,
Department of Physics,
Aligarh Muslim University.

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

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

Dhanajay V. Gadre,
Netaji Subas Institute of Technology,
University of Delhi.

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

Deepak Jain,
Department of Physics and Astrophysics,
University of Delhi.

Long Term Visitor

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

The fourteenth batch of Visiting Associates, who were selected for a tenure of three years, beginning July 1, 2003.

Badruddin

Umesh Dodia

Dhananjay V. Gadre

Deepak Jain

The photographs of the following Visiting Associates from the fourteenth batch are not available: Siddhartha Bhowmick, and Abhinav Gupta.

Appointments of the following Visiting Associates from the eleventh batch were extended for three years : Shyamal K. Banerjee, Ngangbam Ibohal, Moncy V. John, Manoranjan Khan, Ashok K. Mittal, Udit Narain, Bikash Chandra Paul, Sandeep Sahijpal, Asoke K. Sen, K. Shanthi, G.P. Singh, Santokh Singh, and P.K. Suresh.

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
(S.V. Dhurandhar)

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

Head, Recreation Centre
(P. Chordia)

Head, Guest Observer Programmes
(R. Srianand)

Head, Workshops & Schools
(V. Sahni)

Head, Public Outreach Programmes
(T. Padmanabhan)

The Director's Report

Looking back, it was on February 10, 1988 that I joined as the Project Coordinator and established the first lodgings of IUCAA in a room in the Golay Bungalow in front of the Pune University main building. Jayant, Ajit and I prepared the Project Report, the blue book depicting the eight fold activities of IUCAA on the cover. Jayant formally joined as the founder Director on his 50th birthday, July 19, 1988. The Project Report went through a process of scrutiny and approval at the University Grants Commission (UGC) and the Ministry of Human Resource Development, and IUCAA was formally founded on December 29,1988. It was amazing to see what we had projected in the Report almost out of our hat in terms of personnel and funding has stood good for over 15 years.

One of the important happenings of this year was Jayant laying down the reins, which I was asked to pick up. He had not only created a first rate world class institute, but has also set up a very healthy, democratic and participative work culture and administrative machinery. On one hand, it is hard for one to step in after such a great man, while on the other, it is very smooth and effortless, for all that is needed for good and efficient functioning of the institute is already in place and working. It is really fortunate for me to inherit a mature and well geared institute, which is rolling on beautifully on an ascending path. I just need to ride on. I have shared and experienced the building up and growing of IUCAA, a dream being realised in actuality. I once again record my warmest feeling of gratitude and affection to Jayant and it is my great privilege and honour to succeed him.

In his last Director's Report, Jayant has lamented that much needs still to be done in strengthening interaction with the universities. This is a very important question, which I have taken up in right earnest. We had a detailed discussion on it in the faculty meeting and it was unanimously agreed that each faculty member will visit a university of his choice for a period of two weeks in a year and give a course of lectures. This will help in strengthening interaction with university faculty and students, and hopefully it would facilitate collaborative projects and programmes. The interaction is, however, a two-way process and I earnestly appeal to the university colleagues as well as the authorities for help and support.

One of the distinguishing features of IUCAA is to subject itself to scrutiny and review at regular intervals. The Scientific Advisory Committee has been reviewing and overseeing IUCAA's development and growth right from the very primitive stage. It has distinguished colleagues from home and abroad as members, and meets twice in a three year term, for about a week each time. In view of the fact that IUCAA's facilities and programmes are now well in place and fully functioning, it was recommended by the previous SAC (in its meeting in November 2003) that the term be increased to five years, which will also match with the Five Year Plan, and that the committee should meet twice during its term. The Governing Board and the President of the Council have accepted this recommendation and hence, the SAC will have the term of five years beginning from 1 January 2004.

One of the key programmes of IUCAA is the Associateship Programme, through which the university/college faculty visit IUCAA and use its facilities for their work. At present, we have 89 Visiting Associates on our rolls. Reared on the tonic of peer review, IUCAA has taken up the peer review of these Associates, who have completed two 3-year terms, to assess the effectiveness of their interaction with IUCAA. The idea is to make the programme more focused and productive. The review process is under way.

It is unfortunate that IUCAA telescope has not yet been installed due to some difficulty in working through the original contract with PPARC and TTL. A new contract has been signed with TTL for installation and commissioning, while the handing over of a working telescope still remains PPARC's responsibility. The installation work on site will start in the third week of June, and the telescope is expected to be handed over by the end of next February. There has been a long delay and we hope that the process now converges to completion.

I am very grateful to our distinguished friend Professor Russell Cannon for accepting my invitation to join the IUCAA rolls as distinguished honorary Visiting Professor. At our request, he travelled all the way from Australia to UK and negotiated with TTL and PPARC on our behalf, to work out an acceptable arrangement for completion of the IUCAA telescope. He did a marvelous job, and in the two week long journey around the globe necessitated by this, he did not sleep for any two consecutive nights in the same bed! His report as well as his briefing to the Chairman, UGC in Delhi in person was very effective and helpful in getting the approval for the new contract. I cannot adequately thank him for all the help that he has given, except to say that I am living by the word I had given to all my friends that I count and bank upon their support and guidance.

I am very happy to say that one of the best friends and staunchest supporters of IUCAA right from its conception, Professor Donald Lynden-Bell, has accepted our invitation to join the rolls of Honorary Fellows of IUCAA. I look forward to his wise counsel and guidance, and closer interaction.

It is always pleasing to see the impressive entries in the Awards and Distinctions column of the Report and this year is no exception. I would like to make a special mention of the G. D. Birla Award for scientific research, which is open to distinguished contributions in all fields of science, and which has so far only been awarded to four physicists. T. Padmanabhan is the recipient of the prize for 2003, and the previous physics awardees are G.S. Agarwal, A Sood, and Ashoke Sen. Well done and heartiest congratulations, Paddy!

I am glad to say that IUCAA is being recognized and acknowledged as the provider of intellectual resource and leadership to many of UGC's new initiatives and projects. In particular, I would like to mention the UGC-INFONET programme, which envisages providing inter-access and e-subscriptions for most of the universities for all the leading journals in sciences as well as in humanities. Ajit Kembhavi has steered the whole project right from its conception to its successful launch. It is indeed a tribute to his efforts and commitment to the cause of university academics. He has also been invited to shoulder the responsibility of the Chairman of the Governing Board of the Consortium for Education Communication, another Inter University Centre of UGC. I warmly applaud Ajit for his untiring and relentless efforts to improve the academic ambience in the universities.

I took over the reins of IUCAA from a good friend, and I am doubly fortunate to have another friend, Professor N. Mukunda, as the Chairman of the Governing Board, and a friend and former colleague in the Pune University, Professor Arun Nigavekar as the Chairman of UGC and the IUCAA Council. I shall value their guidance and wise counsel.

Last but not the least, I commend whole heartedly all my administrative, scientific and academic colleagues for their dedication and commitment to IUCAA and I see no reason why we cannot scale greater heights together!

Naresh Dadhich

Awards and Distinctions

Ujjaini Alam

Awarded the Late Debleena Choudhury Award of the Indian Physics Association, Pune Chapter, for best oral presentation by a Research Scholar.

Naresh Dadhich and Parampreet Singh

Received "Honourable Mention" in the 2003 Gravity Research Foundation Essay Competition (awarded by the Gravity Research Foundation, USA).

J. V. Narlikar

Recipient of the Padmavibhusan Award from the President of India.

Awarded the Rammohan Puraskar 2004 by the Ram Mohan Mission, Kolkata.

T. Padmanabhan

Fifth Prize in Gravity Research Foundation Essay Competition 2003 (awarded by the Gravity Research Foundation, USA).

Recipient of the 13th G.D. Birla Award from the K.K. Birla Foundation, Kolkata.

Awarded the Miegunah Fellowship - 2004 by the Melbourne University, Australia.

S.N. Tandon

Elected President of the Astronomical Society of India in the year 2003.

Calendar of Events

2003

April 14-May 23	**School Students' Summer Programme** at IUCAA
May 9	**IUCAA-NCRA Graduate School** Second semester ends
May 19-June 20	**Refresher Course in Astronomy and Astrophysics for College and University Teachers** at IUCAA
May 19 -June 27	**Vacation Students' Programme** at IUCAA
June 30 - July 2	**Workshop on Provocative Universe** at IUCAA
August 11	**IUCAA-NCRA Graduate School** First semester begins
September 22-26	**Introductory School on Astronomy and Astrophysics** at The American College, Madurai
December 12	**IUCAA-NCRA Graduate School** First semester ends.
December 29	**Foundation Day.**

2004

January 5	**IUCAA-NCRA Graduate School** Second semester begins
January 14-16	**Workshop on Brane Worlds and Quantum Cosmology** at IUCAA
January 19-22	**Workshop on Galaxies : Structure and Dynamics** at Osmania University, Hyderabad.
January 26-29	**Workshop on Introductory Astrophysics** at Utkal University, Bhubaneswar.
January 29-30	**Workshop on Front-End Controls and Data Retrieval / Archival for Indian Telescopes** at IUCAA
February 4-8	**Mini-School on Introductory Astronomy and Astrophysics** at Kalyani Government Engineering College, Kalyani.
February 23-25	**IIT KGP-IUCAA Workshop on High-Energy Astrophysics** at IIT, Kharagpur.
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

The Thermodynamic Route to Gravity

A novel approach towards understanding the structure of gravity, based on thermodynamic considerations, is being pursued by *T. Padmanabhan.* (Some of the early works in this direction were reported in the previous annual report). During the current year, *Padmanabhan* has managed to provide a fairly detailed and unified account of this approach based on two principles. (a) The physical theories must be formulated for each observer entirely in terms of variables any given observer can access and (b) consistent formulation of quantum field theory requires analytic continuation to the complex plane. These two principles, when used together in spacetimes with horizons, are powerful enough to provide several results in a unified manner. Since spacetimes with horizons have a generic behaviour under analytic continuation, standard results of quantum field theory in curved spacetimes with horizons can be obtained directly. The requirements (a) and (b) also put strong constraints on the action principle describing the gravity and, in fact, one can obtain the Einstein-Hilbert action from the thermodynamic considerations. This leads to a deeper connection between gravity, spacetime microstructure and thermodynamics of horizons, and has several implications for the semiclassical limit of quantum gravity.

The principle of equivalence implies that gravity affects the light cone (causal) structure of the spacetime. It follows that there will exist observers (in any spacetime), who do not have access to regions of spacetime bounded by horizons. Since physical theories in a given coordinate system must be formulated entirely in terms of variables which an observer using that coordinate system can access, gravitational action functional must contain a foliation dependent surface term which encodes the information inaccessible to the particular observer. *Padmanbabhan* has now shown that: (i) It is possible to determine the nature of this surface term from general symmetry considerations and *prove* that the entropy of any horizon is proportional to its area. (ii) The gravitational action can be determined using a differential geometric identity related to this surface term. The dynamics of spacetime is dictated by the nature of quantum entanglements across the horizons and the flow of information, making gravity inherently quantum mechanical at all scales. (iii) In static spacetimes, the action for gravity can be given a purely thermodynamic interpretation and the Einstein equations have a formal similarity to laws of thermodynamics. (iv) The horizon area must be quantized with $A_{\rm horizon} = (8\pi G\hbar/c^3)m$ with $m = 1, 2, \cdots$ in the semi-classical limit.

String Theory and Zero Point Length

It has been often conjectured that gravity will act as a regulator and remove the ultraviolet divergencies in Quantum Field Theory. One concrete model for this — developed by *T. Padmanabhan* in mid-eighties — identifies the planck length as a zero-point length of spacetime. This model was pursued more vigorously in the nineties showing that it has interesting connections with dualities seen in string theories. In particular, it was shown that, if the path integral defining the quantum field theory propagator is modified, so that the amplitude is invariant under the duality transformation $l \rightarrow 1/l$, where l is the length of the path, then the propagator is UV-finite and exhibits a "zeropoint length" of the spacetime. Since string theory uses extended structures and has a T-duality, these results should also emerge directly from string theory.

Recently, *Padmanabhan* (in collaboration with A. Smailagic and E. Spallucci) has shown that one can actually obtain the zero-point length by direct computation from string theory. They use the path integral formulation of string theory to obtain the propagator for the centre of mass of the string. This propagator has a finite coincidence limit and exhibits the precise duality, which was expected. The lowest order string theory correction to the propagator can, therefore, be identified with the one obtained earlier by the hypotheses of path integral duality.

Blackhole Entropy from Quantum Tunnelling

One of the most intriguing aspects of blackhole horizons is its thermodynamic attributes. A possible approach to understanding this phenomenon is by means of quantum tunnelling. It is well-known that quantum theory allows for processes which are classically forbidden because of uncertainty principle. Classically, a blackhole does not allow any material particle or radiation to escape from its inside; but quantum mechanically, there is a finite probability for a system of energy E tunnelling through the horizon and appearing on the outside.

Such ideas have been around for a long time and have been investigated by many people. Recently, *T. Padmanabhan* has provided a very general — and yet simple — derivation of this process without making any specific assumptions regarding the detailed nature of the horizon or the system which is tunnelling. From the structure of the action functional, he showed that the probability for tunnelling can be obtained by distorting the path to complex values of time. This provides a general derivation of the thermal Boltzmann factor, $\exp(-2\pi E/\kappa)$ for any system with energy E to tunnel through a horizon with surface gravity κ. Further, if it is assumed that the tunnelling of radiation changes the surface gravity of the blackhole, one can relate the probability for tunnelling with the change in entropy of the blackhole. Using this fact, *Padmanabhan* has proved that (in general) the entropy per unit area of the horizon is a universal constant and has a value of one quarter in natural units.

Classical Gravity

Quasi-normal Modes in Born Approximation

One of the probes of spacetime with horizons is the behaviour of the solutions to the wave equation in these spacetimes. There have been extensive investigations of the solutions to different kinds of classical wave equations in blackhole spacetimes in order to understand how the horizon affects the wave propagation. This study has shown that, in addition to modes with real frequencies, there exist another important class of modes with imaginary frequencies [usually called quasi-normal modes or QNM, for short], which convey important information about the blackhole. The QNMs are expected to play a vital role in the study of gravitational wave emission from coalescing binaries as well.

When one studies other spacetimes with horizons, like De-Sitter or blackhole De-Sitter, then the structure of QNM changes quite a bit and the situation becomes unclear. It is known that the imaginary parts of the QNM frequencies for the Schwarzschild blackhole are evenly spaced with a spacing that depends only on the surface gravity. On the other hand, for massless uncoupled scalar fields, there exist no QNMs for the pure De-Sitter spacetime. It is not clear what the structure of the QNMs would be for the Schwarzschild-DeSitter (SDS) spacetime, which is characterized by two different surface gravities. The previous literature in this subject has led to contradictory views and there was some confusion regarding the results.

T. Padmanabhan has developed a simple technique, based on Born approximation, to obtain the imaginary parts of the QNM frequencies for a wide class of spacetimes. The analysis showed that the result is closely linked to the thermal nature of horizons and arises from the exponential redshift of the wave modes close to the horizon. Using this method, T. Roy Choudhury and *Padmanabhan* have provided a simple derivation of the imaginary parts of the QNM frequencies for the SDS spacetime by calculating the scattering amplitude in the first Born approximation and then determining its poles. They find that, for the usual set of boundary conditions, where the incident wave is scattered off the blackhole horizon, the imaginary parts of the QNM frequencies have a equally spaced structure with the level spacing depending on the surface gravity of the blackhole. However, if one considers a different boundary condition where the incident wave is scattered off the cosmological horizon, one obtains level spacings proportional to the surface gravity of the cosmological horizon. Several conceptual issues related to the QNM are discussed in the light of this result and comparison with previous work is presented.

Wormholes: Tunnelling Through Spacetime?

Einstein's theory of gravity, the general relativity, contains a number of surprises. The most talked of among them are blackhole, the ultimate end state of even a moderately (a few times solar mass) massive star and the big bang beginning of the universe. They have not only become the standard parts of the physicists repertoire, but have descended down to common scientifically informed person. However, the jury is still out on considerably more exotic objects such as traversable wormholes and time warps. In Einstein's theory, matter/energy produces gravity through curvature of spacetime. The possibility of tunnelling through the curved spacetime, hence, becomes quite pertinent and natural. Wormholes are supposed to be such "tunnells".

What is critically required to create a wormhole? It turns out that some amount of negative energy matter is essential. The question is how much? Matt Visser, Sayan kar and *Naresh Dadhich* have recently shown that it is possible to choose geometric configurations which, require arbitrarily small amount of negative energy exotic matter. They argue that building a traversable wormhole, a spacetime shortcut from "here" to "there", will not be easy — however, the difficulty is more of technical engineering nature rather than massive violations of the laws of physics as we currently understand them. Specifically, it is shown that whereas, traversable wormholes require violations of the so-called "energy conditions" of general relativity, these violations can be made arbitrarily small. Also, remember that such violations have not come about for the first time. One has learnt to accept and live with, for instance, the quantum-induced Hawking evaporation of black-holes, where small but secular violations of the energy conditions are already known to occur, and to lead to dramatic reassessments of the classical picture. Generally quantum interactions do bring along occurrence of negative energy and thereby, violation of positive energy condition locally. The question is whether negative energy so generated is sufficient for making of a wormhole? Visser, Kar and *Dadhich* conclude their investigation with the hope that wormhole engineering, while certainly difficult, does not seem to be completely inimical to the laws of physics, and hence, does hold promise for future "time travel".

Motion of an Extended Body in General Relativity

Motion of a body in a gravitational field is described by geodesics of the background geometry only in the idealized test particle approximation. Einstein, Infeld and Hoffmann derived the geodesic equation from the Einstein field equation and had thus ,shown that the equation of motion for gravitational field contains motion of test particles in that field. This happens because, the field equation determines the background geometry and motion of free particles is geodesic of the geometry. However, there would occur correction to the geodesic motion for an extended body when its extension in space is not negligible compared to the radius of curvature of the background metric. In other words, body possesses multipole moments.

Recall that monopole links to gradient of the potential and higher multipoles would link to higher order derivatives of the potential. The geodesic equation, which describes motion of monopole, contains first derivative of the metric (potential) through the Christoffel symbols, while the curvature tensor contains second derivative. Thus, dipole would link to the Riemann curvature and quadrupole to its derivative. In the past 65 years, very involved and tedious computations were carried out using the conservation equation for energy and momentum to bring in the corrections to the geodesic equation due to dipole and quadrupole couplings to curvature tensor and its derivative. However, there existed no general principle to go beyond the quadrupole coupling.

The most elegant and physically insightful way to obtain the equation of motion is to write an action and then the equations simply follow from its variation. Jeeva Anandan, *Naresh Dadhich* and *Parampreet Singh* have for the first time addressed this question for an extended body in general relativity. Action, besides giving the equation of motion, is of great physical interest for it measures quantum mechanical phase of the wave function. Thus, writing the action for an extended body opens up new vista of measuring quantum phase shift due to multipole moment coupling to gravitational field. In this context, it is pertinent to recall the measurement of phase shift due to monopole coupling with earth's gravity in the neutron interferometry experiment. The new and future generation atomic, molecular and Bose-Einstein condensate interferometry experiments would be able to measure phase shift due to higher order coupling to gravitational field.

By employing an interesting trick of covariantizing the corresponding Newtonian expressions in the expansion of the gravitational potential energy for an extended body, Anandan, *Dadhich* and *Singh* have been able to write not only the action for motion but also have given a simple and elegant alogrithm for computing multipole moments of arbitrary order. They have demonstrated it by writing the correction to the geodesic equation due to the octopole, coupling which is being done for the first time. Their general procedure includes all the previous results. It is for the first time since the seminal Eistein-Infeld-Hoffmann paper of 1938 that an action for motion of an extended body in general relativity has been written.

Astrophysical objects like planets, stars and galaxies are indeed extended objects and hence, their equation of motion should contain multipole moment coupling to gravity. With the astronomical observation becoming more and more precise, it is quite in sight to actually observe the effect of the multipole coupling to the field as abberations in their orbits. Then, general relativity will be tested in a more detailed and comprehenaisve way. Thus, writing an action for an extended body is of experimental significance for the micro as well as macro regimes; i.e., for the quantum phase shifts as well as for the orbits of astrophysical objects.

Embedding Blackhole in the Euclidean Space

The best way to visualize the curvature of space is to look it from the uncurved Euclidean space. In the Einstein's theory, it is the gravity that curves space. Blackhole is the extreme example of curved surface from which light cannot propagate out. Embedding of a curved surface in the Euclidean space visually demonstrates the curvature of the surface. Embedding diagrams, therefore, become excellent tools for visualizing the curvature of spacetime; i.e., the gravitational field. The particle trajectories could easily be seen and they would be analogues of the field lines in electromagnetic theory - they are indeed field lines of gravitational field. Of the most interesting object in this context is blackhole causing critical warping of space around it so that no null ray can propagate out of it. The embedding diagram (see figure 1) would make this phenomenon transparent and visually illuminating.

Conventionally, the $(r-t)$ plane of spherically symmetric blackhole spacetime is embedded into $(2+1)$-Minkowski spacetime. Intuitively speaking, the kinematic part of the field, gravitational potential sits in $g_{tt} = 1 + 2\Phi$, while it is g_{rr} which brings in the contribution of gravitational field energy. The latter is purely relativistic feature, which is absent in the Newtonian theory and is in fact the distinguishing characteristic of general relativity (GR). When we embed the $t = const.$ slice, we are considering the pure spatial curvature which hinges on the field energy, while $(r-t)$ plane would have both the gravitational potential as well as the field energy included and hence, would refer to the entire field. The contributions from the both should act in unison and it can be demonstrated that the space curvature does indeed guide free particle towards the centre and for this to happen – the field energy to be negative.

Aseem Paranjape and *Naresh Dadhich* have attempted to relate the scalar curvature of the surface being embedded with the character of the embedding diagram (see figure 2)for the Reissner-Nordström (RN) blackhole. The $(r-t)$ plane embedding has been carried out, following the same method they do the spatial embedding. Of course, the embedding has to be done over patches for $r_+ \leq r$, $r_- \leq r \leq r_+$, $Q^2/2M \leq r \leq r_-$ where $r_\pm = M \pm \sqrt{M^2 - Q^2}$ are the two horizons. In the former case, it cannot go as far as $r = r_-$ and can even stop above r_+ if $Q^2/M^2 > 8/9$, while the spatial embedding can go down to $r = Q^2/2M$, the hard core radius, covering all the three patches. Of particular interest is the patch below r_-.

Relativistic Effects of Strong Charge and Magnetic Field on Stellar Structure

All astrophysical compact objects are considered to be charge neutral. However, at the time of birth of compact stars, like the neutron stars and strange stars, from the violent supernova process, one cannot rule out the possibility of some baryonic asymmetry. A slight asymmetry can produce a huge amount of charge inside the star which brings in a massive change in the stellar structure. *Subharthi Ray* (in collaboration with Manuel Malheiro, José P. S. Lemos and Vilson T. Zanchin) have studied the effect of charge in the stellar structure for the maximal charge content the star can hold. They find that an extra asymmetry of charged particles (say protons) with a n:p ratio as $1{:}10^{-18}$ is sufficient to produce a huge charge of 10^{20} Coulomb and an electric field of 10^{21} Volts/meter. This amount of charge can be balanced by the global balance of force (hydrostatic equilibrium equation) inside the star. The extra charge fraction does not bring any change in the nuclear matter, because such changes require the n:p ratio to be of the order of 1:1. However, from the local repulsive forces faced by each of the charged particles from the self created field, forces them to leave the star. This creates a second force imbalance and this can collapse the star further to a charged blackhole.

Ray, in collaboration with (Rodrigo Picanço and Manuel Malheiro), has made the Lane Emden analogue for the charged stars, following the work of Tooper (1964). These type of equations are very interesting, because they transform all the structure equations of the stars into a group of differential equations, which are simpler to solve than the source equations. These equations can be solved numerically for some boundary conditions and for some initial parameters.

Also, *Ray*, (in collaboration with Manuel Malheiro, Herman J. Mosquera Cuesta and Jishnu Dey) has modified the Tolman-Oppenheimer-Volkoff (TOV) equation for the presence of charge, from the conservation of the Einstein-Maxwell stress tensor. Taking just the magnetic field, the TOV brings in an interesting phenomena. There exists a critical field limit beyond which the pressure gradient of the TOV reverses its sign, thus, indicating a burst like phenomena. They suggest a model for the GRBs from the Soft Gamma Repeaters (SGRs) - which are also believed to have strong magnetic fields, and are called as magnetars, using the reversal of the gravitational force in the presence of strong magnetic field ($\sim 10^{18}$ Gauss) in some small volumes, called magnetic bubbles. The energy release of the GRBs in SGRs are of the

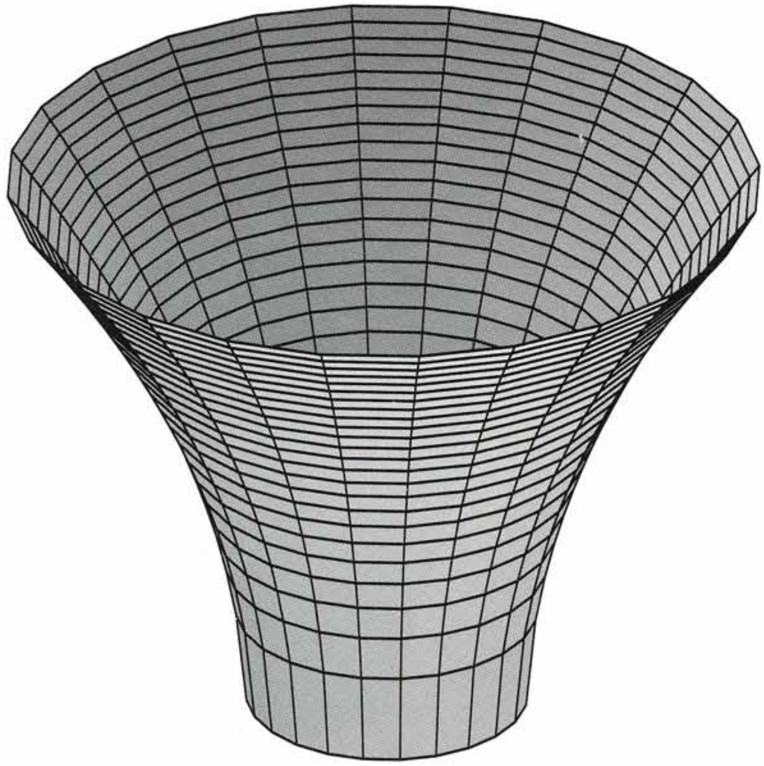

Figure 1: The whole field incorporating the contributions of both potential and field energy

order of 10^{36} erg/s. A magnetic bubble of 1 cm diameter is enough to produce such energy, where due to the burst, all the magnetic energy is released thereby quenching the high field in the bubble to a normal state. The condensation of such high fields in the bubbles comes in through the alignment of the magnetic moments of the nucleons in a density of 10^{14} gm/cc, which is the density inside a normal neutron star.

Gravitational Waves

Overview and Current Status:

The quest for gravitational waves (GW) is becoming more exciting than ever before, because of the recent technological advances in interferometric techniques. The prospect of detecting GW is now looking brighter. As predicted by Einstein's theory of relativity, GW are produced by objects predominantly having a time-varying mass quadrupole moment; 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 spacetime 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 infinitesimally 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 such tiny measurements are involved in detecting GW, the experiment is an extremely difficult enterprise. So much so, that just few decades ago, physicists did not seriously consider GW for detection or observation. But thanks to the enormous strides technology has taken in the last few decades and simultaneous efforts put in by astronomers, it has become viable to observe and study these waves in recent times.

The effort has been multipronged: it all started with resonant bar detectors and now there is a network of resonant bar detectors looking for ~ 1 millisecond bursts of GW. The bars are setting interesting upper limits on the event rates of GW bursts. Several interferometric detectors are either in operation or under construction around the globe. 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 building a 3 km detector near Pisa, Italy; 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 con-

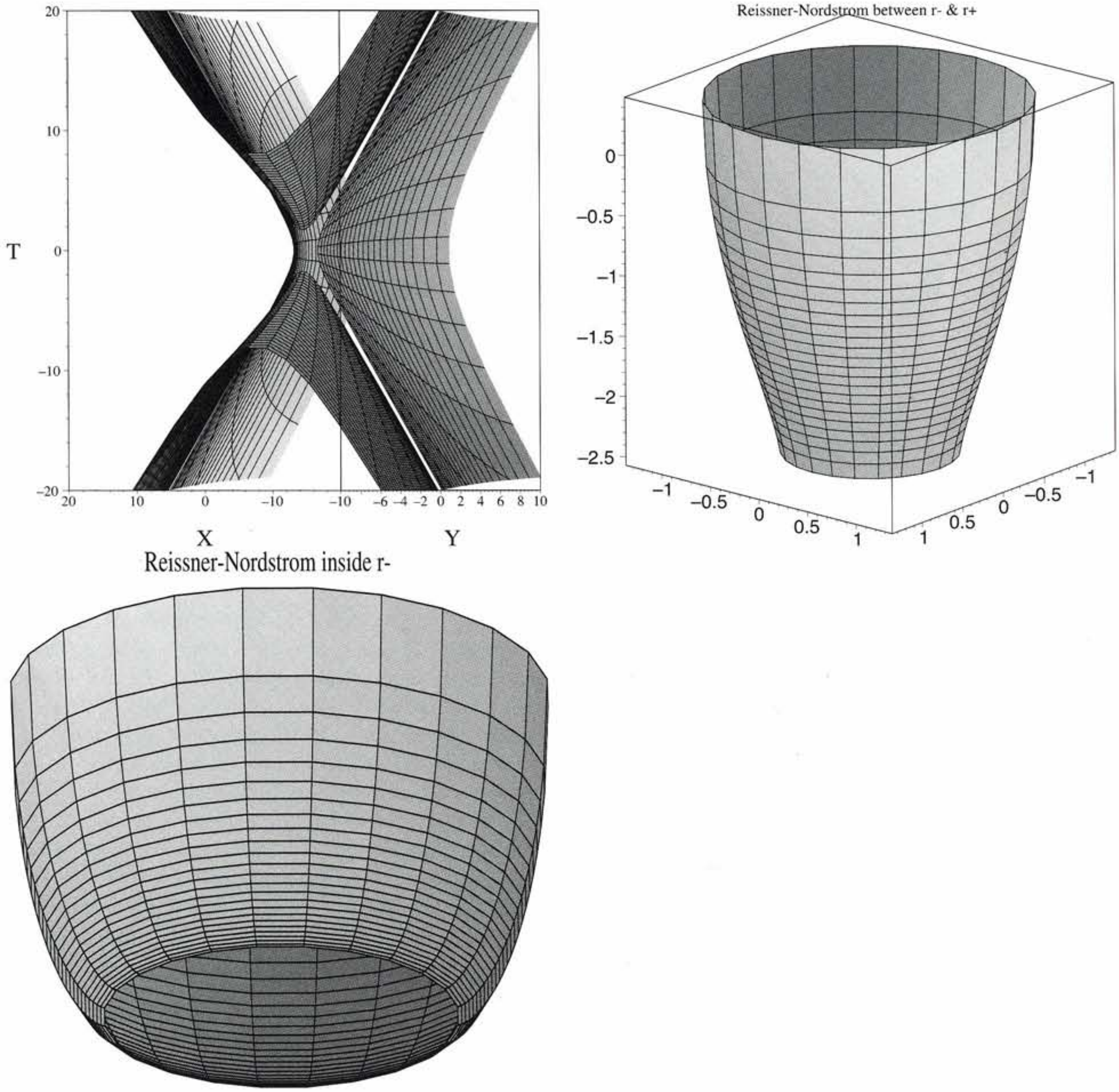

Figure 2: The contribution of the field energy alone. The embedding diagrams do reflect when the curvature changes sign from negative to positive. This would mean the contribution of field energy changing its sense *from attractive to repulsive* and it happens at $r = Q^2/M$, where interestingly $d\Phi/dr$ also changes sign; i.e., gravitational field changes sign. As mentioned in the text, the contributions from the potential as well as the field energy act in unison and hence, they should change their sense at the same radius. The point to be noted is that for attractive gravity, the field energy must be negative and the vice-versa. That is why the two have to change sign at the same radius.

struct a kilometre scale detector. 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 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.

The future holds even better prospects: there are plans for advanced LIGO detectors, which will use the R and D efforts going on in several institutions in the LIGO science collaboration. The LIGO science collaboration (LSC) consists of about 40 institutions around the world and several hundred scientists. **IUCAA is a part of the LSC**. The advanced detectors would have a sensitivity ten times better than the present detectors and 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 $10M\odot$. Blackholes 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 there is good chance of LISA in orbit as early as 2010. The astrophysical sources that LISA could observe include galactic binaries, extra-galactic supermassive blackhole binaries and coalescences, stochastic GW background from the early universe. The LISA and the ground based detectors complement each other in an essential way. Since both types of detectors have similar energy sensitivities, their different observing frequency bands will provide crucial spectral information about the source. This is as important as complementing the optical and radio observations from the ground with observations in space at submillimetre, infra red, ultra violet, X-ray and gamma-ray frequencies. LISA consists of three space-craft located 5 million kilometres apart forming an equilateral triangle. The space-craft are maintained drag-free by a complex system of accelerometers and micro-propellers. Each space-craft 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 space-craft rotate in a circle drawn through the vertices of the triangle and the LISA constellation as a whole revolves around the Sun. Each space-craft houses two lasers and two telescopes each pointing at the two distant space-craft. The light sent out by a laser in one space-craft is received by the telescope on the distant space-craft. The incoming light from the distant space-craft 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 Extended Hierarchical Search for Inspiraling Binaries:

Inspiraling binaries are the most promising sources for both interfeometric 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. The search is essentially sequential and finely covers 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 a rare event. Since in such a case, one is mostly sifting through noise, the following hierarchical strategy turns out to be efficient. S. D. Mohanty and *S. V. Dhurandhar* proposed a *two step* search where the data is searched in two stages. In the first (trigger) stage of the algorithm, a coarse set of templates is used along with a low threshold. The first stage crossings are then followed up by a more fine search in the neighbourhood of the crossings.

The hierarchical search of Mohanty was performed over the two masses of the binary. *A. Sengupta* and *Dhurandhar* from IUCAA and A. Lazzarini from Caltech extended the hierarchy to a third parameter: the time-of-arrival. This work forms part of the 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. 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. Taking into account boundary effects where the templates 'flow' out of the deemed parameter space and the rotation of templates which makes the tiling suboptimal, the cost gain factor over a flat search is about 65 for the initial LIGO noise power spectral density.

The extended search algorithm has been validated and a code has been written following LIGO specifications within the LIGO Algorithms Library (LAL) and the LIGO Data Analysis System (LDAS) environments. The code has been tested on a stand alone machine and runs successfully in the LDAS environment. The code is now being tested and validated on real data.

The second science run (S2) of the LIGO was carried out for two months from February 14 to April 14, 2004. Apart from gravitational wave channels, many useful environmental channels are recorded continuously and flagged according to the quality of the data. These supplementary channels later on help data analysts to check unusual behaviour of the detector at any given time. The data is continuously recorded at the two detector sites and is archived on high speed tapes at the LIGO laboratory at Caltech and also at other LDAS sites in a special format called the Frame format. 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 has been written to analyse 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.

At present, the LDAS implementation of the code is complete and a working data analysis pipeline exists. The testing and validation phase is currently on. 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 behaviour 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 so it is easy to check that the physical parameters corresponding to these detections match the injection parameters as closely as possible.

For S2 data analysis, 10 percent of data has been kept aside as playground data or pipeline tuning so that false alarms and false dismissals can both be minimized and also for tuning the event veto algorithms. Once the LSC is satisfied with these tunings, the pipeline will be run for the whole of S2 data. In a similar vein, 2050 samples (each 256 seconds long) of S2-playground data (available in a suitable form) are locally available at IUCAA on which, Monte Carlo chirp injections will be performed. These will help in determining the efficiency of the pipeline. At this very moment, the results of hardware injections through the pipeline at IUCAA is the acid test; some very encouraging results have been obtained which show that the code and the pipeline at IUCAA give reasonably correct outputs.

Searching for Inspiraling Binaries: Chebyschev Interpolation

Towards obtaining an efficient search method for GW signals, it is important to perform the search with minimum computational cost and also not lose out signals more than the false dismissal rate, one has decided upon. In the flat search where the template bank is very fine and the templates are very closely spaced, the filtered output is strongly correlated. This implies that one is wastefully extracting almost the same information from adjacent templates. *S. Mitra, S. V. Dhurandhar* and S. Finn are exploring the method of interpolation of the likelihood ratio or its surrogate the 'match' between the signal and the template. The goal is to sample the likelihood function as coarsely as possible in order to construct the likelihood function at all points in the parameter space. They use Chebyschev interpolation, because of the minimax property of the Chebyschev polynomials. Specifically, the match or the ambiguity function is constructed by interpolating with Chebyschev polynomials. In order to obtain the desired match, a polynomial of sufficiently high degree is required. This polynomial is constructed by evaluating it at its roots, which are now the templates. Preliminary results show that the same level of match (97% of the maximum SNR) is obtained as the flat search, if the ambiguity function is evaluated at points placed much further apart, namely, by a factor of 3.5 or so. In a parameter range where about 120 templates are required in the flat search, here only 46 templates suffice to produce the same match. These results have been obtained for the initial LIGO design curve and the quadrupole waveform. However, the two methods can be best compared by looking at the the false alarm versus false dismissal curves. Extensive simulations are being performed to achieve this end.

Laser Phase Noise Cancellation in LISA and Optimal Tracking of a GW Source:

LISA sensitivity is limited by several noise sources. A major noise source is the laser phase (frequency) noise, which arises due to phase fluctuations of the master laser. Amongst the important noise sources, laser phase noise is expected to be several orders of magnitude larger than other noises in the instrument. The current stabilisation schemes estimate this noise to about $\Delta\nu/\nu_0 \simeq 3\times10^{-14}/\sqrt{Hz}$, where ν_0 is the frequency of the laser and $\Delta\nu$ the fluctuation in frequency. If the laser frequency noise can be suppressed then the noise floor is determined by the optical-path noise, which fakes fluctuations in the lengths of optical paths and the residual acceleration of proof masses resulting from imperfect shielding of the drag-free system. The noise floor is then at an effective GW strain sensitivity $h \sim 10^{-21}$ or 10^{-22}. Thus, cancelling the laser frequency noise is vital if LISA is to reach the requisite sensitivity. Since it is impossible to maintain equal distances between space-craft, cancellation of laser frequency noise is a non-trivial problem. Several schemes have been proposed to combat this noise. In these schemes, the data streams are combined with appropriate time delays in order to cancel the laser frequency noise. *S. V. Dhurandhar*, *R. Nayak* and J-Y Vinet in an earlier work had presented a systematic and rigorous method using commutative algebra, which generates *all* the data combinations cancelling the laser frequency noise. The data combinations consist of the six suitably delayed data streams, the delays being integer multiples of the light travel times between space craft, which can be conveniently expressed in terms of polynomials in the three time-delay operators corresponding to the light travel time along the three arms. The laser noise cancellation requirement manifests as 'orthogonality' conditions on the six-tuple polynomial vectors. These data combinations or polynomial vectors form a module over a polynomial ring, well known in the literature, as the first module of syzygies.

The access to all data combinations provides the necessary redundancy - different data combinations produce different transfer functions for GW and so certain data combinations could be optimal for given astrophysical source parameters for maximising signal-to-noise (SNR).

Earlier *Nayak*, *Dhurandhar* and Pai and J-Y Vinet had investigated the problem of maximising the SNR for an almost monochromatic source averaged over all directions and polarisations. The same team has now addressed the problem of *optimally* tracking a GW source fixed on the celestial sphere in the barycentric frame. Since the orientation of LISA will change during the observational period, the antenna pattern for any given data combination will change with time, which means that, even if at a given time a particular data combination yields the highest SNR, it will not remain optimal at other times. The basic idea is to continuously switch the data combinations so that the SNR at each moment remains maximum. This problem can be conveniently investigated using the previously set up framework of rings and modules.

The study of the emission of GW from known binaries could be extremely useful for firstly, direct determination of distances, and secondly, possible small general relativistic effects, if the SNR is large enough. For this reason, it is important to optimise the sensitivity of LISA for a given astrophysical source with known direction. The optimisation methods used are algebraic in that one must solve an eigenvalue equation to determine the optimum SNRs. The low frequency case is of considerable astrophysical importance - a large fraction of GW sources are expected to be of this category - and so is dealt with specially. Secondly, it lends itself to simple analytical approximations which throw light on the results obtained. The sensitivities obtained with this strategy are compared with those obtained in the standard way. It is found that the improvement in sensitivity of the network observable over the standard Michelson observable ranges from about 34% to nearly 90% over the bandwidth of LISA for a source lying the ecliptic plane. Finally, a list of few binaries in our galaxy is presented for which the optimal SNRs and the network SNRs have been computed. A method of extracting information about the inclination angle of the orbital plane of the binary is also presented.

Cosmology and Structure Formation

Geometry, Topology and Morphology of Large Scale Structure

(a) Studying Dark Matter Simulations

One of the great observational discoveries of recent times is the realization that we live on a 'Cosmic Web' which is embedded in an accelerating Universe. Fully three dimensional large scale galaxy catalogues,.e.g., 2 degree Field Galaxy Redshift Survey (2dFGRS) and Sloan Digital Sky Survey (SDSS), reveal that the cosmic web consists of an interpenetrating network of superclusters and voids. In the wake of systematically comparing the N$-$body simulations of favoured ΛCDM cosmology with the observed Cosmic Web, it is important to understand and quantify the geometrical and topological properties of large scale structure in the ΛCDM cosmology in a deep and integrated manner.

In a recent work, *Jatush Sheth*, *Varun Sahni* and Sergei Shandarin studied the supercluster-void network in ΛCDM cosmology with emphasis on the sizes, shapes and topologies of individual superclusters and voids. This was the first attempt to comprehensively analyse the large scale structure geometry and morphology, in which over-dense (superclusters) and under-dense (voids) regions were treated on a completely equal footing. Earlier studies have emphasized either over-densities (clusters, superclusters) or under-densities (voids) as a result of which the methods used for the analysis of these two complementary entities (superclusters/voids) often vary greatly in the literature. Thus, over-dense regions have been studied using correlation functions, minimal spanning trees, shape functions, etc., whereas, voids have been constructed from point processes using elaborate boundary and volume filling techniques.

In their investigation, *Sheth*, *Sahni* and Shandarin studied the large scale structure of the universe by considering the geometry and topology of isodensity surfaces $\delta(\mathbf{x}) \equiv \delta\rho(\mathbf{x})/\bar{\rho} = const.$ The density field was prepared by smoothing the $z = 0$ distribution of 256^3 particles over a 128^3 grid (resolution $\ell_g = 1.875h^{-1}$) by a Gaussian kernel of size $5\ h^{-1}$Mpc. At a given threshold $\delta_{\rm TH}$, regions having higher than threshold density ($\delta > \delta_{\rm TH}$) were called "superclusters", while regions with $\delta < \delta_{\rm TH}$ were called "voids". In contrast to many studies, the voids and superclusters were not 'cooked up' with predefined shapes, but individual objects were isolated from the dark matter density field (obtained from ΛCDM N-body simulation of Virgo group) by constructing isodensity surfaces. The sizes and shapes of these objects were computed on the premise of Minkowski functionals. To this end, SURFGEN (reported in earlier Annual Reports) was used as a workhorse in creating isodensity surfaces and evaluating Minkowski functionals for these surfaces.

Figure 3 focusses on the topological properties of superclusters and voids at a set of volume filling fractions. Filling fraction stands for the ratio of overdense (underdense) volume to the total volume. It shows the genus curve in a slightly unusual form. The half of the curve corresponding to high density thresholds is shown as a function of the over-density filling fraction (solid line) while the other half corresponding to low density thresholds is plotted as a function of the under-density filling factor FF_V (dashed line). This allows to better illustrate the deformations of the curve due to *nonlinear effects.* The Gaussian genus curve is symmetric for positive and negative thresholds thus, both parts of it overlap in Figure 3 (dotted line). The vertical dotted lines mark three thresholds: the supercluster percolation threshold at $FF = FF_C \approx 0.07$, the void percolation threshold at $FF = FF_V \approx 0.22$ and both the percolation thresholds in a Gaussian field at $FF = FF_C = FF_V \approx 0.16$.

A marked decrease in the amplitude of the genus curve compared to the Gaussian curve at small FF is noticeable for both over-dense and under-dense excursion sets. (Small $FF \equiv$ high density for superclusters and low density for voids.) The global genus curve has no significant features at either percolation threshold $FF_C \approx 0.07$ or $FF_V \approx 0.22$. The right panel of Figure 1 shows the ratios of the genus of the largest object G_{max} to the global genus of the excursion set G_{ES} for both superclusters (solid line) and voids (dashed line). Both percolation curves shown in the right panel would overlap in the case of a Gaussian field (not shown) and demonstrate the percolation transition at $FF \approx 0.16$.

At any given threshold of density near percolation, there are numerous number of superclusters and voids. However, many of these are quite small, and enter only as noise. Hence, only the the most massive superclusters contributing 90% of all mass in non-percolating over-dense objects and most voluminous voids contributing 90% of total volume in non-percolating under-dense objects were analysed. The rest of the discussion applies to these objects. The smallest over-dense and under-dense objects were excluded from the analysis.

Three characteristic sizes and shapes of superclusters and voids can be estimated from Minkowski functionals of every object. Figure 4 shows the median, 75% and 95% intervals for the length L, breadth B and thickness T of the superclusters and voids. These sizes are defined in the caption of this figure. The sizes of superclusters are shown as a function of FF_C, while the sizes of voids as a function of FF_V. It is surprising that the median thickness of superclusters depends on the threshold so weakly; it is within 4–6 h^{-1}Mpc interval for a range of thresholds between $0 \lesssim \delta \lesssim 6$. This may indicate that the actual thickness of superclusters is significantly smaller and the measured values reflect the width of the smoothing window ($L_s = 5h^{-1}$Mpc). The breadth of superclusters is not much larger than the thickness and it is likely that this quantity is also affected by the width of the filtering window. Voids are a little fatter than superclusters and their median thickness reaches about 9 h^{-1} Mpc at the percolation threshold. Interestingly voids are also wider and longer than superclusters (please note the logarith-

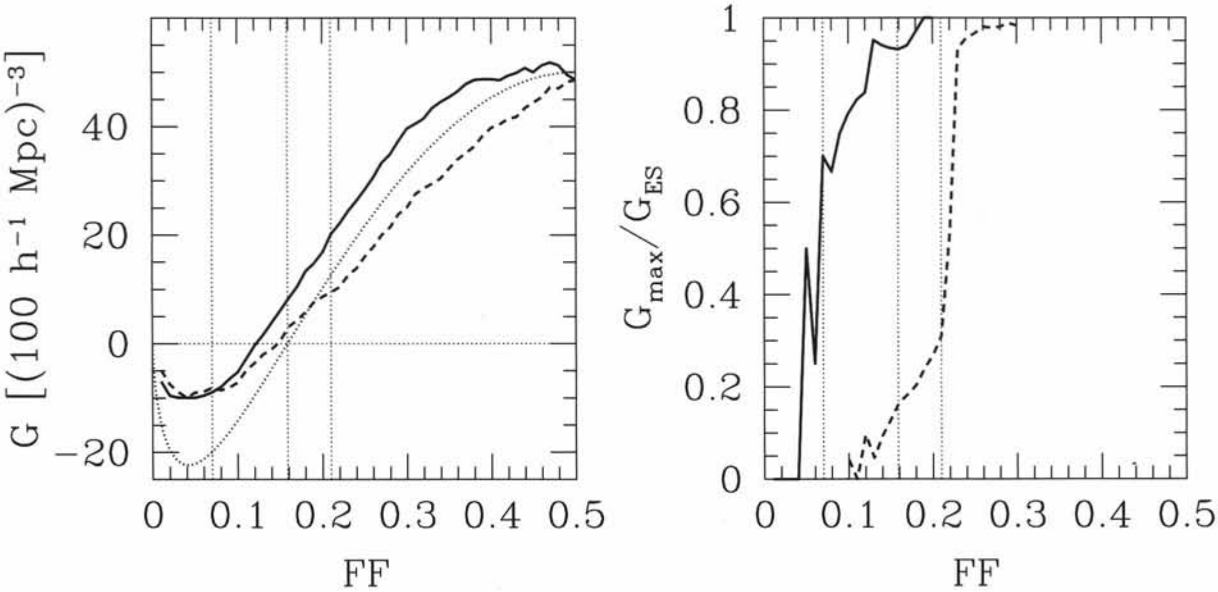

Figure 3: *Left panel*: Global genus is shown as a function of the filling factor for the density field smoothed with $L_s = 5\ h^{-1}$ Mpc. (Details given in the text.) *Right panel*: Percolation transitions in the same density field as indicated; the genus of the largest supercluster (solid line) and largest void (dashed line). The vertical dotted lines mark the percolation thresholds similar to left panel.

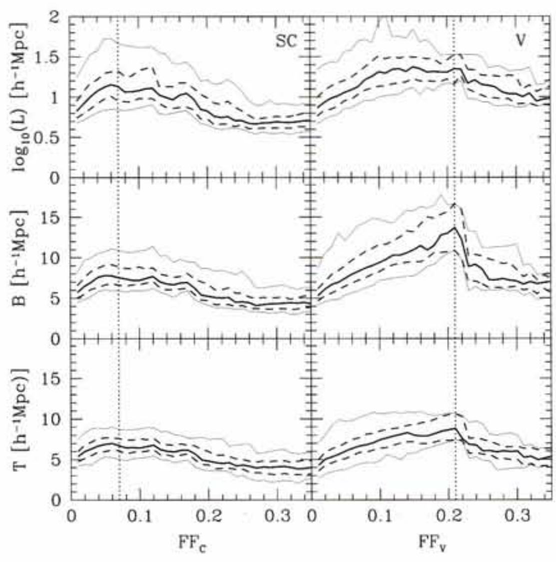

Figure 4: The length L $(=\frac{C}{4\pi})$, breadth B $(=\frac{S}{C})$ and thickness T $(=\frac{3V}{S})$ of all structures with the exception of the largest is shown as a function of the corresponding filling factor. Here, V stands for volume enclosed by the surface, S is its area and C is the integrated mean curvature of the surface.

mic scale used for length). It was concluded from this study that the longest 25% of superclusters are longer than about 50 h^{-1} Mpc and 25% of voids are longer than about 60 h^{-1} Mpc.

Both superclusters and voids reach their largest sizes near their respective percolation thresholds: $FF_C \approx 0.07$ for superclusters and $FF_V \approx 0.22$ for voids. Figure 5 shows the scatter plots of three characteristic sizes (L, B, and T) versus mass for superclusters and versus volume for voids. The combined plots are made for $FF_C = 0.06, 0.07$ and 0.08 for superclusters and for $FF_V = 0.21, 0.22$ and 0.23 for voids. The solid lines show the radius of a sphere having the same volume as a given object ($R = (3V/4\pi)^{1/3}$). All three sizes show a significant correlation with the mass:

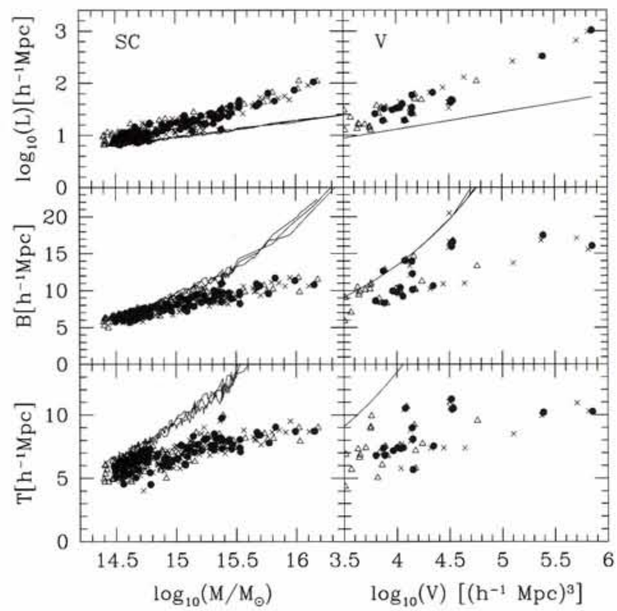

Figure 5: The length, breadth, and thickness versus mass for superclusters and versus volume for voids at percolation. Solid circles show the relation at percolation thresholds: $FF_C = 0.07$ for superclusters and $FF_V = 0.22$ for voids. Crosses show the parameters before percolation ($FF_C = 0.06$ for superclusters and $FF_V = 0.21$ for voids) and empty triangles after percolation ($FF_C = 0.08$ for superclusters and $FF_V = 0.23$ for voids). Solid lines show the radius of the sphere having the same volume as the corresponding object. Note the logarithmic scale used for the length. Three lines correspond to three different thresholds.

the greater the mass, the greater the thickness, breadth and length. The thickness and breadth approximately double their values, and length grows by over an order of magnitude when the mass increases from about $10^{14.5} M_\odot$ to $10^{16.5} M_\odot$. Both the thickness and breadth are considerably smaller than the radius R of a sphere having similar volume for large superclusters ($M \gtrsim 10^{15}\ M_\odot$) as well as for large voids ($V \gtrsim 10^4\ (h^{-1}\ Mpc)^3$). On the other hand, the length is considerably greater than R. This is a clear manifestation of the anisotropy of large-scale objects. Figure 6 shows one of the top 5 superclusters near the onset of percolation. Figure 7 illustrates a generic, *deep* void, just before the voids percolate. The two figures serve to illustrate the complex morphology exhibited by both superclusters and voids.

The plots of planarities and filamentarities for the same objects show a similar correlation: the larger the mass of a supercluster or the larger the volume of a void, the greater its planarity and filamentarity (Fig. 8). One can clearly see that the largest objects (superclusters with $M > 10^{15} M_\odot$ and voids with $V > 10^4 (h^{-1} Mpc)^3$) are the most anisotropic large-scale objects. Note that voids display a higher level of planarity when compared to superclusters. *Indeed, one of the most noticeable results of this analysis is the evidence that voids defined near the onset of percolation of the underdense excursion set are significantly non-spherical.* Finally, the larger the mass of a supercluster, the greater is its mean density, and the more voluminous a void is, the lower is its mean density.

Visual inspection shows that superclusters and voids have noticeable substructure. Isolated voids inside superclusters and isolated clusters and superclusters inside voids are obvious examples. Theory and targeted N-body simulations show that voids are also filled with smaller filaments of high density. In the ΛCDM universe, these filaments are strong enough to survive smoothing on a scale $L_s = 5h^{-1} Mpc$. Figure 9 shows the maximum of the genus of isolated superclusters and voids.

As it can be seen in Figure 9, the genus of an isolated supercluster can be as large as five. It means that there are *at least* five tunnels through the supercluster. The number of tunnels could be even greater if the supercluster harbors a few small isolated voids within itself. (Isolated voids within the supercluster can decrease its genus and compensate for the presence of tunnels which increase the genus value. The vast majority of superclusters are topologically isomorphic to a sphere, i.e., $G = 0$, but the most massive ones have genus greater than unity. A supercluster with genus of unity is homeomorphic to a doughnut and one with genus of two to a pretzel.) The substructure of

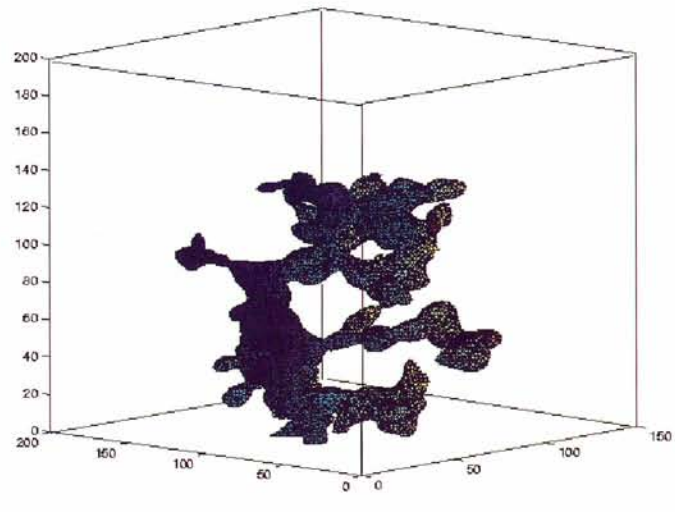

Figure 6: The largest supercluster at a density threshold corresponding to $FF_C \sim 6\%$, $\delta \sim 2.5$. This is a threshold of density just before the onset of percolation. The supercluster shows genus value of 2, and its size is characterised by (T, B, L)=(8.61, 10.95, 358.82)h^{-1}Mpc. Through the pair of Shapefinders (P, F)=(0.12, 0.94), we infer that the supercluster is an extremely filamentary object, which is in agreement with its visual appearance. The mass enclosed by the supercluster is $M = 1.26 \times 10^{16} h^{-1} M_{\odot}$, which is an order of magnitude larger than the mass of a typical rich Abell cluster.

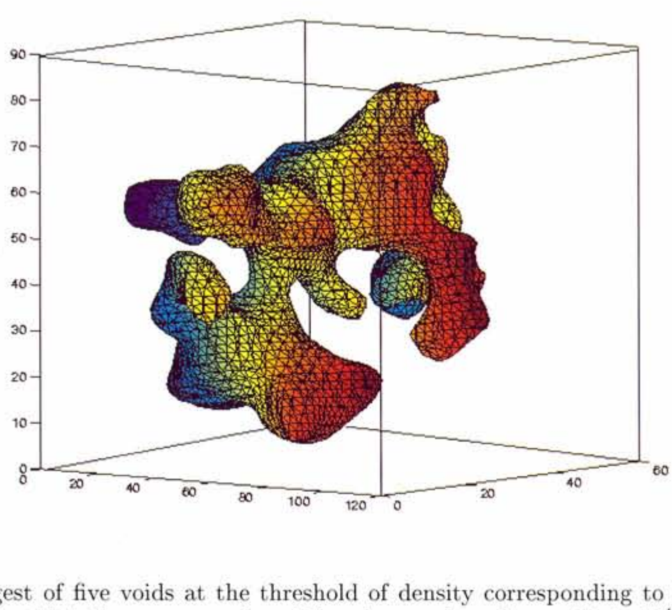

Figure 7: One of the largest of five voids at the threshold of density corresponding to FF_V= 0.1, or $\delta_V \simeq -0.7$. This is a generic, deep void, which shows genus value of 1, and occupies volume of $5.7 \times 10^4 [h^{-1}\text{Mpc}]^3$. Its dimensions are given by (T, B, L) = (11.15, 14.28, 85.44) h^{-1}Mpc. The morphology of the void is mildly planar and dominantly filamentary, as inferred by (P, F)=(0.12, 0.71).

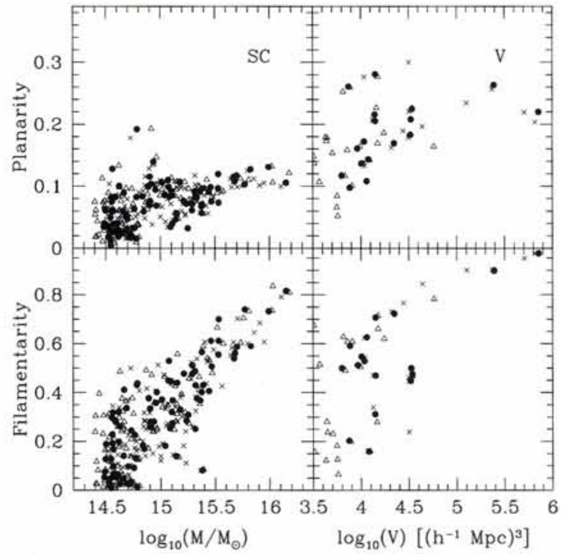

Figure 8: The planarity and filamentarity vs mass (for superclusters) and vs volume (for voids) at percolation. Note that at percolation $\delta_C \simeq 1.8$ for superclusters and $\delta_V \simeq -0.5$ for voids.

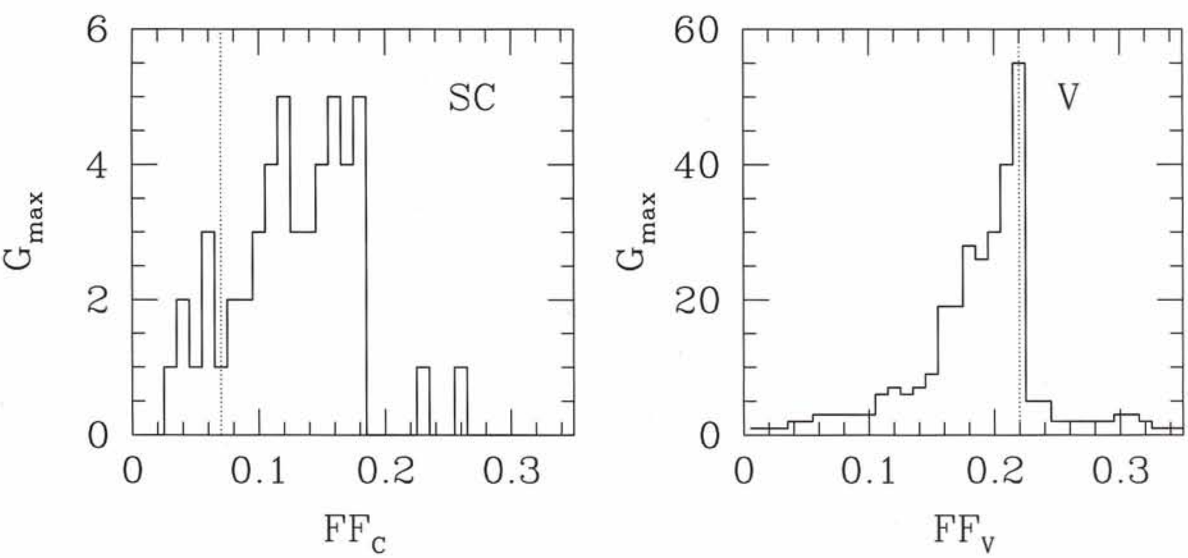

Figure 9: The maximum of genus as a function of the filling factor. Left panel: The maximum genus in isolated superclusters. Right panel: The maximum genus in isolated voids. Note the difference of the scales on the vertical axis.

voids is considerably more complex. The largest genus of voids detected in this simulation is 55, therefore, at least 55 filaments span through the void ! This finding is in general agreement with predictions of Adhesion model and with other studies reported in the literature.

(b) Morphological Study of mock SDSS Catalogues

There is ample observational evidence to suggest that the dark matter is almost 20 times as abundant as the baryonic or visible component of the universe. Furthermore, dark matter is believed to be collisionless and to interact only through gravity. For this reason, the clustering of dark matter is very well understood theoretically, and gravitational clustering in dark matter has been simulated to great precision using cosmological N−body simulations. However, galaxies are composed of baryons and it is still a subject of some debate as to how galaxies form and evolve together with the evolving dark matter. Most theoretical studies assume that baryons follow dark matter on large scales, i.e., on the scales of superclusters. However, on smaller scales, it is not clear how the galaxies may be distributed relative to the dominant dark matter component. In the absence of a complete understanding of baryonic physics, one can try and derive the galaxy distribution from the (simulated) dark matter distribution using a well-motivated ansatz. Such an ansatz is expected to provide the observed bias between the dark matter and galaxies and to satisfy observational constraints on the galaxy-distribution such as the two-point correlation function and the power spectrum.

Sheth analysed 10 realizations of mock SDSS catalogue due to τCDM model and compared the galaxy distributions due to this model with that due to a given ΛCDM mock SDSS catalogue. In *all* the 11 realizations, the galaxy distributions were constrained to reproduce the two−point correlation function (hereafter, TPCF) of galaxies measured from the APM catalogue. Since TPCF is a standard statistic with which to quantify the clustering of matter, and is the same for both the models, it would be a unique challange to quantify the two models and discriminate them using MFs.

Sheth prepared volume limited samples going as deep as about $\simeq$600 h^{-1}Mpc, and ensured the same number density of galaxies across all the 11 samples. The number of galaxies included in the analysis were about $\simeq 2.19\times10^5$. A grid with resolution of 3.5 h^{-1}Mpc was fitted onto the samples, and the samples were smoothed at a length-scale of 6 h^{-1}Mpc using a Gaussian kernel.

Figure 10 shows the samples due to the 2 models; both the samples share the same initial set of random numbers.

Global MFs of superclusters were evaluated for both the models, and 10 realizations of τCDM model were used to investigate the effect of cosmic variance on MFs as estimated by SURFGEN. MFs were studied as functions of overdense volume filling fraction.

Figure 11 shows two global MFs − mean curvature and genus − as functions of overdense volume filling fraction FF. The solid curves represent the mean global MFs due to τCDM model and the error-bars stand for the 1σ standard deviation. The dashed curves stand for the ΛCDM model. Note that the global MFs of the τCDM model are extremely well constrained. This shows the remarkable accuracy with which SURFGEN will enable us to measure the MFs of large scale structure due to large datasets like SDSS and 2dFGRS. Further note that the two models can be distinguished from each other with sufficient confidence using the global mean curvature and genus measurements at $FF \leq 0.5$. From the dynamical point of view, these results carry some surprises. It has been widely established earlier that the amplitude of the genus-curve drops as the N−body system develops phase correlations. Given two density fields, the system with larger genus-amplitude shows many more tunnels/voids which are, therefore, smaller in size. As time progresses, the voids are expected to expand and merge, leading to a drop in the genus-amplitude, while the phase correlations continue to grow. With this simple model, one could correlate the amount of clustering with the relative smallness of the amplitude of genus, and therefore, of the area and the mean curvature. Going by this reasoning, one can conclude from Figure 11 that the ΛCDM galaxy distribution is relatively less clustered compared to that due to τCDM. *Sheth*, *Sahni*, Shandarin and Sathyaprakash reported in the earlier Annual Report that the dark matter distribution of τCDM model shows considerably larger amplitudes for the MFs compared to the ΛCDM model, whereas, one finds the reverse trend in the MFs of "the galaxy distributions" due to the same two models. Evidently biasing appears to be a source of this effect.

To establish this effect more firmly, *Sheth* analysed the τCDM and ΛCDM dark matter Virgo simulations adopting the same resolution (ℓ_g=3.5h^{-1}Mpc) and the smoothing scale (L_s=6h^{-1}Mpc) as utilised in the present analysis. Here , he randomly chose 25% of the dark matter particles, and studied 5 such realizations for both the models. It was confirmed that the MFs are fairly stable even while working with this fraction of particles, and do indeed compare well with MFs computed using the full sample of particles. So as not to introduce any bias due to redshift space dis-

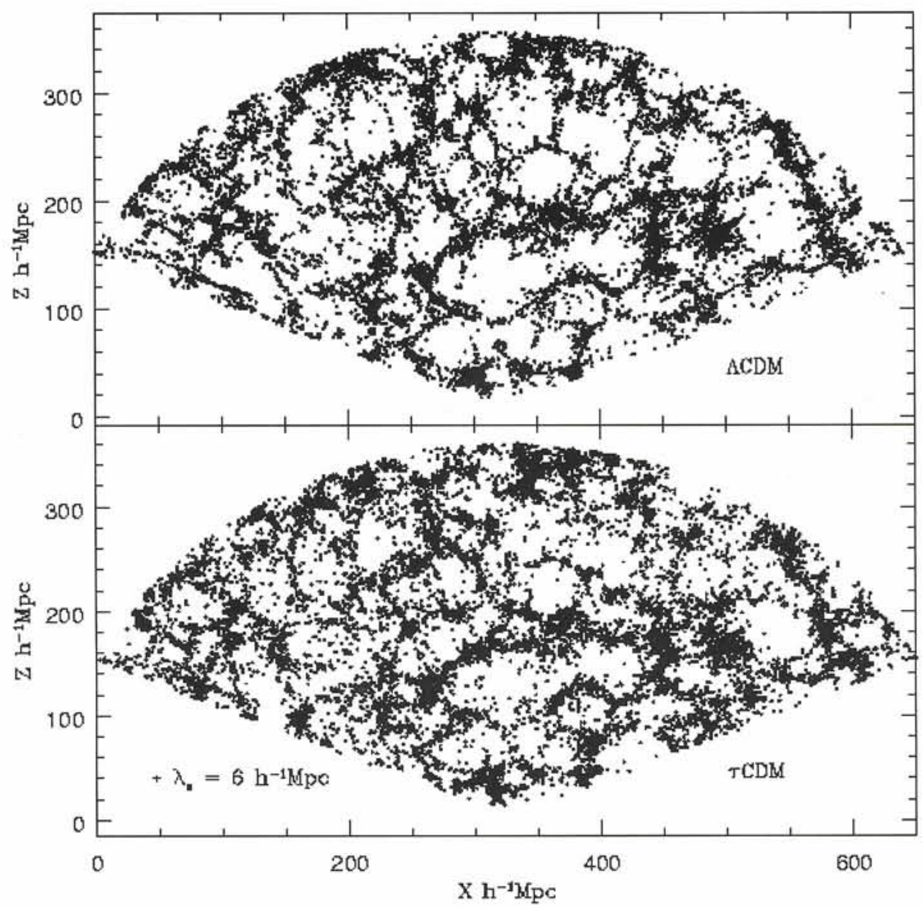

Figure 10: The central slices of the ΛCDM mock SDSS catalogue and of one of the realizations of its τCDM counterpart. Both the catalogues refer to the same set of random numbers. The coordinates refer to the redshift space positions. The *fingers-of-God* effect is evident from these slices. The galaxy-distribution is constrained to match the observed 2-point correlation function, and the two slices qualitatively look quite similar. The voids in ΛCDM are, however, noted to be much cleaner, and the *fingers-of-God* effect stronger. The galaxy distributions are smoothed with a Gaussian window of size 6 h^{-1}Mpc. In the left corner of the bottom panel, we show that the window-size to give a feel for the effective smoothing done around every galaxy.

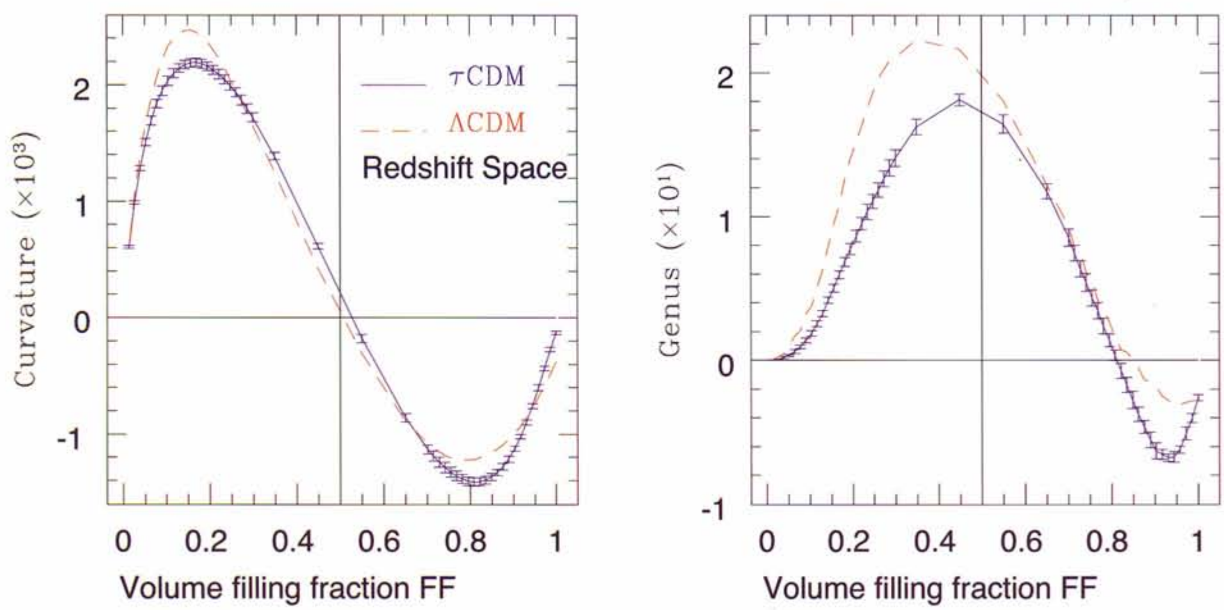

Figure 11: Two of the global Minkowski functionals – mean curvature and genus – are evaluated at 50 density levels at a common set of volume filling fractions and are studied here w.r.t. FF. We show that the values of global MFs as normalised to the volume of $[100\ h^{-1}\mathrm{Mpc}]^3$. The global MFs for τCDM model are averaged over the available 10 realizations (solid lines) and the errorbars represent 1σ deviation. Assuming the same level of accuracy for ΛCDM, we may conclude that these global MFs with volume parametrisation can indeed *clearly* distinguish τCDM from ΛCDM. Considering the fact that all the samples show the same two-point correlation function, the above difference can be attributed to the higher order correlation functions. MFs are able to respond to such a difference, and hence can be taken to be robust measures for quantifying the cosmic web.

tortions, the global MFs were further computed for galaxy catalogues in real space.

The effect of biasing is most dramatically seen in the global genus-curve of the dark matter and galaxies (see Figure 12). Notice that the amplitudes $\mathcal{G}_{DM}^{\Lambda} < \mathcal{G}_{DM}^{\tau}$, whereas $\mathcal{G}_{G}^{\Lambda} > \mathcal{G}_{G}^{\tau}$. Here subscripts DM and G stand for "dark matter" and "galaxies", respectively. To conclude, the matter distribution in ΛCDM is more clustered than that in τCDM, but this trend reverses as one investigates biased distributions of galaxies due to the same two models: the galaxy distribution due to ΛCDM appears to be less clustered than that due to τCDM. From this analysis, it is clear that bias in various structure formation scenarios can play important role, and comparing the dark matter distributions with the SDSS and/or 2dFGRS galaxy distributions is not an advisable way of testing the model(s) of structure formation against the observations. A realistic treatment of bias en route the proper treatment of the physics of galaxy formation in preparing a mock catalogue, is desired in any such exercise.

In order to test whether the length of superclusters can be utilised to discriminate between (Λ, τ)CDM, *Sheth* further studied the cumulative probability function (CPF) of length of superclusters for both the models. Figure 13 shows the results, where the CPF(L) have been evaluated at FF=7.8 per cent (at the onset of percolation) and at FF=11.7 per cent (after the percolation). Notice that at the onset of percolation, the length of the longest τCDM superclusters could be as large as 90 h^{-1}Mpc, whereas, their ΛCDM counterpart structures, which exhibit same degree of statistical significance, are relatively shorter with $L_{\max} \geq 55$ h^{-1}Mpc. Thus, the τCDM superclusters tend to be statistically longer than their ΛCDM counterpart structures.

The large-scale coherence in the superclusters is attributed to the phase-correlations in the density field; the higher the degree of phase-correlations, the larger is the length-scale of coherence. Based on this, and the earlier observation that τCDM galaxy distribution shows larger degree of phase-correlations than ΛCDM, we indeed anticipate the τCDM superclusters to be longer than those in ΛCDM. As we can see, the result reported here agrees well with this anticipation. This is a considerable success for the ansatz of the Shapefinder quantifying length, for as we noted above, it helps us capture the relative effect of phase-correlations among rival models of structure formation.

After the percolation, the longest structure dominates the survey volume and enters only as a Poisson fluctuation in the CPF of length. The remaining structures are evidently shorter in length compared to their longer progenitors at percolation, so that CPF(L) are confined to lower values of L. This effect is evident in the right panel of Figure 13. In both the panels, shown as dashed line is the CPF(L) due to the first realization of τCDM, which shares its set of initial random numbers with the ΛCDM simulation. We note the sharp tendency of τCDM structures to be longer than those of ΛCDM, an effect which successfully enables us to distinguish the two models.

(c) Constraining the size of longest filaments in the universe

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

The two-point correlation function of galaxies fluctuates around zero beyond about 20 Mpc. But we do see structures spanning across much longer length scales. Clearly, detection of the longer structures can be attributed to non-zero higher order correlation functions and correlations among phases. Much like in the case of two-point correlation function, we can assign an effective length to all the correlation functions, beyond which their contribution is negligible. A situation may be envisaged wherein, there is a maximum length-scale in the cosmic density field beyond which the phase correlations are negligibly small. Naturally, this length-scale refers to the largest coherent structures in the universe. Further, the universe can be interpreted as composed of representative volume elements of this size. Thus, this scale is also a scale of homogeneity. *Sheth*, S. Bharadwaj and S. Bhavsar reported measurement of the scale of homogeneity, and of the size of the longest superclusters using 6 slices of the Las Campanas Redshift Survey (LCRS). Here, they adopted a Minkowski functional-based morphological shapefinder, Filamentarity to measure the shapes and sizes of superclusters. Coupled to this, they invoked a statistical method of Cosmic Shuffle to establish the scale of homogeneity.

The slices were divided into square areas of size L, and these squares were shuffled randomly. The length-scale L was varied from 10 to 100 h^{-1}Mpc. The shuffled samples of galaxies have the same correlations upto scale L, whereas, any correlations on scales larger than L are randomised. Filamentarity in all the shuffled samples was also measured. The largest value of L, L_{max} was measured, for which the filamentarity in shuffled and unshuffled samples would match. L_{max} was interpreted to be the

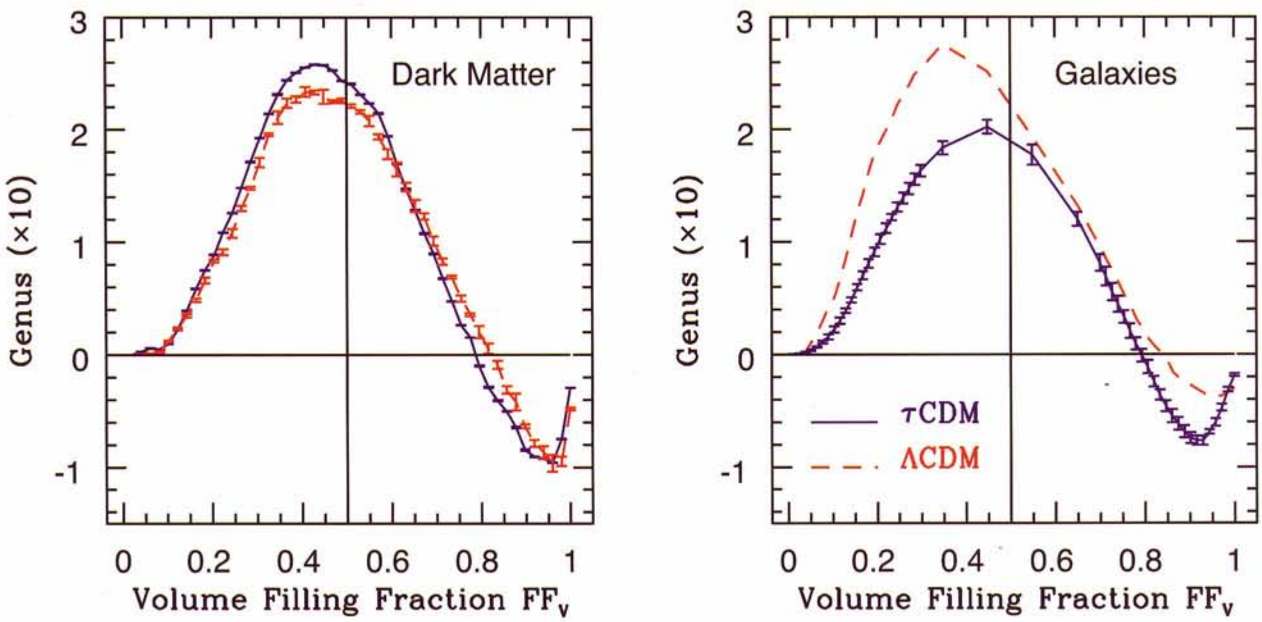

Figure 12: *Left panel:* Global genus curves of ΛCDM and τCDM matter distributions are shown. The values refer to a volume of [100 h^{-1}Mpc]^3. The 1σ error-bars are due to 5 realizations of both the models, each with 25% of the total number of particles. Calculations are carried out on a grid of resolution 3.5 h^{-1}Mpc after smoothing the density fields with 6 h^{-1}Mpc Gaussian kernel. *Right panel:* The galaxy catalogues due to the two models are analysed in *real* space under identical conditions. This figure illustrates the phenomenon of phase-reversal.

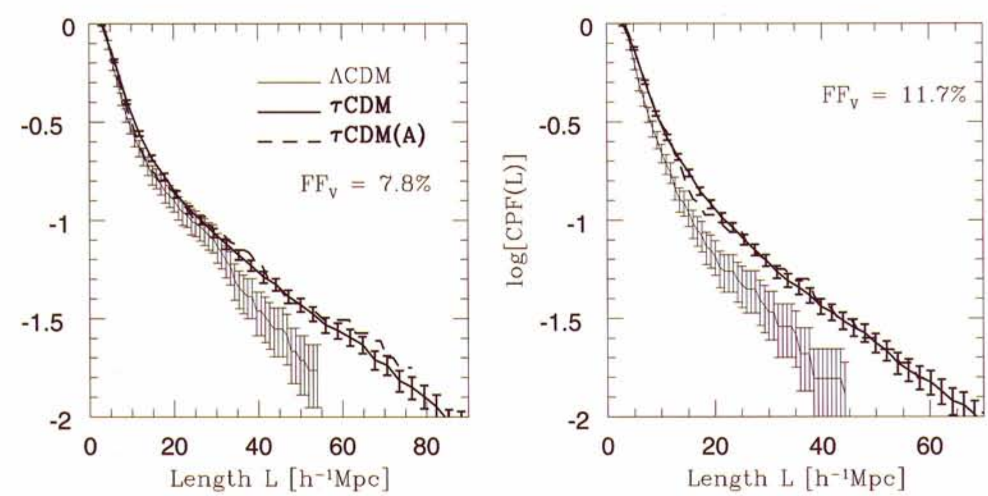

Figure 13: The cumulative probability functions of length $\mathcal{L}$ for clusters of τCDM and ΛCDM at two thresholds of density corresponding to FF_V=7.8 per cent (just before the onset of percolation) and FF_V=11.4 per cent (after the onset of percolation). It is found that the CPFs of the two models to be distinctly different at longer length-scales. The dashed line refers to the CPFs due to the first realization of τCDM which shares the initial set of random numbers with ΛCDM. The largest superclusters of τCDM are systematically larger than those due to ΛCDM.

largest length-scale of coherence upto which correlation functions in LSS contribute significantly. Beyond L_{max}, the LSS statistically repeats itself. Hence, L_{max} can also be interpreted as the scale of homogeneity of LSS. L_{max} was found to be between 60 to 80 h^{-1}Mpc in all the LCRS slices.

Statefinders : New Diagnostics for Dark Energy

*Ujjaini Alam*and *Varun Sahni*have been studying the properties of the mysterious dark energy component of the universe using new methods. The existence of this dark energy has been proved conclusively from observations of distant supernovae, as also independently from observations of the cosmic microwave background and large scale structure in the universe. It is well-known now that we live in an accelerating universe, and this acceleration is caused by a negative pressure energy component which dominates over matter at present. However, there is no consensus yet on the nature of dark energy. Many models have been proposed to explain the existence of dark energy, from the simplest cosmological constant (ΛCDM) to the higher dimensional braneworld theories. Indeed, even as each day passes, a new physically motivated model is thought up to explain the conundrum of dark energy. It is therefore the need of the hour to figure out a suitable way to discriminate between all these different models of dark energy, in particular, to distinguish the constant dark energy model (ΛCDM) from the models with evolving dark energy. To this goal, *Alam*, *Sahni*, T. D. Saini and A.A. Starobinsky have proposed a new pair of cosmological parameters, called the "Statefinder pair" which have very specific properties and can be used to break the degeneracies present in the different models of dark energy.

The statefinder pair $\{r, s\}$ is constant at $1, 0$ for ΛCDM. For other models, it behaves differently. For the quintessence models with constant equation of state of dark energy, the statefinder r varies with time, whereas the statefinder s is constant. For quintessence models where dark energy is depicted by a scalar field with tracker potential, and for which both the dark energy density and equation of state evolve, the statefinders both vary over time. In Figure 14, the evolution of the statefinder pair for different models of dark energy is shown. It is clear from this figure that different models show very different evolution of the statefinder pair. The vertical line at $s = 0$ effectively divides the $r - s$ plane into two halves. The left half contains Chaplygin gas (CG) models of dark energy which commence their evolution from $r = 1, s = -1$ and end it at the ΛCDM fixed point $(r = 1, s = 0)$ in the future. The quintessence models occupy the right half of the $r - s$ plane. These models commence their evolution from the right of the ΛCDM fixed point and, like CG, are also attracted towards the ΛCDM fixed point in the future. For quiessence models, r decreases monotonically while s remains constant. For quintessence models, on the other hand, s decreases monotonically to zero, while r first decreases to a minimum value then increases to unity. It is interesting that the second statefinder, s, is positive for quintessence models, but negative for the CG. Similarly the first statefinder, r, is < 1 (> 1) for quintessence (CG). The distinctive trajectories which quiessence, quintessence and CG follow in the $r - s$ plane demonstrates quite strikingly the contrasting behaviour of different dark energy models for these parameters. The efficacy of this diagnostic pair can be further studied by simulating data for different models of dark energy and checking the accuracy with which these parameters can be reconstructed from this data. Using the errors and redshift distribution of supernovae which is expected to be obtained by the space-based mission SuperNova Acceleration Probe (SNAP), a 1000 realisations of data were generated for a fiducial model of ΛCDM. Using a model independent fit, the statefinder pair is reconstructed for this dataset. Figure 15 shows the results obtained for these realisations for the statefinder pair. Here, the statefinder pair is averaged over redshift $\{r, \bar{s}\}$ to make the demonstration clearer. From the figure, it is seen that the statefinder pair are quite useful in discerning the cosmological constant model from other models of dark energy even when the matter density is not known to high accuracy. If it is known very accurately, then they behave even better. Since, the measurements on matter density are getting only better over time, and more and more supernovae are being observed every day, it is expected that the statefinder pair can be used successfully as a tool for understanding the riddle of dark energy.

Constraints on Evolution of Dark Energy

Alam, *Sahni*, Saini and A.A. Starobinsky have also worked on extracting information about dark energy from the current supernova data over the past year. The latest data set consisting of 194 SNe, published by the HZT (High-z Supernova Search Team) has been used for this purpose. The goal is to test the data for evidence of evolution (or lack there of) of dark energy. Earlier studies of this sort have concentrated on models with a constant equation of state or models which do not violate the Weak Energy Condition $(w > -1)$. It is found

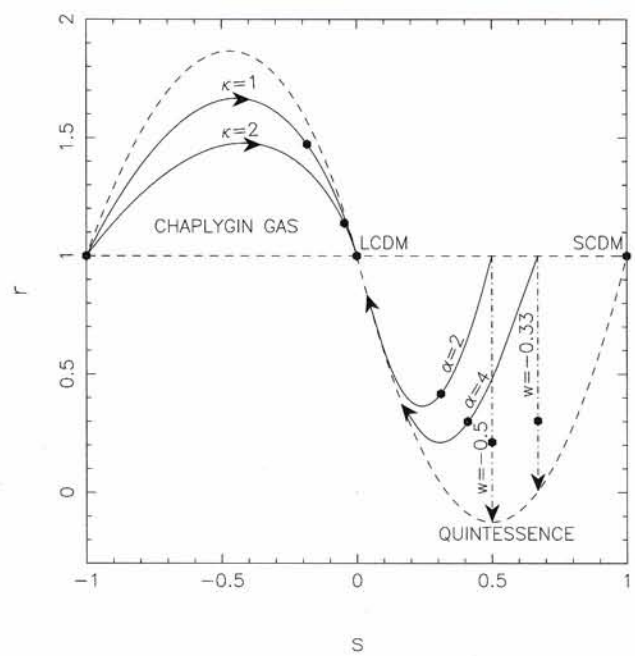

Figure 14: The time evolution of the statefinder pair $\{r, s\}$ for quintessence models and the Chaplygin gas. Quintessence models lie to the right of the ΛCDM fixed point ($r = 1, s = 0$) (solid lines represent scalar fields with tracker potentials, dot-dashed lines representing quiessence with constant equation of state). For quiessence models, s remains constant while r declines monotonically. For tracker models, s monotonically decreases to zero whereas, r first decreases from unity to a minimum value, then rises to unity. These models tend to approach the ΛCDM fixed point ($r = 1, s = 0$) from the right at in the past. Chaplygin gas models (solid lines) lie to the left of the ΛCDM fixed point. For these models, κ is the ratio between matter density and the density of the Chaplygin gas at early times. For all Chaplygin gas models, s monotonically increases to zero from -1, whereas r first increases from unity to a maximum value, then decreases (to unity). The dashed curve in the lower right is the envelope of all quintessence models, while the dashed curve in the upper left is the envelope of Chaplygin gas models.

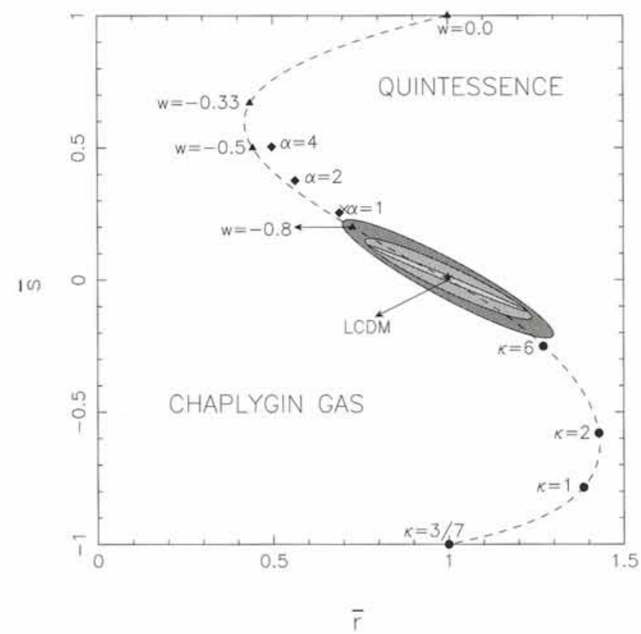

Figure 15: The 3σ confidence levels in the statefinders $\{\bar{r}, \bar{s}\}$. The fiducial model is assumed to be ΛCDM and a polynomial fit to dark energy is used to reconstruct the statefinder pair. The current observational uncertainty in the value of the matter density is incorporated by marginalising over the value of Ω_{0m}. The dark grey outer contour shows results for the Gaussian prior $\Omega_{0m} = 0.3 \pm \sigma_{\Omega_{0m}}$ with $\sigma_{\Omega_{0m}} = 0.05$, the grey contour in the middle uses the Gaussian prior $\sigma_{\Omega_{0m}} = 0.015$, and the light grey contour is when $\Omega_{0m} = 0.3$ exactly. The dashed line above the ΛCDM fixed point represents the family of quiessence models having $w =$ constant. The dashed line below the ΛCDM fixed point shows Chaplygin gas models. The ΛCDM fixed point is marked by a solid star. In the upper half of the figure, the solid rhombi correspond to tracker potentials while triangles show $w =$ constant quiessence models. In the lower half of both panels, solid circles show Chaplygin gas models with different values of κ. (The constant κ gives the initial ratio between cold dark matter and the Chaplygin gas). All these models are for $\Omega_{0m} = 0.3$. The cross marks the braneworld model with $\Omega_{0m} = 0.24$ which best fits the current supernova data. It is clear that the Statefinder pair do a good job of differentiating the cosmological constant model from the other models even when Ω_{0m} is not known to very high accuracy.

that a maximum likelihood analysis of this data without assuming such priors on the equation of state yields rather unexpected results. Both the dark energy density and the dark energy equation of state behave in a way that is very different than that expected for the cosmological constant.

In figure 16, the logarithmic variation of the dark energy density with redshift for $\Omega_{0m} = 0.3$ is shown. An interesting point to note is that initially, dark energy density decreases with redshift, showing the phantom-like nature ($w < -1$) of dark energy at lower redshifts of $z \lesssim 0.25$, while at higher redshifts, the dark energy density begins to track the matter density. The dark energy density for cosmological constant would have remained constant over redshift. In the figure 17, the variation of the equation of state of dark energy with redshift is shown. The equation of state varies from a very negative value $w < -1$ at present to zero at $z \simeq 0.7$. Since, matter has zero equation of state, from this point onwards, the equation of state of dark energy appears to track that of matter. Since the value of the equation of state is less than -1 at present, this points to more exotic models of dark energy beyond the cosmological constant and the usual quintessence models. This result appears stable to the change of matter density within a reasonable range, to subsampling of the data, and to change in the fitting functions used for dark energy. However, it should be noted that ΛCDM is still allowed at 2σ, so the time has not yet come for a definitive statement on the nature of dark energy. One can say at this point that evolving dark energy models are as probable as the cosmological constant at 2σ. To make a final decision on the possible evolution of dark energy, one has to wait for more high precision data on supernovae which is expected to become available over this decade from SNAP and HST.

Singularity Free Cosmological Model

Varun Sahni and Yuri Shtanov have constructed a singularity free cosmological model within the framework of higher-dimensional cosmology. Virtually all physically interesting homogeneous and isotropic cosmological models described by 3+1 Einstein gravity are marked by an 'initial singularity', at which the invariants of the Riemann tensor diverge ($R_{iklm}R^{iklm} \to \infty$) and associated physical quantities such as the density of matter become infinite. At the singularity, the very notion of spacetime geometry looses its conventional meaning as the laws of physics begin to break down. It is well known that within classical General Relativity the existence of a 'big bang' cosmological singularity is almost generic and the Hawking-Penrose theorems discuss this issue in great detail. Nevertheless, this does not preclude the possibility that the universe may be singularity free when described within the framework of a more general class of gravity models or within the context of cosmological models with extra dimensions.

Ever since, the seminal work of Kaluza (1921) and Klein (1926) higher dimensional cosmological models have attracted and received much attention. Although, earlier work in this field (notably in the 1960's) focussed on the possibility of deriving gauge interactions from compact extra dimensions, more recent work, notably that of Randall and Sundrum (RS), discusses non-factorizable spacetimes in which our universe is a three dimensional brane (derived from the word membrane), which is embedded in a higher dimensional universe. An interesting feature of the RS approach is that the higher dimension need not be compact. *Sahni* and Shtanov have proposed a generalisation of the RS cosmology, in which the extra dimension is timelike so that the full five dimensional spacetime has the signature $(-,-,+,+,+)$. In such a spacetime the expansion of our three dimensional 'brane' universe becomes singularity free, since the modified Einstein equation $H^2 \propto \rho - \rho^2/\lambda$ forces the Hubble meter to zero, when the density ρ becomes very large. The universe 'bounces' at high densities when $H = 0$ and this leads to a smooth transition from a phase in which the universe is contracting to one in which it is expanding, without the presence of a big bang type singularity (see Figure 18). An important feature of the singularity free models developed by *Sahni* and Shtanov is that the singularity is absent for a *generic* form of the energy momentum tensor and that there is no fine tuning involved. It also appears that the singularity is absent for anisotropic models although this issue needs to be investigated in greater detail. The removal of the initial singularity could have far reaching consequences for cosmology, in general, and for models of the early universe, in particular.

Comparing the Supernova Data Sets

The supernova observations leading to an accelerating phase of the universe has now become standard lore in modern cosmology. As the observations improve, it is important to keep track of the shifting trends and also see whether more precise statements can be made regarding the cosmological parameters. The last annual report contained a description of the analysis of SN data by *T. Padmanabhan* and *T. Roy Choudhury*, in which they tried to emphasize certain aspects which are not conventionally highlighted.

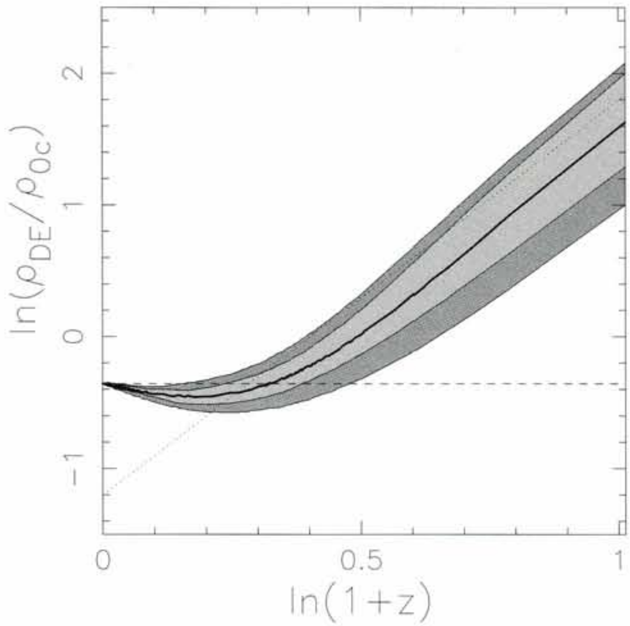

Figure 16: The logarithmic variation of dark energy density $\rho_{\rm DE}/\rho_{\rm 0c}$ (where $\rho_{\rm 0c} = 3H_0^2/8\pi G$ is the present day critical density) with redshift for analysis using real data. The thick solid line shows the best-fit, the light grey contour represents the 1σ confidence level, and the dark grey contour represents the 2σ confidence level around the best-fit. The dashed horizontal line denotes ΛCDM and the dotted line represents matter density $\Omega_{\rm 0m}(1+z)^3$, where $\Omega_{\rm 0m} = 0.3$ is assumed. The dark energy density at high redshifts appears to almost track the matter density.

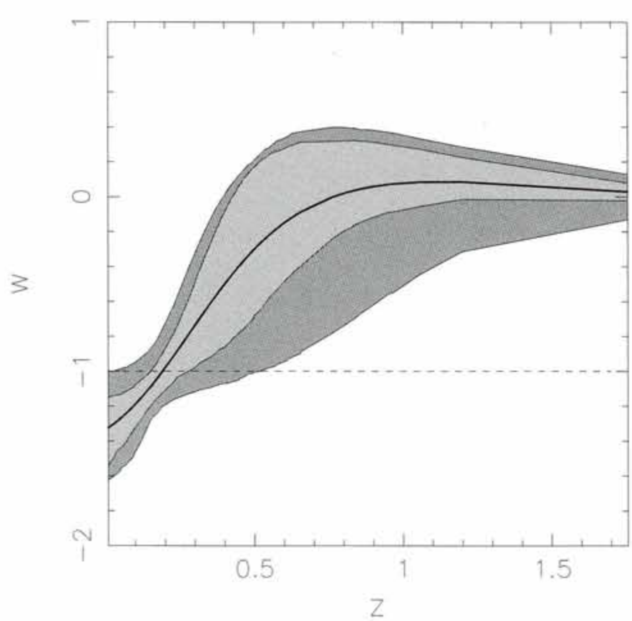

Figure 17: The evolution of dark energy equation of state with redshift for analysis using real data. The thick solid line shows the best-fit, the light grey contour represents the 1σ confidence level, and the dark grey contour represents the 2σ confidence level around the best-fit. The dashed horizontal line denotes ΛCDM. $\Omega_{\rm 0m} = 0.3$ is assumed. The equation of state appears to increase rapidly from a very negative value < -1 at present to zero at a redshift of $z \simeq 0.7$, which behaviour is extremely different from what is expected for the cosmological constant.

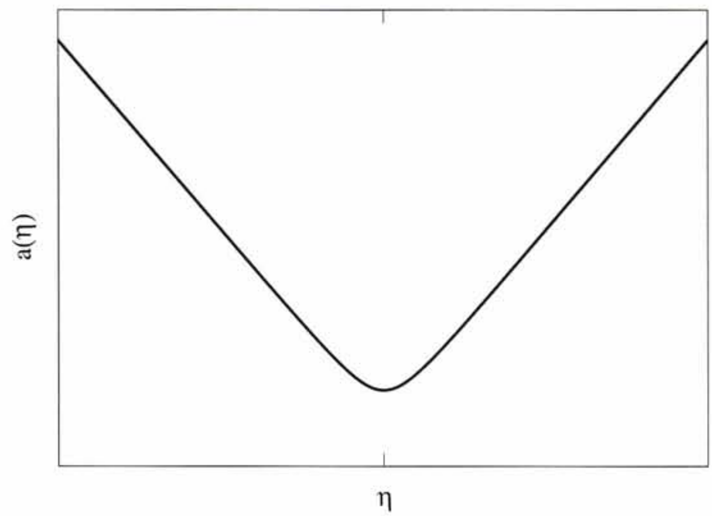

Figure 18: The expansion factor for a non-singular 'bouncing' cosmological model is shown as a function of the conformal time η. The universe is assumed to be radiation dominated.

During the current year, new data has been made available by different groups and also some amount of "cleaning up" of the data has taken place. In view of this, *Roy Choudhury* and *Padmanabhan* re-analysed the problem using three different data sets. The first data set consists of 194 points obtained from various observations, while the second discards some of the points from the first set, because of large uncertainties and thus, consists of 142 points. The third data set is obtained from the second by adding the latest 14 points observed through HST.

A careful comparison of these different data sets help us to draw the following conclusions: (i) All the three data sets strongly rule out non-accelerating models. Interestingly, the first and the second data sets favour a closed universe (with probability ~ 0.97) and are in mild disagreement with the "concordance" flat model. However, this disagreement is reduced (the probability of obtaining closed models being ≈ 0.9) for the third data set, which includes the most recent points observed by HST around $1 < z < 1.6$. (ii) When the first data set is divided into two separate subsets consisting of low ($z < 0.34$) and high ($z > 0.34$) redshift supernova, it turns out that these two subsets, individually, admit non-accelerating models with zero dark energy. However, these non-accelerating models seem to be ruled out using only the low redshift data for the other two data sets, which have less uncertainties. (iii) They have also found that it is quite difficult to measure the evolution of the dark energy equation of state $w_X(z)$ though its present value can be constrained quite well. The best-fit value seems to mildly favour a dark energy component with current equation of state $w_X < -1$, thus, opening the possibility of existence of more exotic forms of matter. However, the data is still consistent with the the standard cosmological constant at 99 per cent confidence level.

WMAP and the Equation of State of the Universe

In the last decade, observational evidence for an accelerating universe has become stronger. Accelerated expansion of the universe requires either a cosmological constant or some form of dark energy to drive the acceleration. Although a cosmological constant is a simpler solution from a phenomenological point of view, there is no natural explanation of the small observed value. This has inspired theorists to develop toy models where a field, typically a scalar field, provides the source of dark energy. All such models require fine tuning in order to ensure transition to a dark energy dominated universe at $z \sim 0.5$. A distinctive feature of these models as compared to the cosmological constant is that the equation of state changes with time and it is in general different from -1. In the absence of significant spatial variations in these fields, this is the only difference between cosmological constant and other models of dark energy. Current observations do not rule out $w = -1$; thus, observational evidence for a varying equation of state will be of great significance. The latest release of the high redshift supernova data has led to a few attempts to look for variation in the equation of state. This issue requires greater scrutiny as a varying equation of state can also leave an imprint on the growth of large scale structures. Indeed, in the few cases, where the growth of fluctuations in such models has been studied, models that differ significantly from the cosmological constant have been found wanting. *H. K. Jassal*, J. S. Bagla and *T. Padmanabhan* carried out a detailed comparison of models with observations to constrain the variation of equation of state of dark energy. The supernova constraints are combined with the constraints from WMAP data. The evolving dark energy affects the features of temperature anisotropies in the CMBR in at least two ways. The angular location of features in temperature anisotropy, like the acoustic peaks, changes. The integrated Sachs-Wolfe (ISW) effect depends on the nature of dark energy and its evolution, this effect is more relevant at large angular scales. Thus, observations of temperature anisotropies in the CMBR can be used to constrain the evolution of dark energy. Combined with the fact that supernova observations constrain the low redshift expansion of the universe, this puts tight constraints on the equation of state of dark matter and its evolution. The results rule out any rapid change in $w(z)$ in recent epochs and are completely consistent with the cosmological constant as the source of dark energy.

Higher Dimensional Theories

Recently, *H. K. Jassal* studied cosmological consequences of the five dimensional, two brane Randall-Sundrum scenario. The radius of the compact extra dimension was taken to be time dependent. It was shown that the radius of the extra dimension rapidly approaches a constant non-zero separation of branes. A radion dominated universe cannot undergo accelerated expansion in the absence of a potential. It was shown that a simple quadratic potential with minimum at zero leads to constant non-zero separation of branes in a similar level, but now accelerated expansion is possible. After stabilization, the quadratic potential contributes an effective cosmological constant term. With a suitable tuning of parameters, the requirements for solving the hierarchy problem and getting an effective dark energy can be satisfied simultaneously.

Alternative Cosmological Model

Work is continuing on developing the quasi-steady state cosmology as an alternative cosmology to the standard model. In collaboration with Geoffrey Burbidge, *J. V. Narlikar* has discussed the oscillatory nature of the QSSC in the context of gamma ray bursts, arguing that close to the oscillatory minima the minibangs produced by newly created matter appear to have properties of burst-like events. Other issues related to cosmogony such as structure formation, dark matter, quasars, and active galactic nuclei, receive different interpretations within the QSSC. The claimed redshift periodicities have not, however, been explained by this new paradigm so far.

Observational Cosmology

Weak Shear Analysis of a Collapsing, Filamentary Proto-cluster of Galaxies

Numerical simulations show that in all of the currently favoured cosmologies, the largest structures expected to exist today are supercluster-sized filaments. Many publications (e.g., Einasto, et al. 2002, AJ 123, 51) have shown how Abell clusters and galaxies trace a network of such filaments. Recently, *J. Bagchi* with collaborators announced the discovery of a large-scale filamentary network of galaxies around the cluster ZwCl 2341.1+0000, extending over at least 10 Mpc, at $z = 0.3$. Brand, et al. have demonstrated the evidence of even larger ($\sim$100 Mpc) filamentary structures in the 7C radio survey at the same redshift. On the largest scales, Myers et al. have found evidence in WMAP data of extended Sunyaev-Zel'dovich decrement that could be associated with inter-cluster gas in supercluster filaments. In spite of evidence of their existence, none of these filaments has been studied in enough detail to establish their dynamical properties and evolutionary history. This inhibits our ability to address the more general and compelling question of what physical processes are important during the collapse of the primordial density fluctuations that lead to structure formation. In order to observationally establish a physical model of the formation of cosmological structures, multifrequency observations of large-scale filaments are essential.

Bagchi, in collaboration with T. Erben, Somak Raychaudhury, T. Ensslin, F. Miniati, H. Bohringer, and P. Schneider, is carrying out an observational programme - with the ESO 2.2 meter telescope and its wide-field imaging camera - for dark matter gravitational lensing analysis in this filamentary structure of galaxies ZwCl 2341.1+0000. This project would obtain more than 12 hours of deep photometric data for this purpose.

ZwCl 2341.1+0000 is a filamentary network of galaxies, at least 10 h_{50}^{-1} Mpc long, consisting of a

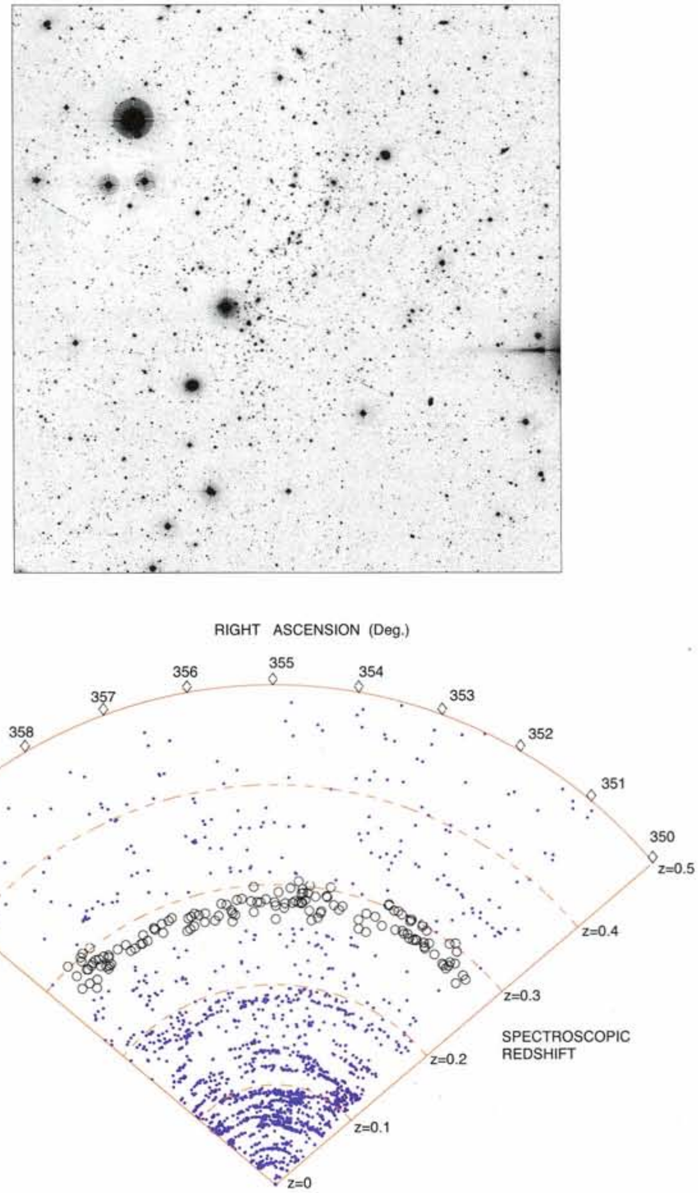

Figure 19: **Top panel**: The central portion ($20' \times 20'$) of a CCD image of ZwCl 2341.1+0000 in R-band, taken with the ESO 2.2m telescope and the wide-field imaging camera (WFI). **Bottom panel**: Cone-diagram plot of all galaxies with spectroscopic redshifts in the direction of ZwCl 2341.1+0000, from the Sloan Digital Sky Survey (SDSS) data – those between $0.26 < z < 0.30$ as circles. The galaxies are located within a thin wedge in the R.A. range 351 - 360 deg. and declination range -1.25 to +1.25 deg. There is an overdensity of factor $\approx 2-3$ compared to several random directions studied, indicating a large filamentary structure at $z \approx 0.3$

main galaxy chain and several side chains. Spectroscopic and photometric redshift estimates obtained from Sloan Digital Sky Survey (SDSS) have confirmed that it is a single, coherent superstructure at $z \approx 0.3$, stretching over ~ 100 Mpc (see Fig.19).

This structure is also marginally detected in the ROSAT all-sky survey with a tentative 0.1-2.4 keV luminosity of 10^{44} erg s^{-1}. Surprisingly, diffuse continuum radio emission at 330 and 1420 MHz was also detected from this filament. A significant fraction of this emission can not be attributed to any active radio galaxy and therefore, should originate in the intergalactic medium.

Most likely ZwCl 2341.1+0000 is a protocluster of galaxies, which will become a massive galaxy cluster in a cosmologically short time due to gravitational collapse. The extended diffuse radio emission is likely of a similar kind as the already known cluster radio halo and cluster radio relic emission detected in several merging clusters of galaxies. In these systems, the radio emission is interpreted as a direct tracer (in the case of cluster radio relics) or an indirect, retarded tracer (in the case of cluster radio halos) of intra-cluster medium shock waves dissipating kinetic energy of infalling material and of merging subclumps. If such processes also accelerate and power the synchrotron emitting relativistic electrons, which are responsible for the diffuse radio emission observed in ZwCl 2341.1+0000, then we are witnessing a rapid growth event and/or the starting collapse of this filament. The importance of the gravitational lensing observation lies in that, that this target is the *only* known supercluster scale filamentary structure where both magnetic field and radio emission - possibly originating in structure formation accretion shocks - have been detected.

Recently, *Bagchi, et al.* have been allotted time for new X-ray observations, jointly with CHANDRA and XMM, to obtain a better understanding of the key physical properties and the energetics of the intra-cluster medium in this high-z filament. A crucial (and still missing) part in this campaign is a sensitive mass estimate of the filament. As outlined above, we are probably looking at a proto-cluster in its formation, so that estimates depending on thermal equilibrium (X-rays) or the virial theorem (i.e., assumption of the physical system being in virial equlibrium) provide no conclusive answers. Hence, a mass reconstruction by weak lensing techniques that does not depend on light emission in the electromagnetic spectrum, is the method of choice for investigating the mass properties of ZwCl 2341.1+0000. A detailed comparison of a weak lensing mass map, X-ray, radio, and galaxy distribution should then help us to understand the dynamical state of the filament.

Among other issues, this will allow to test the hypothesis that the diffuse radio emission is caused by structure formation shock waves. If this scenario could be confirmed it would have several important implications: It would demonstrate that structure formation shock waves in galaxy filaments were able to accelerate relativistic electrons. Such acceleration was proposed to produce TeV energy electrons, which would contribute to the extragalactic X-ray background by inverse Compton up-scattering of CMB photons. A confirmation of this scenario would also open the possibility to detect many more such active galaxy filaments with the upcoming sensitive radio telescopes like LOFAR, ATA, EVLA, and SKA, allowing to study structure formation in action also at a mass scale below that of galaxy clusters. Besides the question of the origin of radio emission, a mass reconstruction of the filament would be very important for its own sake. It will allow us to study a snapshot of the dynamical processes in a highly non-virialized proto-cluster of galaxies. A detailed mass map of a massive filament with an extent of ~ 10 Mpc can be compared to models of similar structures appearing in numerical simulations. A sensitive weak lensing observation of ZwCl 2341.1+0000, would, therefore, allow probing poorly explored regimes of cosmic structure formation.

Discovery of Giant 'Radio Relics' in Cluster Abell 3376

Recent advances in observational cosmology have revealed that the largest and the most massive virialized structures are the galaxy clusters, which assemble through the hierarchical process of gravitational infall of smaller mass components. During this process of 'structure formation', the accretion of intergalactic matter, and collisions and mergers of smaller groups and clusters take place mainly along the axes of large filaments of galaxies of length of a few Mpc to up to $\sim$100 Mpc. Such events are amongst the most energetic known. During a merger, the enormous kinetic energy of colliding subclusters ($\sim 10^{63-64}$ erg) is dissipated in the form of shock-waves, which play a pivotal role in heating of the intra-cluster medium (ICM) to the virial temperature. These Mpc size supersonic 'merger shock' fronts (of Mach numbers $M \sim 2-5$) have recently been identified in high angular resolution *Chandra* X-ray observations, showing spatial variations of gas temperature and entropy within the intra-cluster medium. It is also expected that in the peripheral regions of evolving clusters, there should form large-scale 'accretion shocks' due to supersonic convergent flows of background intergalactic plasma.

Due to combination of massive energies, large sizes and long lifetimes, these shocks - in and around the clusters - are potential sites for the acceleration of cosmic-ray (CR) particles up to very high energies ($10^{18} - 10^{19}$) eV near the 'ankle' region of CR spectrum, and they may also act as the seeds for the ICM magnetic fields. Recently, it has been pointed out that the cosmic-ray ions accelerated at intergalactic shocks could accumulate in the structure, storing a significant fraction of the total energy there. The connection between non-thermal radiation and cluster mergers has been recently highlighted. Direct evidence for the ability of cosmic shock waves to accelerate particles is given by the observed association of the so called cluster 'radio relic' sources with locations, where shock waves are expected from X-ray observations. Diffusive shock acceleration may be operative at these locations and responsible for the radio emitting electrons. In this context, perhaps

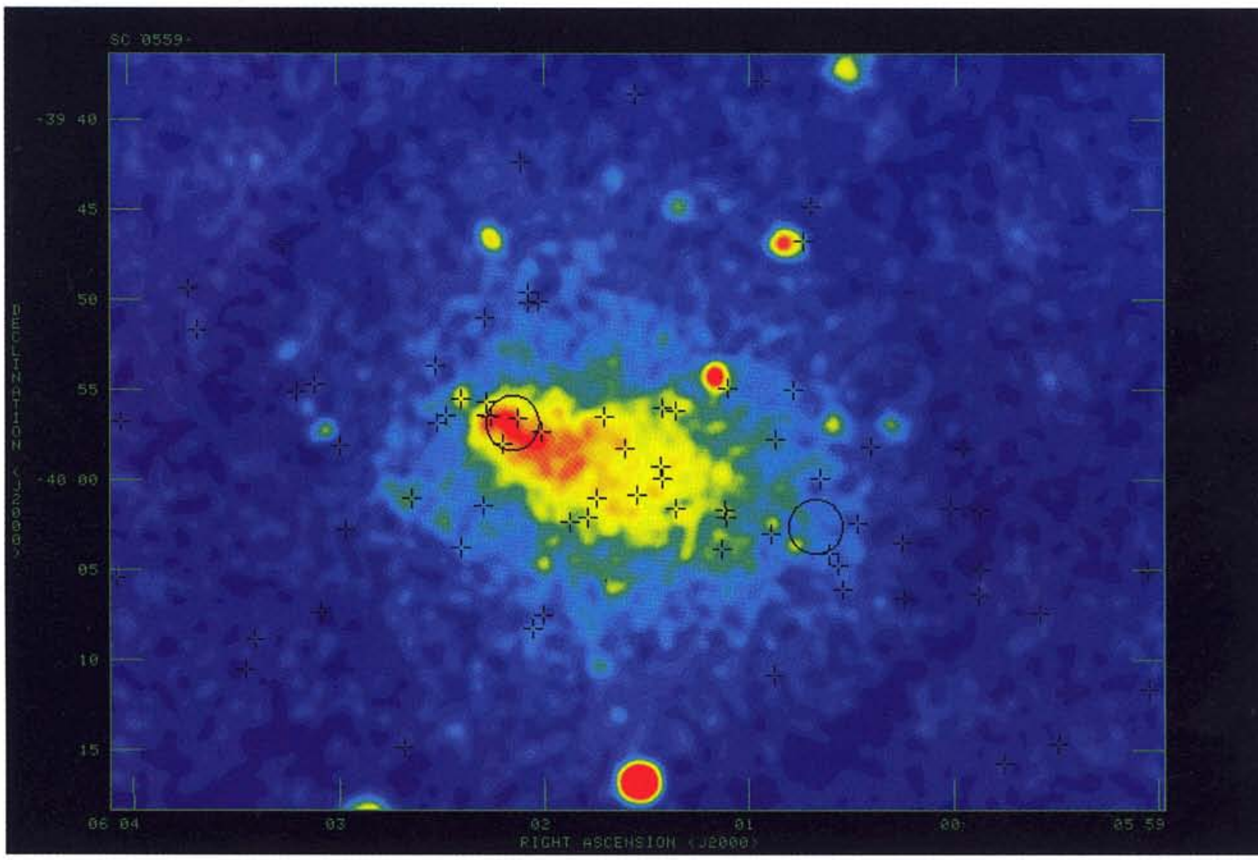

Figure 20: The ROSAT PSPC broad band X-ray image. Circles locate the two brightest cluster galaxies and their associated subclusters and the '+' signs denote other cluster member galaxies from the Dressler catalogue (Dressler & Shectman 1988). The brightest cD galaxy is inside the circle at lower right.

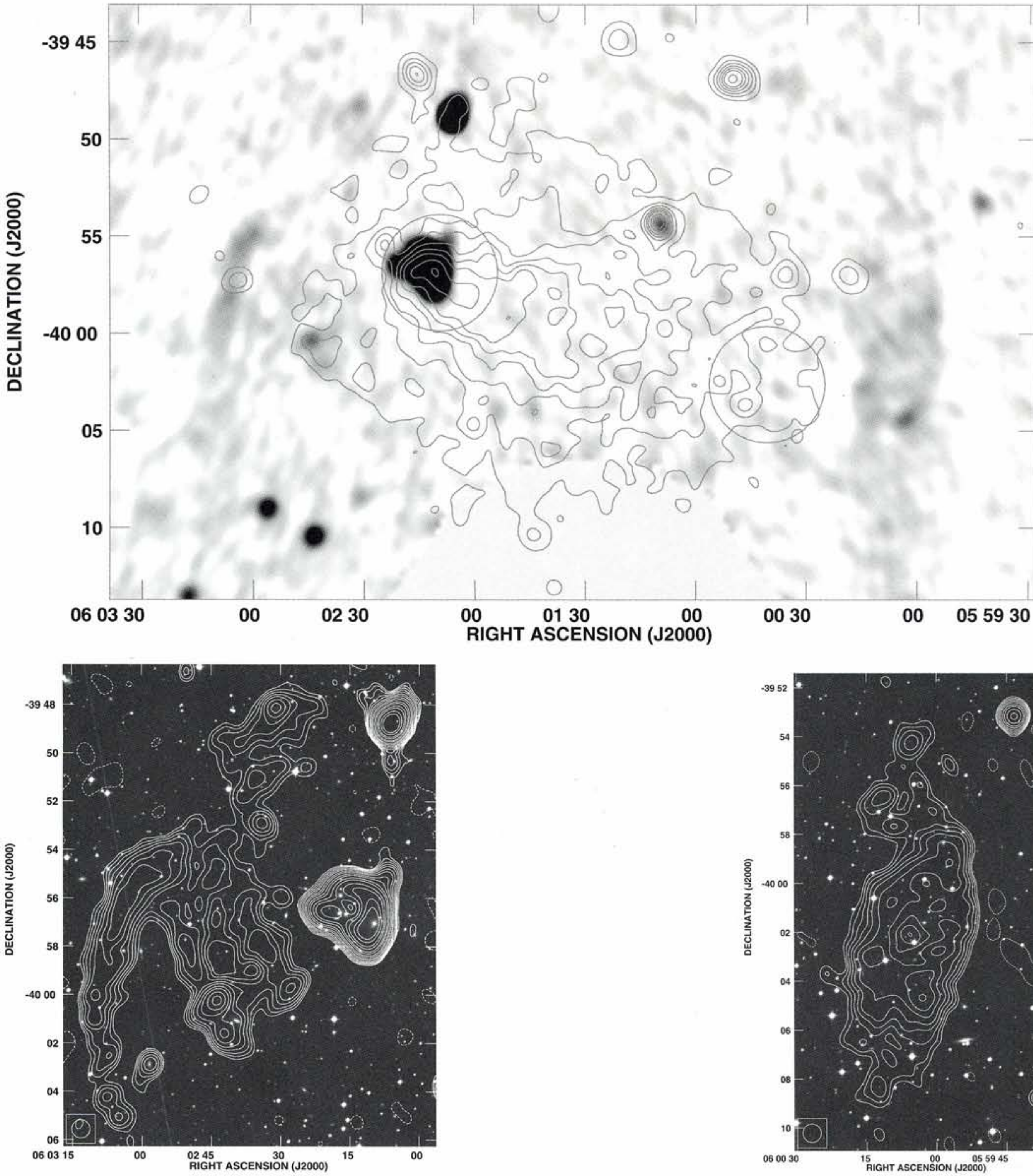

Figure 21: The VLA 1.4 GHz NVSS survey radio data (in grey scale) is shown superposed on the ROSAT PSPC broad band X-ray image (contours) as shown above. (See Fig. 20). Particularly striking is the location of pair of 'radio arcs' at the opposite ends of thermal bremsstrahlung X-ray emission arising from the intra-cluster medium. Morphology of these 'radio arcs' can be seen in better detail on the deep VLA 1.4 GHz radio maps shown superposed on the UK Schmidt telescope optical images.

the strongest evidences are the recent discovery of large, diffuse 'radio-arcs' in merging cluster Abell 3667 by Rottgering, et al., and the first evidence of shock accelerated relativistic particles and magnetic fields in a large scale collapsing filament of galaxies ZwCl 2341.1+0000 by *J. Bagchi*, et al. (see previous section). Although the role of shocks in accelerating cosmic-ray particles up to $\sim 10^{15}$ eV 'knee' energies in supernova blast waves is beginning to be understood, much remains mysterious about the astrophysical aspects of particle acceleration in large-scale structure formation.

From the multi-wavelength data obtained from ROSAT and CHANDRA in X-rays, and VLA and GMRT in radio, *Bagchi* found striking evidence for these energetic processes in a nearby cluster of galaxies Abell 3376 at redshift 0.046 . Abell 3376 is an X-ray bright cluster $[L_x(0.1-2.4\,\mathrm{keV}) = 2.48 \times 10^{44}\,\mathrm{erg\,s^{-1}}]$, selected for study mainly due to it's remarkable X-ray morphology. It shows several evidences of ongoing energetic merger activity. The optical galaxies are distributed in a bar-like structure (projected), extending along a position angle of $\approx$ 70 deg., defining the merger axis. The two brightest cluster members are located near the centres of major subcluster of galaxies, which are lined-up along the same position angle (see Figure 20). The X-ray data from ROSAT archives further confirms the merger scenario, revealing a highly disturbed, non-equilibrium state of the intra-cluster gas - with the bremsstrahlung X-ray emission elongated along the same direction - as the optical merger axis of the colliding groups (i.e., p.a. $\approx$ 70 deg). In addition, the X-ray image shows clear evidence for striking surface-brightness asymmetry - an off-centered 'cometary' shape, centroid shift, and pronounced twisting and compression of the inner isophotes - near the X-ray peak. All these features are strongly indicative of an off-axis merger scenario, also reproduced in some recent numerical simulations (Ricker P.M., 1998, ApJ 496, 670; Takizawa M., 2000, ApJ 532, 183). The comparison of ROSAT X-ray data with VLA 1.4 GHz NVSS image reveals perhaps the most interesting aspect of this cluster: a pair of very large ($\sim$ Mpc) and diffuse radio sources (the 'radio arcs') - positioned at the opposite ends of the extended X-ray emitting gas - about 36 arcmin ($2.6\,h_{50}^{-1}$ Mpc) apart from each other (see Figue 21). For better understanding of the nature of these radio arcs, *Bagchi* obtained deeper and higher resolution images with VLA at 1400 and 320 MHz, which reveal extremely complex morphology. There is no convincing evidence for any optical galaxy obviously associated with the radio arcs, and hence they are unlikely to be the canonical cluster radio galaxies. It is also implausible that they are radio-lobes of a single giant radio galaxy (GRG), as no obvious radio link (jets or plumes) exists between them and any central optical galaxy, and GRGs of this large size ($> 2h_{50}^{-1}$ Mpc) are extremely rare. On the other hand, the symmetric and tangential juxtaposition of the radio arcs relative to the merger axis, the brightest cluster galaxies, and relative to the X-ray contours (see Figure 21), argue strongly that they are part of this cluster and likely originate in a large-scale energetic process linked to the merger activity.

Further, detailed multi-wavelength observations and computational study of the phenomenon are underway in order to understand the details of acceleration process involved. The most plausible explanation is the diffusive shock acceleration (DSA) of cosmic ray particles (electrons, protons and ions) on the shock fronts, putatively located near the radio arcs. The prevailing physical conditions of the disturbed ICM: large-scale bulk flows, turbulence, and collisionless MHD shocks, all provide ideal environment for particle acceleration through stochastic Fermi mechanism and amplification of seed magnetic fields.

Probing the Nature of Enigmatic Radio-jet Source CGCG049-033

J. Bagchi, in collaboration with Gopal Krishna and *P. Subramanian*, used the GMRT's multi-wavelength mapping capability to investigate the nature of the large, jet-like radio source CGCG049-033, which was serendipitously discovered in the NVSS image of the region around the Abell cluster 2040 at z = 0.04. The importance of this source lies in that it bears a striking morphological resemblance to the well known quasar 3C 273, which has remained to date a rather singular example of a powerful radio source with one-sided radio jet and lobe (see Figure 22).

Interestingly, the overall structure of CGCG049-033 is similarly strongly one-sided, because current radio maps fail to show any signs of a radio-lobe associated with the jet-like feature to the north. The 1.4 GHz NVSS and GMRT 610 MHz images of CGCG049-033 do reveal a faint extension northwards from the bright central AGN radio core, However its true nature, i.e., whether it is a Doppler-dimmed counter-jet with a missing radio lobe, or simply a disrupted jet, is not yet known. Even ignoring the faint northern jet-like extension, the total extent of the southern jet alone, emanating from the core, is $\sim 500\,h_{70}^{-1}$ kpc, thus, making CGCG049-033 a unique object having one of the largest radio-jets known. Thus, it is one order-of-magnitude larger than its famous analogue 3C273.

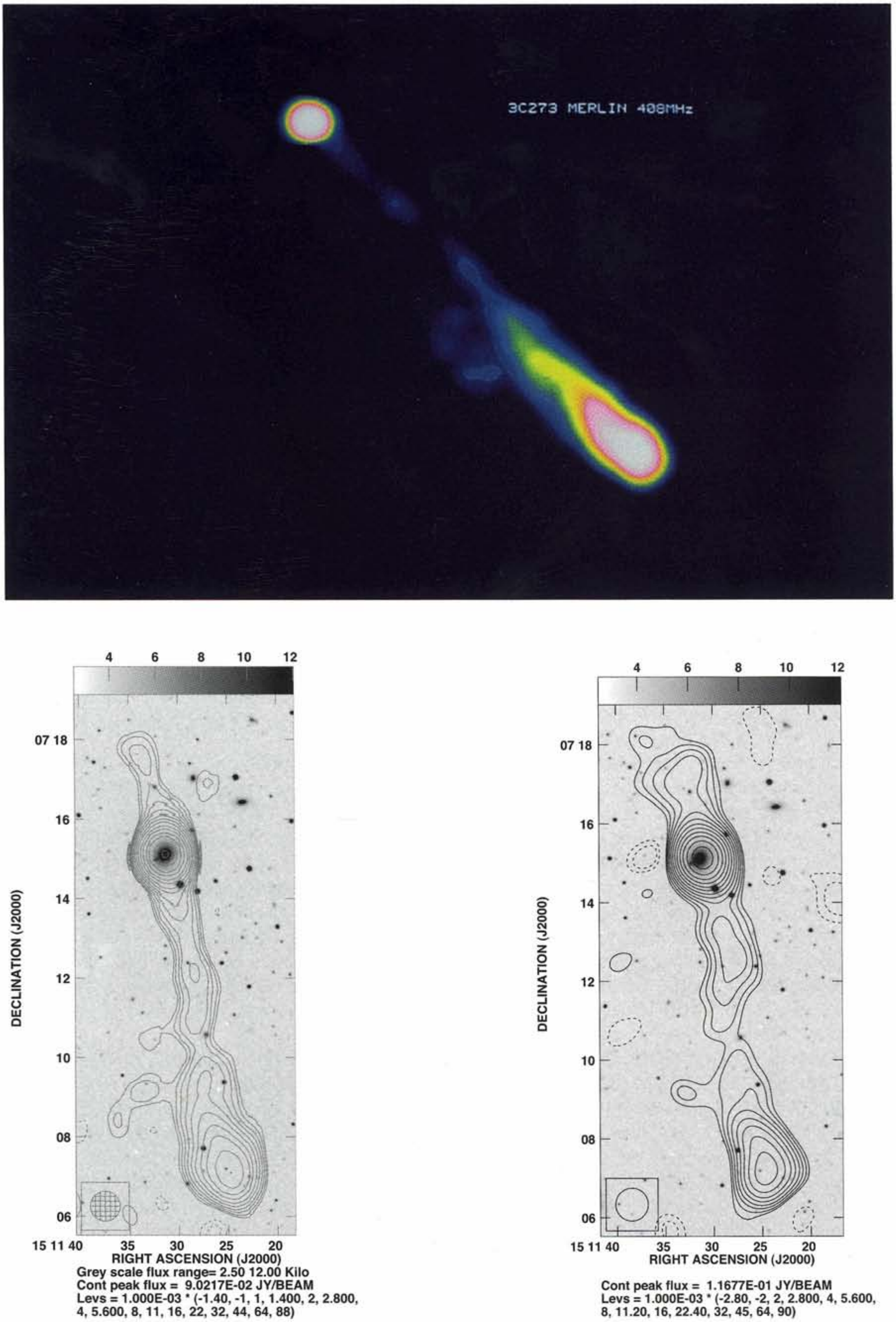

Figure 22: The radio structure of quasar 3C273 at 408 MHz as observed by MERLIN (Davis, et al., Nature 318, 343, (1985)). The total angular size for the radio structure is ≈ 21 arcseconds (∼ 54 kpc).On the bottom left: The VLA 1.4 GHz radio map from the NVSS survey at 45 arcsec resolution. Note the morphological similarity to historical radio quasar 3C273 shown above. On the bottom right:The GMRT 610 MHz radio map of CGCG049-033 at 50 arcsec resolution. Both this, and the 1.4 GHz radio image shown are overlayed on the optical DSS2 blue sensitive image. The total angular size for the radio jet structure is ≈ 10 arcmin (∼ 500 kpc).

In GMRT Cycle 3 observation, one basic issue in unraveling the nature of this radio source was to identify its radio nucleus. Since the northern peak appears as an unresolved component of ~ 80 mJy on the VLA FIRST map at 1.4 GHz, this peak is most likely to be the nucleus. The GMRT 610 MHz image confirms this identification by revealing a flat spectrum for this point source detected in FIRST survey. The GMRT radio peak and the FIRST core position both agree to within 2 arcsec of the parent optical E/S0 galaxy CGCG049-033 at redshift z = 0.046.

More sensitive, multi frequency GMRT observations at 20, 50 and 90 cm wavelengths are being carried out to : (a) Investigate why it is so predominantly one-sided. (b) Search for a possible faint counter-lobe not detected in NVSS and in the existing GMRT data. (c) Obtain high resolution and high dynamic range images of the core, jet and lobe/hotspot regions, and (d) compare the physical properties of CGCG049-033 with 3C273 for a better understanding of both these enigmatic objects. The reason for the morphological similarity with the bright radio quasar 3C273, despite a huge difference in their radio powers and physical sizes, is not clear at present and this requires further investigation. One notes that 3C273 is completely one-sided source (see Figure 22) in which attempts have been made to explain the one-sidedness as a result of relativistic beaming. But this requires highly relativistic flow speeds througout the source in order to hide both the counter-jet and counter-lobe at jet-side/counter-jet-side brightness ratio of larger than $10,000$, in contradiction of the estimated low Doppler factors. The key question: Is 3C273 relativistically beamed, or is it intrinsically one-sided ?, remains unresolved. In this context, CGCG049-033 could prove valuable in providing some fresh insights into the mystery of 3C273. Note that in CGCG049-033 even the 'hotspot' seen at the southern extremity of the jet does not exhibit the canonical hotspot-lobe morphology. It appears that the jet is not yet sufficiently decelerated to form a lobe structure. The proposed GMRT observations, in conjunction with the NVSS data, would reveal whether this peculiar radio morphology is accompanied by an equally abnormal spectral gradient, as seen in the case of 3C273. Moreover, the combination of a fairly high surface brightness, and a large linear extent of this bright object, offers an opportunity to study the exceedingly rare phenomenon of undecelerated jet extremities. As a parallel effort, observations are being planned for a radio/X-ray follow-up of this extraordinary object, including a recently submitted proposal for making its deep 8.4 GHz map with the 100-metre Effelsberg radio telescope.

Cosmic Microwave Background Radiation

Primordial Magnetic Fields and the CMB

K. Subramanian and S. Sethi have explored the influence of primordial magnetic fields on the thermal and ionization history of the post-recombination universe. After recombination, the universe becomes mostly neutral, resulting also in a sharp drop in the radiative viscosity. Primordial magnetic fields can then dissipate their energy into the IGM via ambipolar diffusion and, for small enough scales, by generating decaying MHD turbulence. These processes can significantly modify the thermal and ionization history of the post-recombination universe. Detailed calculations were done to examine whether such damping can lead to the early reionization implied by WMAP observations of the polarization of the CMB. They find that the dissipation effects of magnetic fields which redshifts to a present value $B_0 = 3 \times 10^{-9}$ Gauss smoothed on the magnetic Jeans scale and below, can give rise to Thomson scattering optical depths $\tau \gtrsim 0.1$, although not in the range of redshifts to explain the WMAP polarization observations. Early structure formation induced by magnetic fields, even 3 times smaller, is however, potentially capable of producing the early re-ionization implied by the WMAP data. Future, CMB observations will be very useful to probe the modified ionization histories produced by primordial magnetic field evolution and constrain their strength.

A scenario for the generation of primordial fields is also being explored in the context of theories of varying fine structure constant by *Subramanian* and J. D. Barrow.

Cosmic Microwave Background Anisotropy

Recent developments in cosmology have been largely driven by huge improvement in quality, quantity and the scope of cosmological observations. The measurement of temperature anisotropy in the Cosmic Microwave Background (CMB) has arguably been the most influential of these recent observational success stories. A glorious decade of CMB anisotropy measurements has been topped off by the data from the Wilkinson Microwave Anisotropy Probe (WMAP) of NASA. While on one hand, the observations have constrained theoretical scenarios and models more precisely, some of these observations have thrown up new challenges to theoretical understanding and others that have brought issues from the realm of theoretical speculation to observational verification. *Tarun Souradeep* has been working on a broad range of research problems in CMB anisotropy that use the WMAP data .

(a) 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 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, has been recently proposed by *Amir Hajian* and *Tarun Souradeep* as a measure of violation of statistical isotropy in the CMB anisotropy map. They have also calculated the analytical expressions for the bias and cosmic variance of κ_ℓ. Figure 23 shows the estimation of the BiPS from synthetic statistically isotropy maps measured by WMAP. The bias and cosmic variance error bars from the analytical expressions exactly matched the results obtained using 1000 realizations.

Since then, *Amir Hajian* and *Souradeep* have completed a BiPS analysis of the full sky CMB anisotropy maps obtained from the first year of data from the WMAP satellite to asses their statistical isotropy. The CMB maps were smoothed by a family of window functions to isolate and test SI in the different regions of the multipole space. Preliminary results shown in Figure 24 indicate that the CMB anisotropy maps from WMAP do not strongly violate statistical isotropy. The results are expected to provide strong constraint on the cosmic topology and the ultra-large scale structure of the universe.

(b) Initial Power Spectrum from CMB Anisotropy

Cosmological parameters estimated from CMB anisotropy assume a specific form for the spectrum of primordial perturbations believed to have seeded the large scale structure in the universe. Accurate measurements of the angular power spectrum over a wide range of multipoles from the WMAP have opened up the possibility to deconvolve the primordial power spectrum for a given set of cosmological parameters. *Arman Shafieloo* and *Souradeep* have estimated the primordial power spectrum from angular power spectrum of CMB anisotropy measured by WMAP. The most prominent feature of the recovered primordial power spectrum, shown in Figure 25, is a sharp, infra-red cutoff on the horizon scale. It also has a localized excess just above the cutoff, which leads to great improvement of likelihood over the simple monotonic forms of model infra-red cutoff spectra considered in the post WMAP literature. The form of infra-red cutoff is robust to small changes in cosmological parameters. 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. Work is in progress with other collaborators (R. Rangarajan and P. Panigrahi), to employ wavelet analysis to asses the significance of the features in the primordial spectrum. Inclusion of the CMB polarization spectrum to be announced soon by WMAP into this analysis is an important future plan.

The initial power spectrum extracted from cosmological observations can then be connected to the details of early universe physics, such as the inflation potential. Jeremie Lasue, a visiting student and *Souradeep* reconstructed the inflation potential from the primordial spectrum inferred from the WMAP data. They obtain very interesting constraints on single scalar field inflation arising from an infra-red cutoff in the primordial power spectrum. It is well known that the generation of perturbations from inflation can be cast into a scattering problem of quantum mechanics. Features in the primordial power spectrum can then be linked to features in this effective scattering potential. Yasin Memari, an undergraduate student carried out a three month long research project under the guidance of *Tarun Souradeep* to reconstruct features of the effective scattering potential of the inflaton field fluctuations from primordial power spectra.

(c) Observational issues in CMB anisotropy

The non-circularity of the experimental beam has become progressively important as CMB experiments strive to attain higher angular resolution and sensitivity. Recent CMB experiments such as ARCHEOPS, MAXIMA, WMAP have significantly non-circular beams. Future experiments like Planck are expected to be even more seriously affected by non-circular beams. *Sanjit Mitra*, *Anand Sengupta* and *Souradeep* have carried out a comprehensive study of the effect of a non-circular beam on CMB power spectrum estimation. They computed the bias in the naively estimated power spectrum and then constructed an unbiased estimator using the bias matrix. The covariance matrix of the unbiased estimator is computed for non-rotating smooth beams. The WMAP beam maps are fitted and shown to be significantly non-circular. The effect of a non-circular beam on the estimated power spectrum is calculated for a CMB map made by an experiment with a beam which is non-circular at a level comparable to the WMAP beam. This work is the starting point of more extensive collaborative

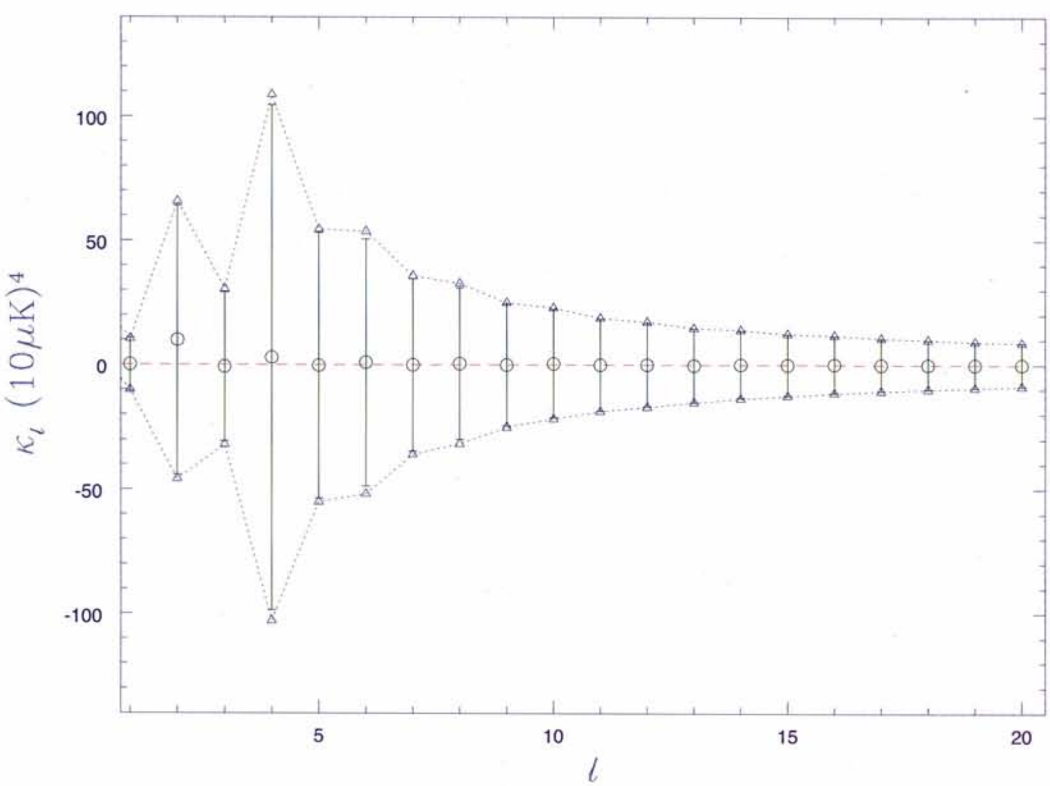

Figure 23: The bias corrected 'measurement' of Bipolar power spectrum (BiPS) κ_ℓ of a SI CMB sky with a best fit LCDM power spectrum smoothed by a Gaussian beam ($l(l+1)C_l = \exp(-l^2/40^2)$). The cosmic error, $\sigma(\kappa_\ell)$, obtained using 1000 independent realizations of CMB (full) sky map match the analytic results shown by dotted curve with triangles *(ApJ* **597**, *L5 (2003))*.

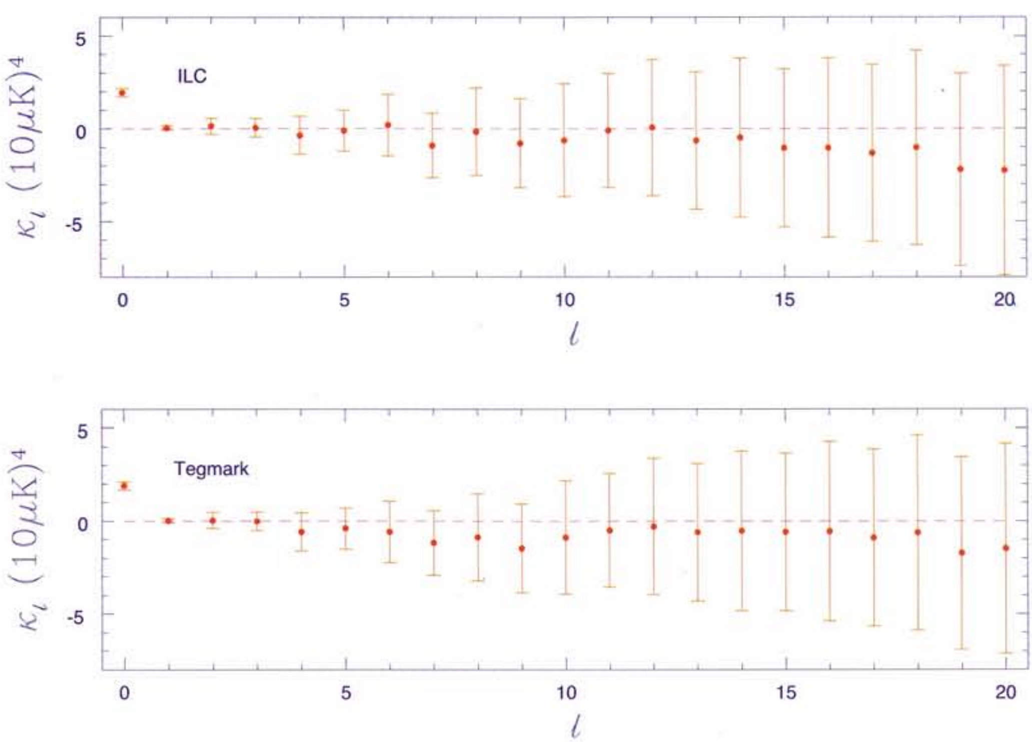

Figure 24: The measured values of the Bipolar spectrum κ_ℓ for the two full sky maps constructed from the first year data from WMAP. These are the ILC (internal linear combination) map of NASA/WMAP science team and the foreground free map made by Tegmark, et al. 2003. Maps are filtered with a window with that retains power in the multipole range $20 < l < 40$. There is no strong evidence for violation of statistical isotropy of CMB anisotropy measured by WMAP in the region of multipole space where certain anomalies have been reported.

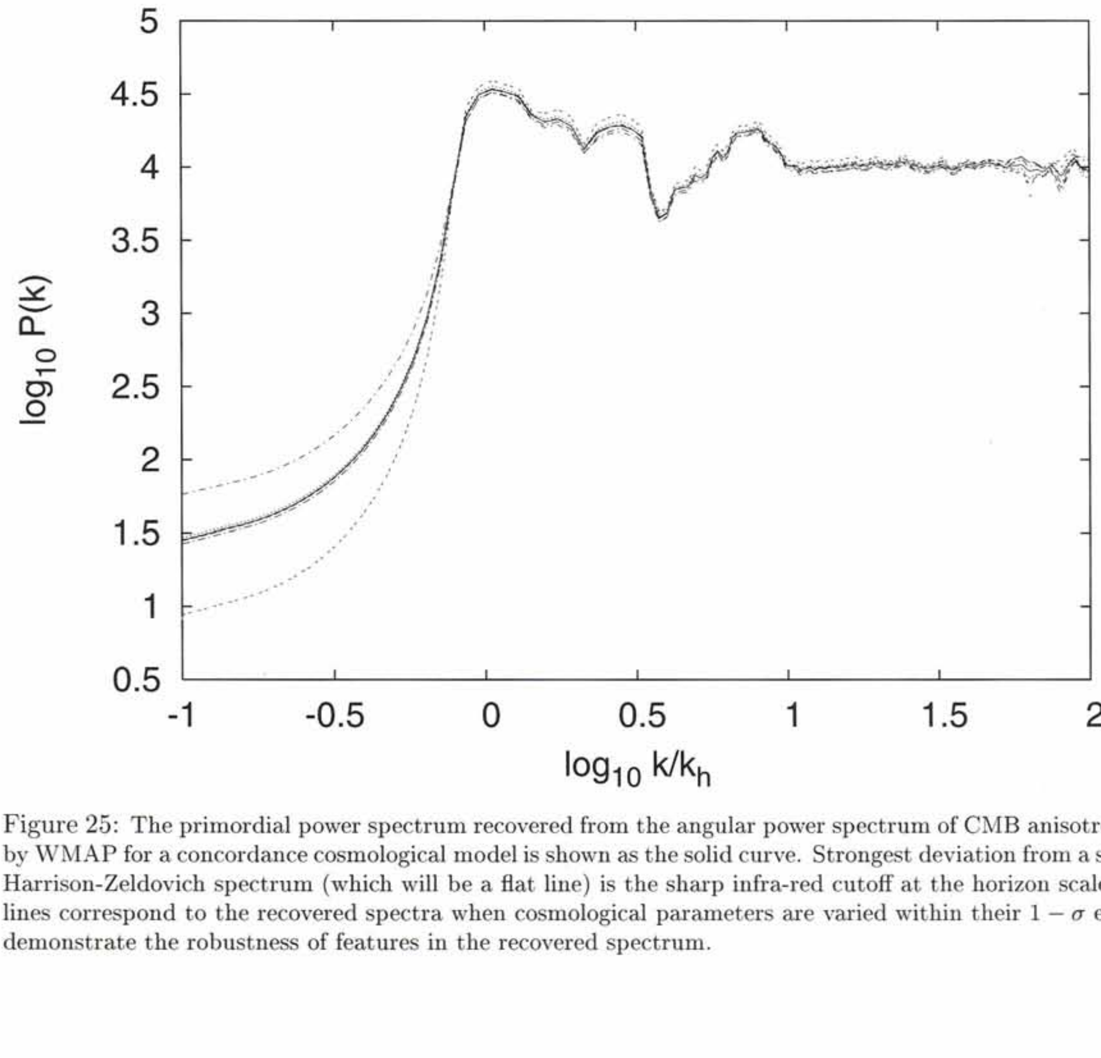

Figure 25: The primordial power spectrum recovered from the angular power spectrum of CMB anisotropy measured by WMAP for a concordance cosmological model is shown as the solid curve. Strongest deviation from a scale invariant Harrison-Zeldovich spectrum (which will be a flat line) is the sharp infra-red cutoff at the horizon scale. The dotted lines correspond to the recovered spectra when cosmological parameters are varied within their $1-\sigma$ error bars and demonstrate the robustness of features in the recovered spectrum.

work addressing the issue of non-circular beam in future experiments.

In collaboration with a visitor R. Sinha, the recently acquired HPC facility in IUCAA has been used by *Souradeep* to set up and carry out cosmological parameter estimation in a multi-dimensional space of parameters at par with others groups using the latest datasets and with adequate computational resources to reach for large number of parameters.

Nonlinear Turbulent Dynamos

The microscopic theory of the turbulent transport coefficients in nonlinear mean field dynamos was revisited, using a new closure approximation by *K. Subramanian* and A. Brandenburg. In this closure, called the minimal tau approximation (MTA), triple correlations are assumed to provide relaxation of the turbulent electromotive force. The turbulent transport coefficcients involved in the transport of magnetic fields were recalculated using the MTA, for the case when helicity is induced by rotation and stratification. These results are applicable to the nonlinear regime, where by Lorentz forces back react on the turbulence

The validity of the above closure has been tested using numerical simulations. Under MTA, the alpha effect in mean field dynamo theory becomes proportional to a relaxation (or correlation) time scale times the difference between kinetic and current helicities. It was shown by Brandenburg and *Subramanian* that the value of the relaxation time is firstly positive and of order unity in natural units. This suggests that MTA is indeed a reasonable closure.

The most important nonlinear contribution to the alpha effect, as mentioned above, comes from the current helicity of the small scale fields. In earlier work the dynamics of this term had been obtained from magnetic helicity conservation. However, in the presence of boundaries, magnetic helicity has to be defined carefully to make it gauge invariant. Instead, a new approach has been initiated to directly study the dynamics of the current helicity; the advantage being that the current helicity is always gauge invariant. One of their aims was also to examine possible fluxes of helicity which arise when one allows for weak inhomogeneity in the system. Indeed, Vishniac and Cho derived an interesting flux of helicity, which arises even for nonhelical, but anisotropic turbulence. This flux has now been derived using MTA, generalizing the original derivation to include also nonlinear effects of the Lorentz force and helicity in the fluid turbulence. It was shown that the Vishniac-Cho flux can also be thought of as a generalized anisotropic turbulent diffusion. Further, due to nonlinear effects other helicity flux contributions arise which are due to the anisotropic and antisymmetric part of the magnetic correlations

A. Shukurov and *Subramanian* have initiated work on in understanding the origin of Cluster magnetic fields as being due dynamo generation by the transient turbulence, which arises when the cluster is first assembled.

Active Galactic Nuclei and Quasar Absorption System

Constraining the Time Variation of the Fine Structure Constant

The variation of several fundamental constants in physics can be probed by measuring wavelengths of atomic transitions in the high redshift Universe. In particular, any possible variation in the electromagnetic fine-structure constant ($\alpha = e^2/\hbar c$) can be detected in the absorption spectra of distant quasars. Using a well defined sample of absorption line systems, *R. Srianand* and *H. Chand* in collaboration with P. Petitjean and B. Aracil, derive a 3σ upper limit on the time variation of α of $-2.5 \times 10^{-16}\ \mathrm{yr}^{-1} \leq (\dot{\alpha}/\alpha) \leq +1.2 \times 10^{-16}\ \mathrm{yr}^{-1}$.

Most of the successful physical theories rely on the constancy of a few fundamental quantities (such as the speed of light, c, the fine structure constant, α, the proton-to-electron mass ratio, μ, etc.). However, some of the modern theories of fundamental physics try to unify fundamental interactions. They require the existence of extra compact spatial dimensions and allow for the cosmological evolution of their size. As a result, these theories naturally lead to the prediction of cosmological variation of fundamental constants in a 4-dimensional sub-space. Therefore, constraining the possible time variations of these fundamental physical quantities is an important step toward a complete physical theory.

One of these constants is the fine-structure constant α ($= e^2/\hbar c = 1/137.03599976(50)$), where e is the charge of the electron and $\hbar$ the reduced Planck constant. It characterizes the strength of the electromagnetic interaction between charged particles. The time evolution of α can be probed in the framework of standard big-bang models using measurements performed at different redshifts (z). One has to measure a quantity that is sensitive to a change in α, in the remote universe and to compare to its value on earth. The strongest constraint on α

comes from the Oklo phenomenon, a natural fission reactor that operated 2 Gyrs ago, or $z \sim 0.16$ (Fujii, et al. 2000). By studying the products of nuclear reactions that occurred, then it is possible to constrain some cross-sections that depend on α. It is found that $[\Delta\alpha/\alpha\Delta t] = (-0.2 \pm 0.8) \times 10^{-17}\ \mathrm{yr}^{-1}$.

At higher redshifts, the possible time dependence will be registered as small shifts in the absorption line spectra seen toward high redshift QSOs as the energy of the atomic transitions depend on α. One has to disentangle the contributions of the global redshift due to the expansion of the universe and the shift due to the variation in α. To do so, one needs at least two transitions with different sensitivity coefficients for the variations in α. As the redshift will be the same for all transitions, the relative shift will, therefore, constrain $\Delta\alpha$. Initial attempts to measure the variation of α were based on alkali-doublets (e.g., Varshalovich, et al. 1996) such as the well known Si IV doublet. The best constraint obtained using this method is $\Delta\alpha/\alpha = (-0.5 \pm 1.3) \times 10^{-5}$ (Murphy, et al. 2001). The generalization of this method, called many-multiplet (MM) method (Dzuba, et al. 1999) gives an order of magnitude improvement in the measurement of $\Delta\alpha/\alpha$ compared to alkali-doublet method by using not only doublets from the same species, but several multiplets from different species (e.g., Webb, et al. 2001). The sensitivity to variations in α of different line transitions from different multiplets were computed using many-body calculations taking into account dominant relativistic effects (Dzuba, et al. 2002). In simple terms, MM method exploits the fact that the energy of different line transitions vary differently for a given change in α. For example, rest wavelengths of Mg II$\lambda\lambda$2797,2803 and Mg Iλ2852 transitions are fairly insensitive to small changes in α thereby, providing good anchor for measuring the systemic redshift (see Figure 26), whereas the rest wavelengths of Fe II multiplets are quite sensitive to small variations in α. Thus, measuring consistent relative shifts between an anchor and different Fe II lines can in principle lead to an accurate measure of $\Delta\alpha$. The accuracy at which the variation can be measured depends very much on how well absorption profiles can be modeled. It is usual to use for this Voigt profiles that are convolved with the instrumental profile and characterized by column density (N), velocity dispersion (b) and redshift (z), in addition to the rest-wavelength of the species. In real data, small relative shifts can be introduced due to various systematic effects such as inhomogeneities in the absorbing region, poor wavelength calibration, isotopic abundances, and atmospheric dispersion effects, etc. However, most of the random systematic effects may be cancelled by using a large number of measurements. MM method applied to large heterogeneous samples of QSO absorption lines resulted in the claim for smaller value of α in the past, $\Delta\alpha/\alpha = (-0.574 \pm 0.102) \times 10^{-5}$ for $0.2 \leq z \leq 3.7$ (Murphy, et al. 2003).

The data used in this new study were obtained with the Ultra-violet and Visible Echelle Spectrograph (UVES) mounted on the ESO KUEYEN 8.2 m telescope at the Paranal Observatory for the ESO-VLT Large Programme "Cosmological evolution of the Inter Galactic Medium" (PI Jacqueline Bergeron). This programme has been devised to gather a homogeneous sample of echelle spectra of 19 QSOs, with an uniform spectral coverage, resolution and signal-to-noise ratio suitable for studying the intergalactic medium in the redshift range 1.7−4.5.

Spectra were obtained in service mode observations spread over four periods (two years) covering 30 nights under good seeing conditions (≤ 0.8 arcsec). The wavelength calibration has been carefully checked using the calibration lamp and it is better than $\delta\lambda/\lambda \sim 7\times10^{-7}$ rms over the full wavelength range of interest, 310−540 nm and 545−900 nm. Details can be found in *Chand*, et al. (2004) and Aracil, et al. (2003). They have only used absorption lines that are redshifted beyond the position of the Lyman-α emission line from the quasar for the analysis. Signal-to-noise ratio of about 40 to 80 per pixel and spectral resolution better than about 45000 are achieved over the wavelength range of interest. This is a factor two improvement on signal-to-noise ratio at similar (or slightly higher) resolution compared to data used in earlier studies.

As a first step, they have performed a detailed analysis on simulated data to have a clearer understanding of various possible systematics that can affect the analysis of real data. The results of this exercise are used to validate the procedure, and define selection criteria that will minimise systematics in their analysis. Absorption spectra of Mg II and Fe II were simulated for given column density, N, and Doppler parameter, b, at spectral resolution and signal-to-noise ratio similar to our data, introducing spectral shifts corresponding to a given value of $\Delta\alpha/\alpha$. They considered two cases: a simple single component system and a highly blended two-component system. In the highly blended case, they restricted the separation between the two components to be always smaller than the velocity dispersion of one of the components. They then fitted the absorption lines in order to recover $\Delta\alpha/\alpha$ introduced in the input spectrum. This exercise allowed them to determine the precision that can be reached using the fitting procedure.

They have used the Voigt profile fitting method and standard χ^2 statistics to fit the absorption profiles consistently and to determine the best fit value of $\Delta\alpha/\alpha$. The relationships between the input and recovered value of $\Delta\alpha/\alpha$ are shown in Figure 27. The method works very well in the case of simple single component systems, where one expects minimum uncertainties due to systematics. The deviation of the recovered value with respect to the true one, distributes like a Gaussian with $\sigma = 0.21 \times 10^{-5}$. This shows that $\Delta\alpha/\alpha$ can be constrained with an accuracy of 0.06×10^{-5} when we use 10 such systems. In the blended case one can see that a tail in the distribution appears and that the accuracy is less ($\sigma = 0.34 \times 10^{-5}$). Using strongly blended systems may, therefore, lead to false alarm signals. Based on detailed simulations they come up with selection criteria that will minimise the systematics in their analysis.

Figure 28 illustrates the method used in the study using 4 randomly chosen systems from the sample. $\Delta\alpha/\alpha$ is varied from -5.0×10^{-5} to 5.0×10^{-5} in steps of 0.1×10^{-5}, and each time all the lines are fitted together. The χ^2 minima obtained for each of these fits are plotted as a function of $\Delta\alpha/\alpha$ (right most panel in Fig. 28). The value of $\Delta\alpha/\alpha$ at which this χ^2 is minimum is accepted as the measure of best possible $\Delta\alpha/\alpha$ value. Following standard statistical procedure, they assign 1σ error bar to the best fitted value of $\Delta\alpha/\alpha$ by computing the change in $\Delta\alpha/\alpha$ implying $\Delta\chi^2 = \chi^2 - \chi^2_{min} = 1$.

Results obtained for the 23 systems in their sample and that from the literature are summarized in Figure 29. The shaded region passing through most of the error bars is the weighted mean (with 1/error^2 weights) and its 3σ error from their sample. The histogram in the left hand side of the panel shows the distribution of $\Delta\alpha/\alpha$. It is clear that most of their measurements are consistent with zero within the uncertainties. The simple mean, weighted mean and standard deviation around the mean obtained for their sample are $(-0.02 \pm 0.10) \times 10^{-5}$, $(-0.06 \pm 0.06) \times 10^{-5}$ and 0.41×10^{-5} respectively. The weighted mean value is consistent with all the data points with a reduced $\chi^2 = 0.95$. Thus, their study gives a more stringent 3σ constraint of $-0.24 \leq \Delta\alpha/\alpha($ in $10^{-5}) \leq +0.12$ over the redshift range of $0.4 \leq z \leq 2.3$. The median redshift of the whole sample is 1.55 which corresponds to a look-back time of 9.7 Gyr in the most favoured cosmological model today (Ω(total) = 1, $\Omega_\Lambda = 0.7$, Ω(matter) = 0.3, and H_0 = 68 km s^{-1}Mpc^{-1}). This gives a 3σ constraint on the time variation of $\Delta\alpha/\alpha$ to be -2.5×10^{-16} yr$^{-1} \leq (\Delta\alpha/\alpha\Delta t) \leq 1.2 \times 10^{-16}$ yr^{-1}. This is the strongest constraint from QSO absorption line studies till date. In conclusion, their study does not support the claims by previous authors of a statistically significant change in $\Delta\alpha/\alpha$ with cosmic time at $z > 0.5$.

Even though their study is consistent with no variation in α, it still does allow smaller variations in excess of what is found based on the Oklo phenomenon. Thus, it is important to further improve the constraints at higher redshifts. In addition, there are some short comings of the MM method that needs to be avoided. For example, MM method assumes that all species trace each other perfectly. However, any ionization or chemical inhomogeneity in the absorbing cloud may produce relative shifts between Mg II and Fe II lines at the level expected in the case of small variations in α. Also, any peculiar isotopic abundance of Mg can mimic small variations. Thus, it is important to perform detailed MM analysis using only multiplets from single species such as Ni II (or Fe II as in Quast et al. 2004) using a well defined high quality sample. It is also demonstrated that OH and other molecular lines can be used to improve limits on the variation in α . In addition, other constants can be constrained in a similar way. Although, it is hard to make any quantitative prediction, theorists estimate that variations of the proton-to-electron mass ratio, μ, could be larger than that of the fine structure constant by a factor of 10-50. A way to constrain the cosmological variations of μ is to measure the wavelength of rotational transitions of H_2 molecules at high redshifts. *Srianand* and *Hum Chand* (in collabortion with P. Petitjean, A. Ivanchik, D. Varshalovich, E. Rodrigues, B. Aracil, C. Ledoux and P. Boisse) have measured with high precision the positions of 79 molecular absorption lines of Lyman and Werner bands from two absorption systems at $z_{\rm abs}$= 2.594733 and 3.024988, in the spectra of QSOs Q 0405-443 and Q 0347-383, respectively. Data are of highest spectral resolution (R = 53000) and S/N ratio (30 - 70). As the absorption lines are not saturated, the profiles can be modeled as simple Gaussian functions. They find a correlation between the observed redshift of the lines and the sensitivity of the lines to the change in μ. Correlation exists even when they restrict their analysis to lines from J = 2 alone.

This correlation can be interpreted as a variation of μ with $\Delta\mu/\mu = (2.97 \pm 0.74) \times 10^{-5}$ over the past $\sim$12 Gyrs (see Fig. 30). However, uncertainties in the laboratory wavelengths are not quantified well and the observed correlation could just be an artifact of poor laboratory wavelengths. Thus,

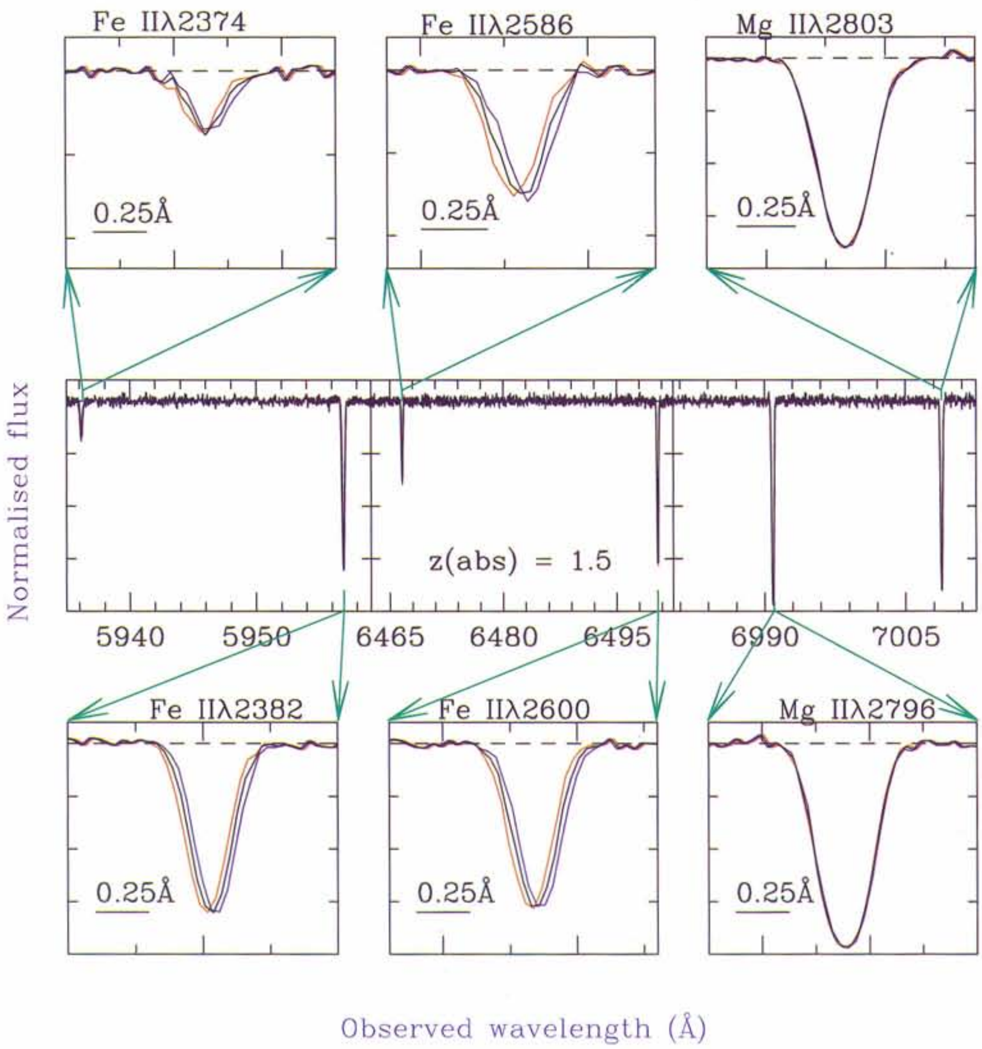

Figure 26: Middle panel shows the simulated spectrum of Fe II multiplet and Mg II doublet produced by an absorbing gas at $z_{\rm abs}$= 1.5 for $\Delta\alpha/\alpha = 0.0$ (black), 5.0×10^{-5} (red) and -5.0×10^{-5} (blue). The zoomed in view of different absorption lines are shown in bottom and the top panels. It can be seen that Mg II lines are virtually insensitive to small values of $\Delta\alpha/\alpha$, while Fe II lines are very sensitive to these changes. Thus Mg II can be used for obtaining the absorption redshift and then Fe II lines will be used to probe the variation in α. This is the main idea behind the MM method. The difficulty in detecting the α variation can be appreciated from the fact that the values of $\Delta\alpha/\alpha$, used in this illustration are 10 times more than the detection claimed by Webb, et al (2003).

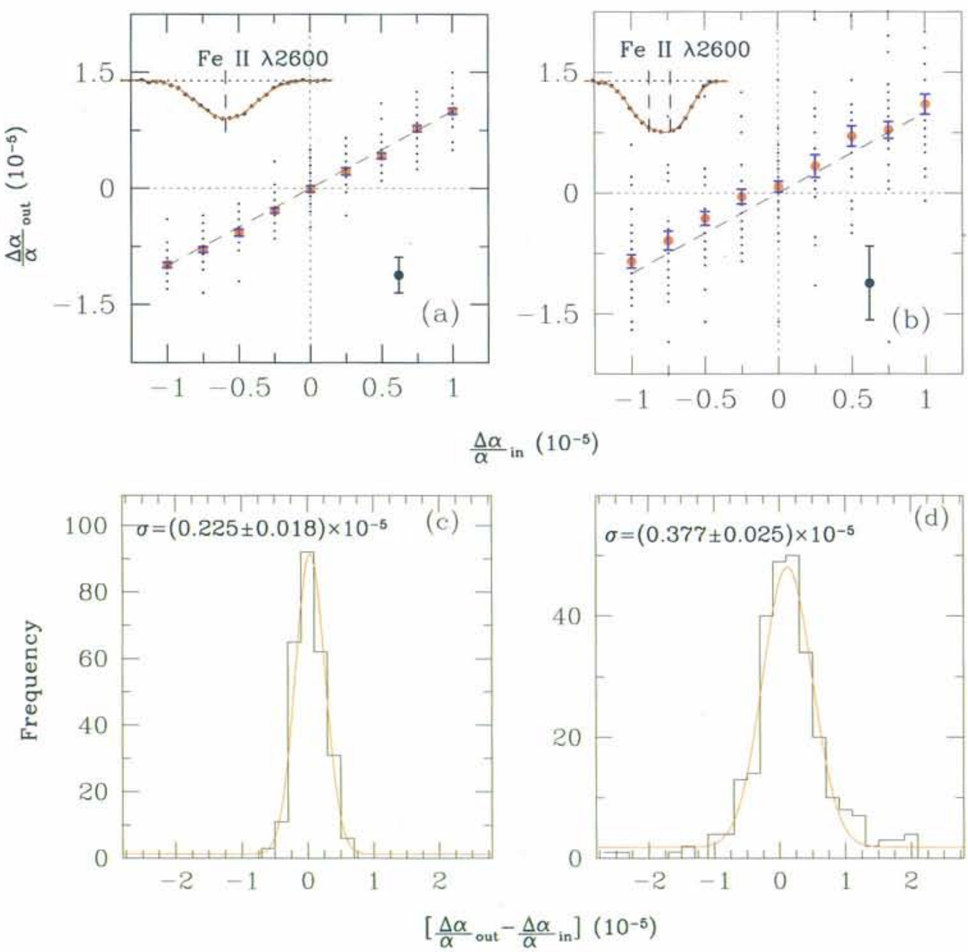

Figure 27: Absorption spectra of Mg II and Fe II are simulated using random values of the column densities, N, the Doppler parameter, b, and noise, keeping the signal-to-noise ratio, wavelength sampling and spectral resolution as in a typical UVES spectrum. Spectral shifts corresponding to a given value of $\Delta\alpha/\alpha$ are introduced. Our procedure is applied to the simulated data and best fitted value of $\Delta\alpha/\alpha$ is recovered. Top panels show the relationship between the input and derived value of $\Delta\alpha/\alpha$ in the case of a single clean component (left-hand side) and a blend of two components (right-hand side). A typical absorption profile is also shown in these panels. Dots are the values from individual realizations and the points with the error bars are the weighted mean obtained from 30 realizations. The lower panels give the distribution of the recovered $\Delta\alpha/\alpha$ around the true one. Best fitted Gaussian distributions are over-plotted.

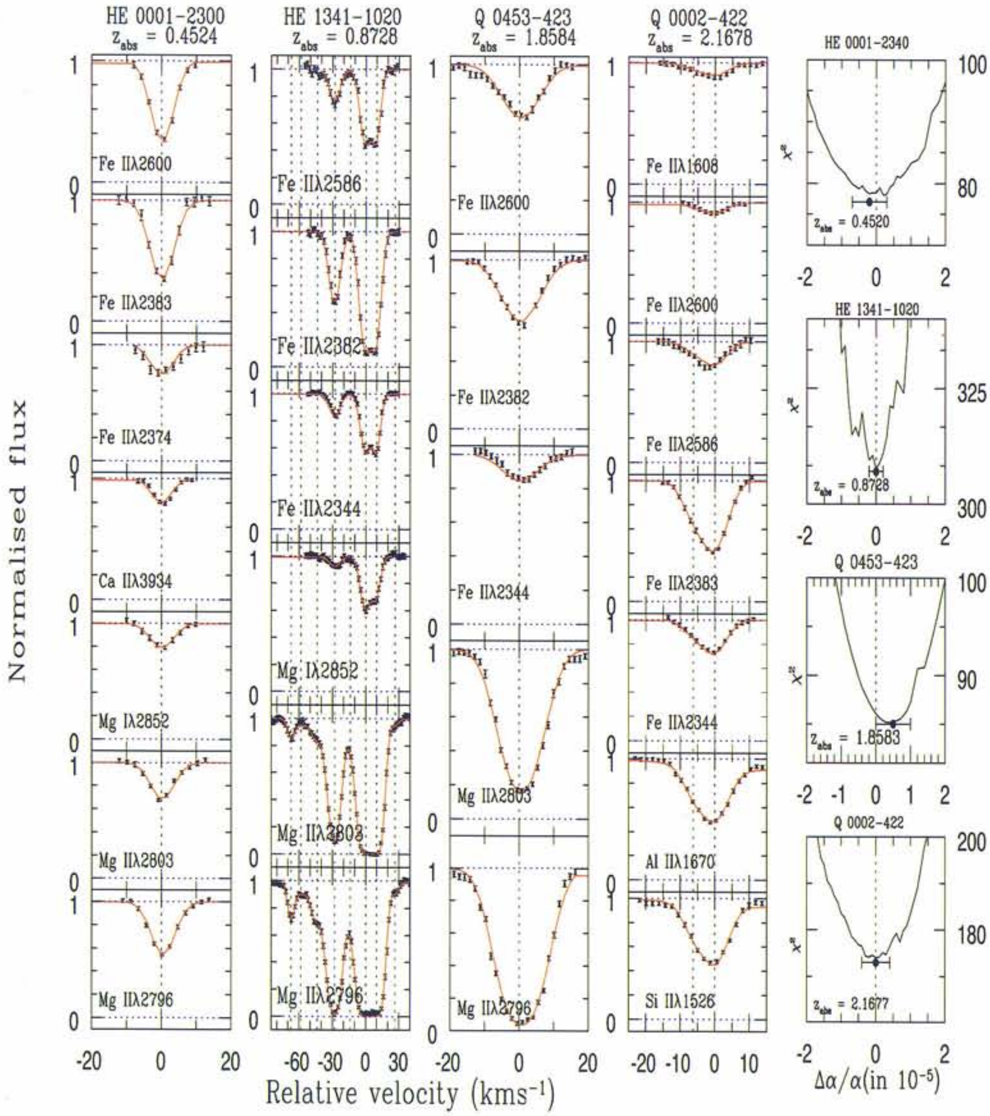

Figure 28: **Example of $\Delta\alpha/\alpha$ estimation from real data:** Voigt profile fits to 4 randomly chosen systems (out of 23) in the sample are shown in the first 4 columns from the left. The QSO name and absorption redshifts are given on top of the panels. The points with the error bars are the observed data and the continuous curve is the fit obtained using multicomponent Voigt profile decomposition. The locations of different components are marked with vertical dotted lines. The plots in the right most column demonstrate how $\Delta\alpha/\alpha$ is extracted from these systems. The χ^2 is plotted as the function of $\Delta\alpha/\alpha$. The minimum in this curve (marked with a dot) gives the best fitted value of $\Delta\alpha/\alpha$ and the error in this measurement (error bar around the dot) is based on the standard statistical method of computing errors from $\Delta\chi^2 = 1$.

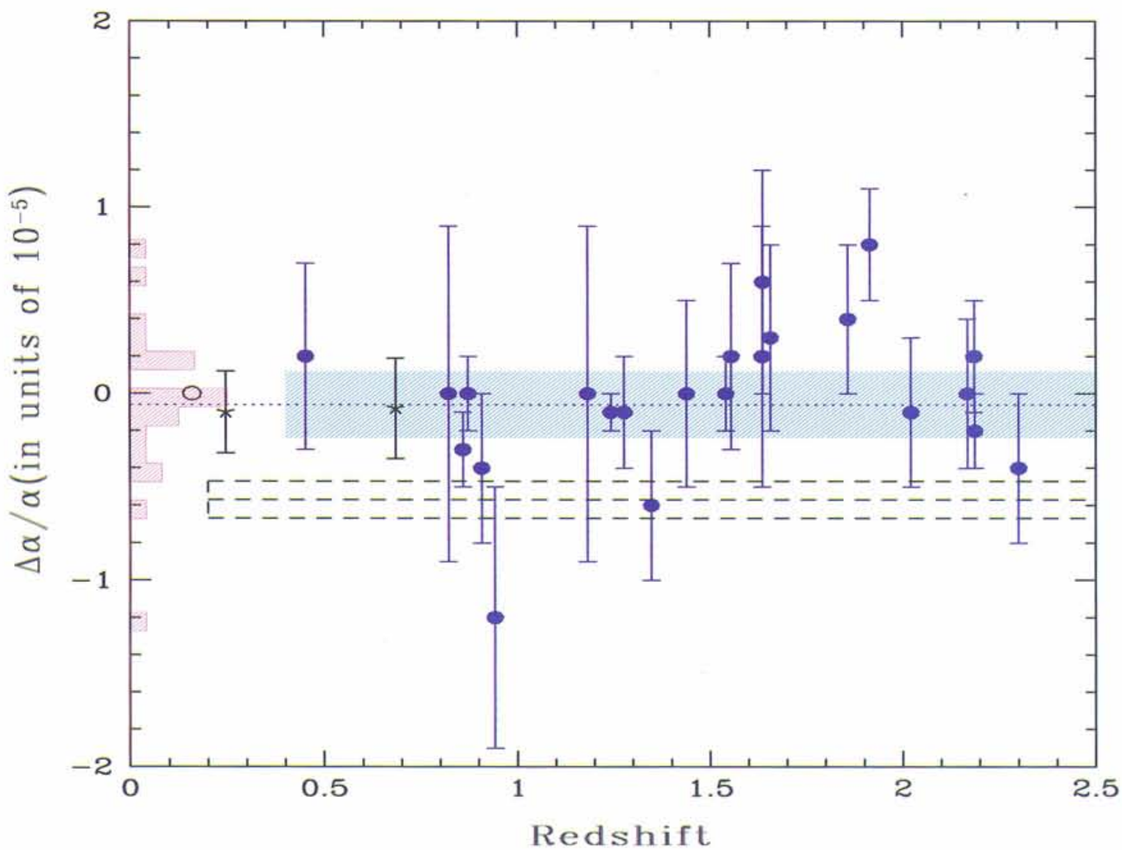

Figure 29: $\Delta\alpha/\alpha$ **measurements from the UVES sample:** The measured values of $\Delta\alpha/\alpha$ from the sample (filled circles) are plotted against the absorption redshifts of Mg II systems. Each point is the best fitted value obtained for individual systems using χ^2 minimization. The open circle and stars are the measurement from Oklo phenomenon (Fujii, et al., 2000) and from molecular lines (Murphy, et al., 2001a) respectively. The weighted mean and 1σ range measured by Murphy, et al. (2003) are shown with the horizontal long dashed lines. Clearly, most of the current measurements are inconsistent with this range. The shadow region marks the weighted mean and its 3σ error obtained from our study [$< \Delta\alpha/\alpha >_w = (-0.06 \pm 0.06) \times 10^{-5}$]. The data gives a 3σ constraint on the variation of $\Delta\alpha/\alpha$ to be -2.5×10^{-16} yr^{-1} $\leq (\Delta\alpha/\alpha\Delta t) \leq 1.2 \times 10^{-16}$ yr^{-1} in the case of flat universe with $\Omega_\lambda = 0.7$, $\Omega_m = 0.3$ and $H_0 = 68$ km s^{-1}Mpc^{-1} for the median redshift of 1.55.

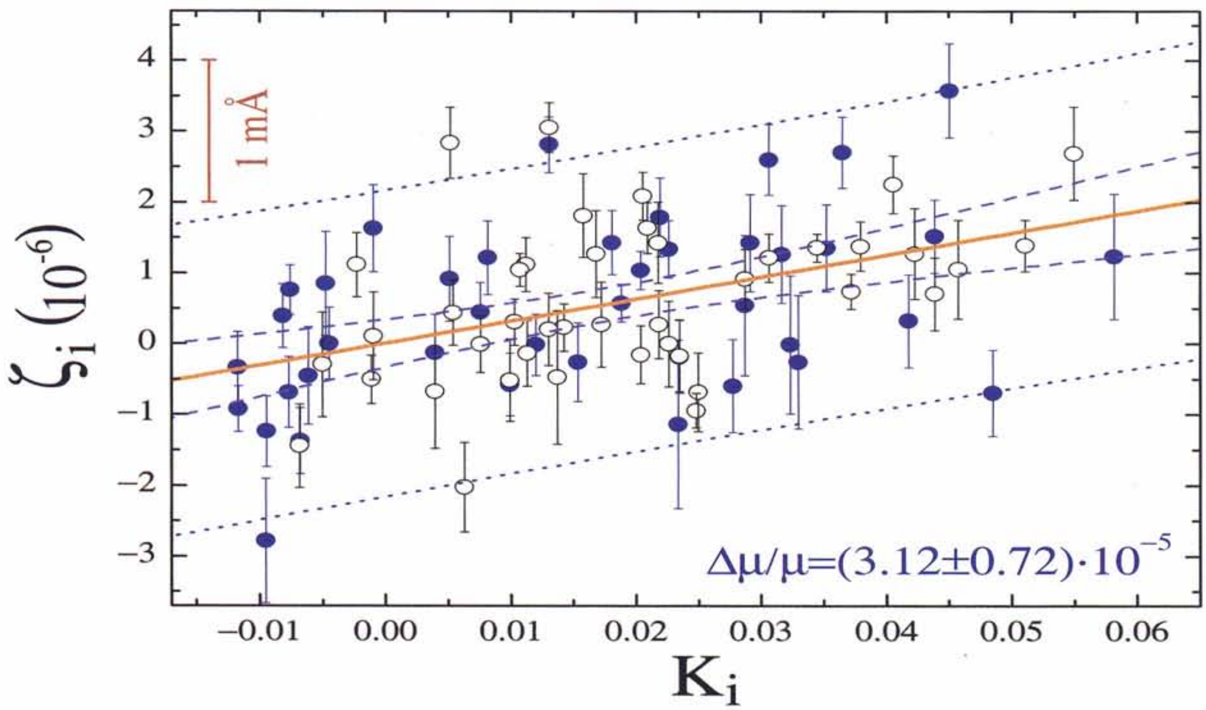

Figure 30: The relative positions of the absorption lines, $\zeta_i = (z_i^{obs} - z_{abs})/(1+z_{abs})$, are plotted versus the sensitivity coefficient $\mathbf{K}_i$. Filled and open circles are the measurements toward Q 0405−443 and Q 0347−383 respectively. Solid line shows the linear weighted fit to the data. The long dashed curves show the 95% confidence domain. The best fit is $\Delta\mu/\mu = (2.97 \pm -0.74) \times 10^{-5}$.

the next logical step is to obtain accurate laboratory wavelength measurements for confirming any possible variation in μ. Also, one may need to estimate the sensitivity coefficients using ab initio calculations.

Viscous Torques in Accretion

Prasad Subramanian has elucidated the nature of the viscous torque between neighbouring annuli in quasi-Keplerian accretion disks around blackholes with Bhalchandra Pujari, and Peter A. Becker. There have been several attempts in the literature at obtaining the standard fluid dynamical expression for this viscous torque using simple, physically motivated arguments, and several of them have been proven to be wrong. They have cleared several misconceptions and showed a consistent, simple, physically motivated way of deriving this expression based on the interchange of parcels between neighboring annuli. *Subramanian* has been also participating in a study with Peter A. Becker, which shows that, contrary to current perception, the Shakura-Sunyaev prescription for viscosity in accretion disks is the only one which is physically allowable, given the boundary conditions at the inner edges of these disks.

Search for Correlated Intra-night Variability of Blazars at Radio, Optical and TeV Wavebands

An interesting property of active galactic nuclei is that they are variable on all timescales across the whole electromagnetic spectrum from the radio range up to the gamma-ray-range. An especially interesting type of variability arises in the radio range on the timescales of less than one day, called intraday variability (IDV). The IDV at radio frequencies challenges the standard picture of beamed, intrinsically isotropic, incoherent synchrotron emission. If the variability timescale is used to calculate the source size by the ligh-travel-time arguement, the resulting brightness temperatures reach up to the range $T_b = 10^{16-20}$ K, far in excess of the inverse Compton limit of $T_b = 10^{12}$ K. The question arises: What is the physical nature of this very intense variable radio emission? Another key question is about the origin of highly variable emission in the TeV range observed in several AGN (e.g.,Gaidos, et al. 1996, Nature 383, 319).

To address some of these important questions, an entirely indigenous, multi-wavelength observational programme is being carried out by Gopal Krishna, *J. Bagchi* along with collaborators from

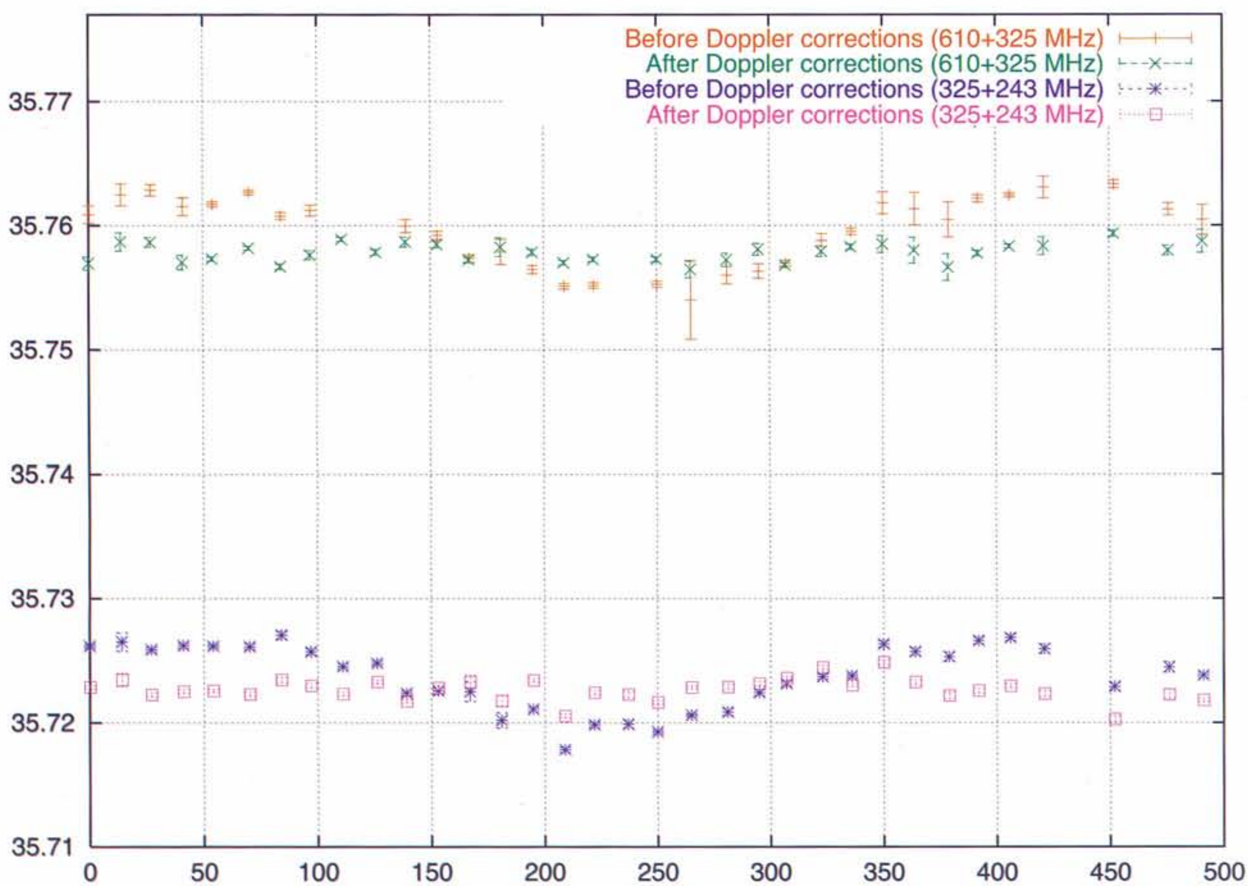

Figure 31: Variation of DM value with time, before and after Doppler corrections for pulsar B1642-03 observed with frequency combinations of 610 and 325 MHz (upper part) and 325 and 243 MHz (lower part).

IIA, Bangalore; ARIES, Nainital, and the cosmic ray group from TIFR. The project involves simultaneous radio (GMRT), optical (Nainital, Hanle) and TeV (Panchmarhi array) monitoring of 15 EGRET or TeV-detected blazars (Flat Spectrum Radio Quasars and BL Lac objects) for their IDV (actually, the intra-night variability).

An important scientific goal is to find out if coherent radio emission plays a role. Whereas, coherent radio emission is an established feature of pulsars, a few authors have considered such a possibility also for the case of AGN as well. Observational motivation for this came from the discovery of IDV of blazars with a typical amplitude of 25%. The inferred brightness temperatures are commonly 10^{18-19} K, i.e., 6-8 orders-of-magnitudes higher than the limit imposed by the inverse Compton catastrophy. To explain such IDV in terms of the usual incoherent synchrotron radiation would require bulk Lorenz factors of $\sim$ 100, or more, for the blazar jets. These values are an order-of-magnitude higher than those inferred from VLBI observations of the superluminal motion in blazar nuclei. This constitutes the basis for the possibility of coherent radio emission. However, recently, it has been argued that much of the IDV seen at even centimetre wavelengths can be due to interstellar scintillations. On the other hand, this cannot readily explain the few cases, where the radio IDV was found to be accompanied by an optical flare or the radio IDV was seen to correlate either with radio polarization or with radio specral index.

What is needed, is to establish the statistical significance of such correlated radio-optical rapid variability events. However, despite its central importance to AGN physics, no systematic, long-term search for such correlated radio-optical variability on hour-like time scale has been undertaken and this current GMRT based project is designed to fill this important observational gap in the study of AGN phenomenon. Fortunately, the needed facilties are now available within the country and this makes the project logistically viable. It may be noted that at $\nu \sim 1.4\ GHz$, even a 10 mJy over a time scale of an hour would correspond to a brightness temperature in excess of 10^{20} K, which is far above the well known 10^{12} K limit set for an incoherent source, by the inverse Compton catastrophy. So far, about 10 sessions of GMRT observations (about 100 hours) have been carried out. Recently, they monitored the blazars Mrk 421 and 1426+428, which were simulataneously monitored from Hanle (optical) and Pachmarhi (TeV). Full processing of these recent GMRT data is in progress, together with the reduction of the simultaneous optical and TeV observations.

Galaxy Morphology

Galaxies have complex morphology in general, and yet there is a great deal of order in the large scale structure. This is particularly evident in elliptical galaxies, which seem to have rather regular shapes which can be represented by a series of elliptical isophotes. High dynamic range imaging shows the presence of dust, small emission structures, and shapes distorted by obvious interactions with other galaxies, while observations in the radio band shows, in a small fraction of all galaxies, complex radio shapes with luminosities, which can exceed the optical luminosity of the galaxy, and observations in the X-ray band have revealed the presence of hot gas.

Setting all these complications aside, the surface brightness of ellipticals can be very well represented as a three parameter family, characterized by the central surface brightness $\mu(0)$, a characteristic length r_e which encompasses half the total light in the galaxy, and a shape parameter n which determines how fast the surface brightness decreases as a function of the major-axis distance from the centre of the galaxy. In the classic de Vaucouleurs' law, $n = 4$, and galaxies form a two parameter family. Several correlations like the Kormendy relation between the central surface brightness and the half light radius, and the Faber-Jackson relation between the galaxy luminosity and an important dynamical parameter, the central velocity dispersion Σ, have been known. These correlations are very interesting, but suffer from rather large scatter about the mean relation, which in each case indicates the presence of another parameter which must be taken into account. This situation led to the discovery of the fundamental plane of galaxies, which a tight planar correlation between the average surface brightness $\mu(< r_e)$ (which for de Vaucouleurs' law differers from $\mu(0)$ by just an additive constant), r_e and σ. Elliptical galaxies are known to be distributed with rather small scatter around the best-fitted fundamental plane, and the tight relation allows distances to individual galaxies to be estimated within an accuracy of about 20 per cent, and put restrictions on the functional form of the mass-to-light ratio M/L.

The fundamental plane relation is generally derived from the data assuming de Vaucouleurs' law, but there is now increasing evidence that the more general Sersic law, which treats n as a free parameter to be determined from the data, is the more appropriate one. The fundamental plane has, therefore, to be generalized to take this account, which can lead to smaller scatter, and possibly a better discriminant between different situations like the crowded environment in the centres of rich clusters and more sparsely populated ones like the field. Moreover, it is possible to obtain a planar relation between the three parameters $\mu(0)$, r_e and n. This new plane is called the photometric plane, and is nearly as tight as the fundamental plane. The interesting feature of this correlation is that it is possible to include the bulges of disk galaxies in it, and it is found that the bulges of early type galaxies mix very well with the ellipticals, perhaps indicating a common origin for both.

It is found that the scatter around the best fit photometric plane, while small, is larger than may be expected from errors of measurement and fitting. This cosmic scatter indicates that there must be another parameter in the background. It has been shown by Ravi Kumar, *Ajit Kembhavi*, B. Mobasher (STScI) and V. C. Kuriakose that the scatter is very well correlated with the dispersion velocity σ, and that it is, therefore, possible to unite the four parameters into a single hyper plane, which has significantly less scatter than the photometric plane. The latter, in fact, is a simple projection of the former, which follows from taking an average over the σ. It can also be shown that the fundamental plane can be obtained from the hyper plane, though not as a simple projection. The existence of the hyper plane changes the relation between M/L, the morphological parameters and σ, and other consequences are being worked out.

It is not easy to see the distribution of the bulges of spiral galaxies around the hyper plane, because of a paucity of σ values for the bulges. But it has been shown that the bulges of lenticular galaxies mix very well with ellipticals (S. Barway, Ravi Kumar, *Ajit Kembhavi*, S.K. Pandey). It is important to see how the photometric plane and hyper plane behave at high redshifts, and this is being done using galaxies at a redshift of upto unity from the GOODS field (*Abhishek Rawat* and *Ajit Kembhavi* in collaboration with F. Hammer and H. Flores of the Paris Observatory).

High Energy Astrophysics

Variability of Blackhole X-ray Binaries

Blackhole X-ray binaries are variable on a wide range of timescales. A detailed analysis of their rapid variability is crucial to the understanding of the geometry and dynamics of these high energy sources. While significant results have been obtained based on the response of the system to temporal variations, the origin of the variability is still not clear. Important insight into the origin can be obtained by the detection and quantification of the possible non-linear behaviour of the fluctuations. For example, the presence of stochastic fluctuations would favour X-ray variations driven by variations of some external parameters (like the mass accretion rate), or the possibility that X-ray producing flares on top of the accretion disk occur randomly. On the other hand, if the fluctuations can be described as a deterministic chaotic system, then disk instability or coherent flaring activity could be the likely origin. The non-linear time series analysis (NLTS) seems to be the most convenient tool to check if the origin of the variability is chaotic, stochastic or a mixture of the two and has been adopted in several disciplines to study complex systems (e.g., human brain, weather) and predict their immediate future. *R. Misra*, K. P. Harikrishnan, B. Mukhopadhyay, G. Ambika and *A. K. Kembhavi* have developed a modified NLTS analysis technique, which computes the correlation dimension D_2 in a non-subjective manner. This technique was used to analyze the X-ray light curves of the blackhole system GRS 1915+105 in all twelve temporal classes. For four of these temporal classes D_2 saturates to $\approx 4-5$ which indicates that the underlying dynamical mechanism is a low dimensional chaotic system. This result is being confirmed and extended by using other non-linear techniques like surrogate analysis, Lypanov exponent computation and Singular Value Decomposition (SVD).

Knotty Jets

The detection of kilo-parsec (kpc) scale jets with knots in several active galactic nuclei (AGN) by the *Chandra* observatory has opened a new window on the nature of these phenomena. The standard model to explain the formation of these knots is the internal shock model, where relativistically moving blobs ejected from the AGN collide at a distance from the source. S. Sahayanathan and *R. Misra* have applied this model to the radio/X-ray knots of several AGN and find that the model can explain the observations, if the knot forming (i.e., colliding) blobs are ejected typically within 10^{10} secs of each other and if such sporadic blob ejection occur on a 10^{11} sec timescale.

The inner regions of accretion disk around blackholes have non-thermal electrons which Comptonize soft photons to high energies. 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, via p-p collisions, produce electrons, positrons and γ-rays. For such a scenario, in an earlier work, S. Bhattacharyya, N. Bhatt, *R. Misra* and C. L. Kaul computed the steady state electronpositron distribution taking into account Compton cooling, e^-e^+ pair production (due to $\gamma - \gamma$ interactions) and pair annihilation. The particle evolution was approximated by the standard Fokker-Planck approximation, where it is assumed that the change in energy of the leptons per scattering is small. They have now extended this work by taking into account the exact but complicated energy exchange expression for Compton scattering. They find that the final resultant spectra has different characteristics than those obtained by the standard approximations.

Incompressibility of Strange Matter

Subharthi Ray (in collaboration with Manjari Bagchi, Monika Sinha, Jishnu Dey, Mira Dey and Siddhartha Bhowmick) have modelled the strange stars using a realistic equation of state (EOS), that incorporate chiral symmetry restoration as well as deconfinement at high density. They compare their calculations of incompressibility for this EOS with that of nuclear matter. One of the nuclear matter EOS has a continuous transition to ud-matter at about five times normal density. Another nuclear matter EOS incorporates density dependent coupling constants. From a study at the consequent velocity of sound, it is found that the transition to ud-matter seems necessary.

Breathing Modes in Strange Stars

The strange star (SS) model of *Subharthi Ray* (in collaboration with Jishnu Dey, Mira Dey and Siddharth Bhowmick) is a bare strange star, with a sharp surface and a surface density of about 5 times ρ_0 (normal nuclear matter). This unique feature can be used to explain many peculiar features of the astrophysical compact stars. Recently they suggested the existence of skin vibrations in strange stars. Emission lines in the eV and keV range by certain stellar candidates from their recent analysis raise the question of their possible origin. Recently, it has been suggested that the resonance absorption at 0.7, 1.4, 2.1 and 2.8 keV in 1E1207-5209 and at 0.35, 0.7 and 1.4 keV in RX J1856.5-3754 are due to harmonic surface vibrations in strange stars. They propose that these harmonic vibrations may also be responsible for emission lines in the above mentioned compact stellar candidates.

Galaxy and Interstellar Medium

Study of Pulsar Dispersion Measure using the GMRT

The interstellar medium (ISM) disperses 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 broad band pulse arrive later than the higher frequency components. In constructing accurate pulse profiles and measuring arrival times, this broadening in time of the radio pulses has to be corrected, for 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.

A pulsar is a very accurate clock, because it rotates at a nearly constant rate. To measure the correct period of a pulsar, its DM has to be measured to high precision, so that dispersion corrections can be made. Precise knowledge of DM 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 large scale irregularities in the ISM. Accurate values of DM can be used to estimate the distance to a pulsar.

Dispersion measures are most accurately measured by the simultaneous multi-frequency observations of the radio pulses. With such accuracy, it is possible to study fluctuations in the value of DM over time. The Giant Metrewave Radio Telescope (GMRT) of the National Centre for radio Astrophysics (NCRA), Pune, has a unique capability for such measurements. A project for multi-frequency observations of a number of pulsars over an extended period of time is being carried out by *Ajit Kembhavi* and *Amrit Lal Ahuja* of IUCAA, in collaboration with Yashwant Gupta, who is the originator of this key project. As a part of this project, about a dozen pulsars were observed simultaneously at two frequencies out of 243, 325 and 610 MHz, with the GMRT once every two weeks over a total period of about one and a half year. The aim of project is to develop a reliable technique to estimate the pulsar DMs with a fractional accuracy of $\sim 10^{-4}$ and better.

Analysis of the data has shown that while some DM values agree with their cataloged counterparts, others do not, indicating variations. It was found necessary to separate out components of the variation produced due to causes related to the way in which observations were made, rather than true systemic variations. For example, a small quasi-sinusoidal variation was traced to the Doppler shifting of the observed frequency, relative to the emitted frequency, due to the motion of the Earth (see Figure 31).

Some of the pulsars, observed with two different frequency pair combinations and differences, are seen in the DM values obtained using the two pairs (see Figure 31). It is possible that this difference is because of different emission heights in the pulsar polar cap. To confirm this possibility, it will be necessary to observe the pulsars in simultaneous triple frequency observation mode.

Another interesting result they have obtained is that in the case of some pulsars (e.g., B0329+54), the DM value obtained from average profile method and single pulse analysis method show an offset. This is still to be understood. To convert the raw data into usable form the catalog DM value is used to de-disperse data in all 256 spectral channels (each channel 62.5 kHz). If the catalog value of DM used in the analysis differs from the actual value of DM, the measured pulse shape may be affected, biasing the final result. They have developed a technique to make the results converge to the correct DM value, starting from the catalog values. This technique of pulsar DM estimation is quite robust and reliable, and in the future it will be extended to other pulsars.

Interstellar Dust and Extinction by Non-spherical Grains

In continuation of the ongoing research on modeling of interstellar dust grains, Ranjan Gupta (in collaboration with D.B. Vaidya, Asoke K. Sen and T. Mukai) has developed an alternative model, called T-Matrix, which can reproduce the interstellar extinction curves in good agreement with the earlier DDA model. (Refer Figure 32).

Search for Microorganisms in the Earth's Atmosphere

This India-UK joint project, under the leadership of *J. V. Narlikar*, is being supported by the Indian Space Research Organization. Its purpose is to examine the contents of air samples at heights up to 41 km above the surface of the Earth. The samples collected during the 2001 balloon flight are still being analyzed for their biological content and nuclear composition. After the confirmation of living cells and bacterial life-forms by the Cardiff-Glasgow scientists in the project, it will be of interest to examine the nuclear abundances of the matter collected on filters to see if they are extraterrestrial. Attempts are being made to get this examination carried out in a suitably equipped laboratory. Meanwhile, ISRO has been approached for support for another balloon flight with a more sophisticated payload.

Stellar Physics

Brown Dwarf Polarimetry

Quite a few recent models predicted small levels of polarization in the optical light from brown dwarfs. This could be due to several reasons such as the presence of unsettled dust in the atmospheres of relatively warm brown dwarfs or imhomogenities in the dust distribution. These predictions were vindicated with the recent detection of polarization in some brown dwarfs by a group led by Menard et. al. using one of the Very Large Telescopes in Chile. However, the detected polarization levels are in general lower than the theoretically predicted values. In order to understand the nature of the origin of ploarization we need to study its wavelength dependence and time-variability. *A. N. Ramaprakash and S. N. Tandon* are collaborating with S. Sengupta and M. Maiti (IIA, Bangalore) to exploit the extremely low instrumental polarization of IMPOL ($\tilde{0}.05\%$) to detect polarization in brown dwarfs brighter than about V=17 with the 2.3m Vainu Bappu Telescope, to carry out a systematic study of polarization in brown dwarfs.

Coude Feed Spectral Library

Ranjan Gupta has completed, in collaboration with H.P. Singh and Jim Rose and his team, a DST-NSF (Indo-US) proposal entitled 'A Comprehensive Digital Library of Stellar Spectra' in August 2003. The Figure 33 shows a sample of one of the K type star spectra and Figure 34 shows an attempt of Artificial Neural Networks (ANN) classification on this large optical library of more than 1250 spectra.

Classification of 2000 IRAS Sources

In collaboration with K. Volk and S. Kwok, *Ranjan Gupta* has successfully classified 2000 bright IRAS sources from their spectral morphology using Artificial Neural Network scheme into 17 pre-defined classes.

Figure 35 shows the result of ANN classification as a histogram, where more than 85% of the spectra have been correctly classified. Figure 36 shows a 3D representation of this result.

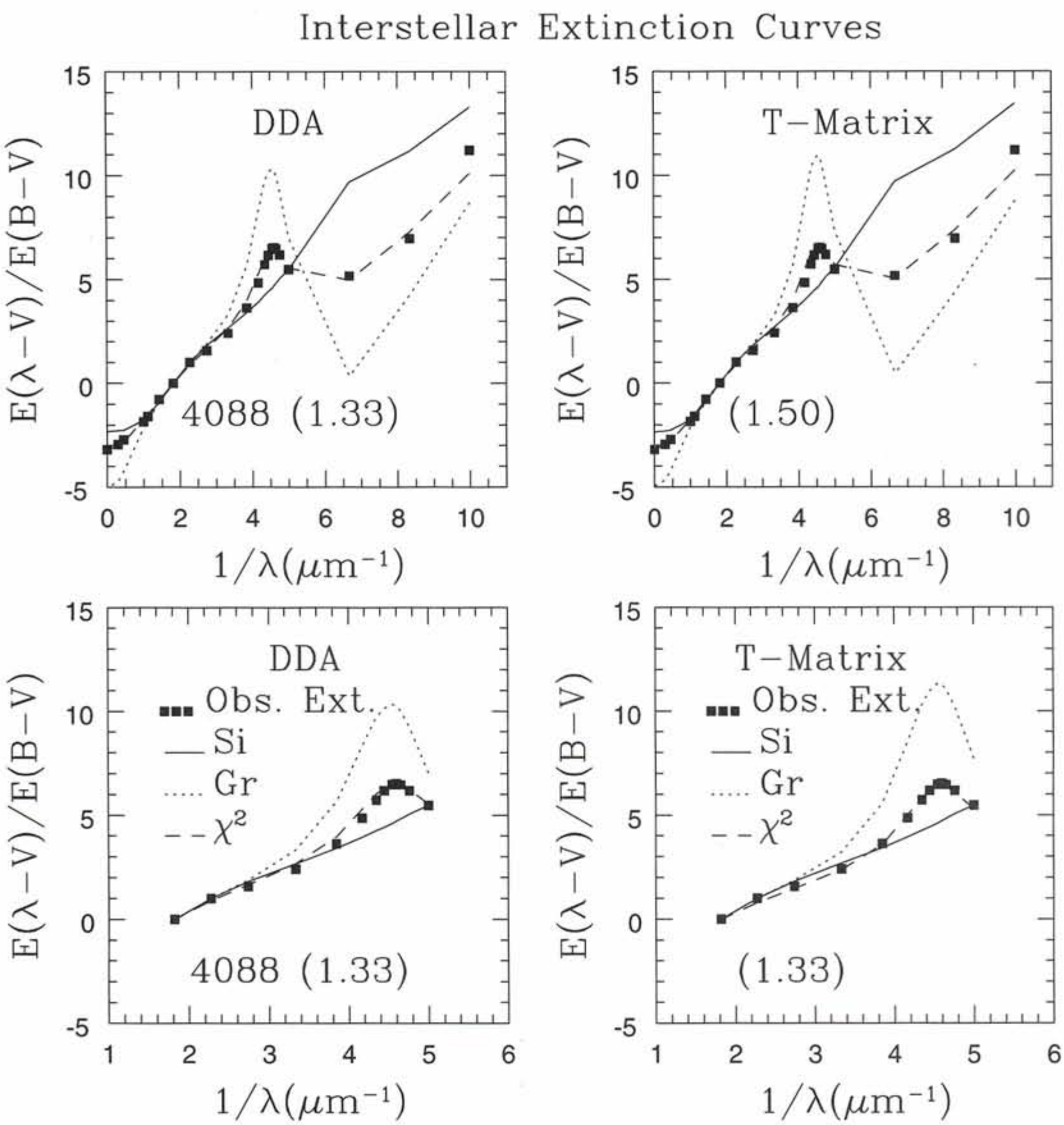

Figure 32: The top panels show the comparison of observed interstellar extinction curve with the best fit model combination curve for spheroidal silicate and graphite grains using DDA and T-matrix. The lower panels show the bump region.

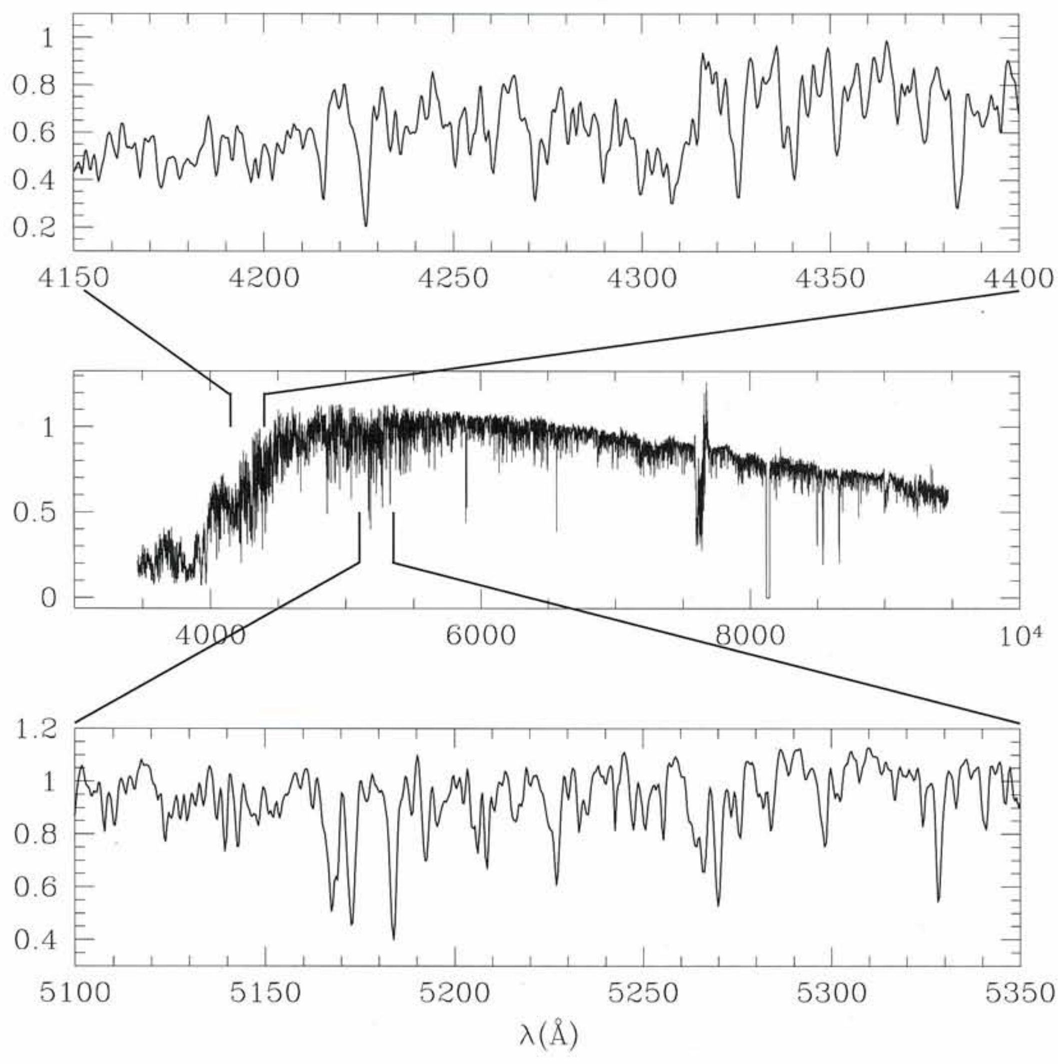

Figure 33: The spectrum of the K0III HD4128, with expanded regions to show the large information content of the spectrum. Given that the S/N ratio exceeds 100:1 per pixel, essentially all features discernible in the spectrum are real.

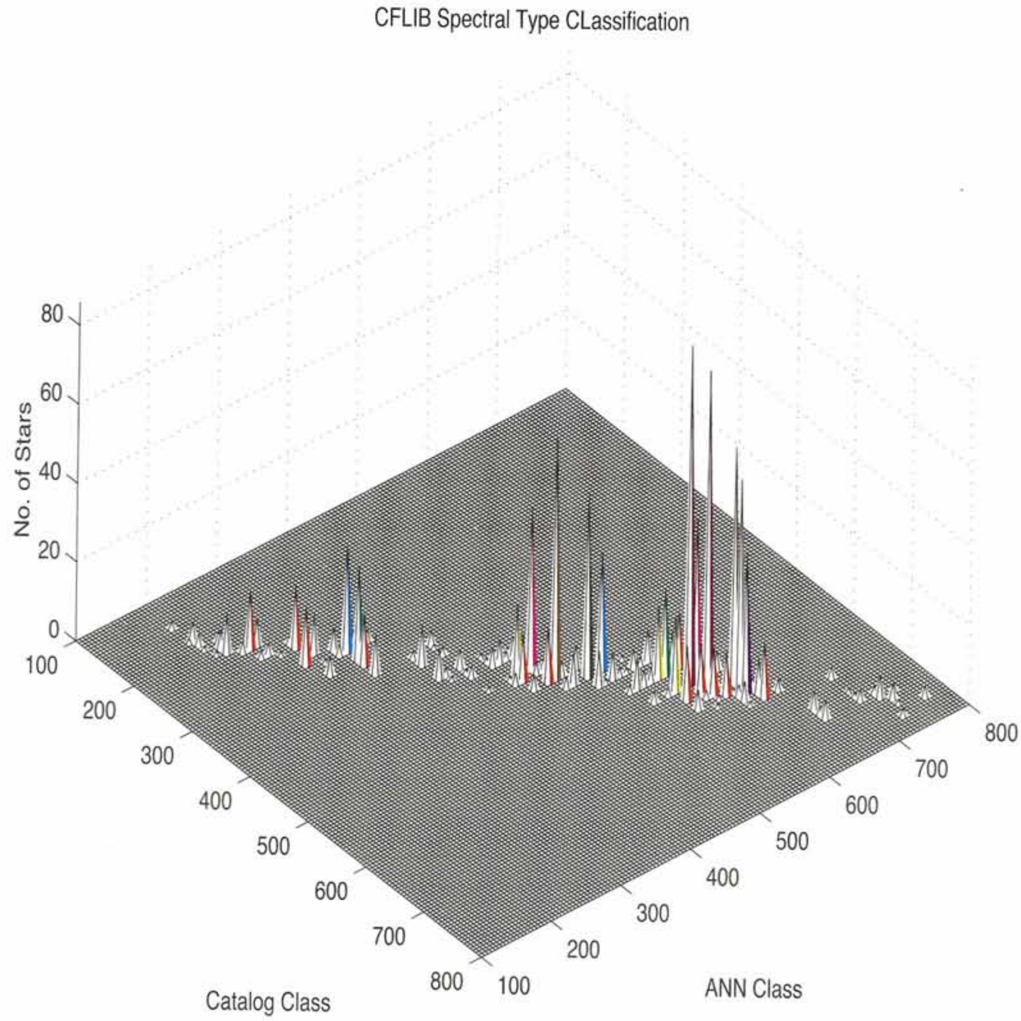

Figure 34: The ANN classification of about 1250 spectra using the blue region of CFLIB library and also gives an idea of the range of spectral types covered by the library.

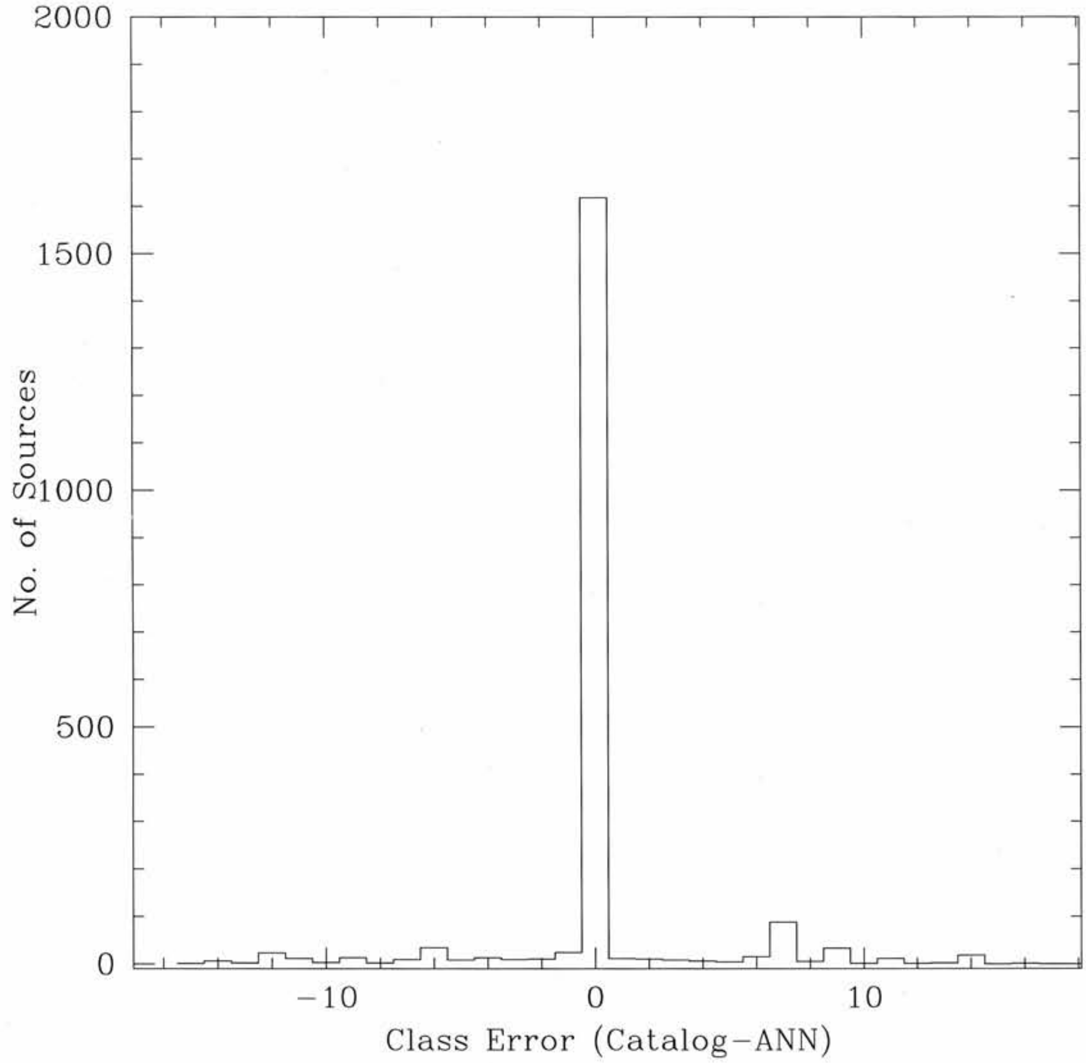

Figure 35: Histogram of classification accuracy for the 2000 test patterns with 17 pre-defined training classes shown on the left panel.

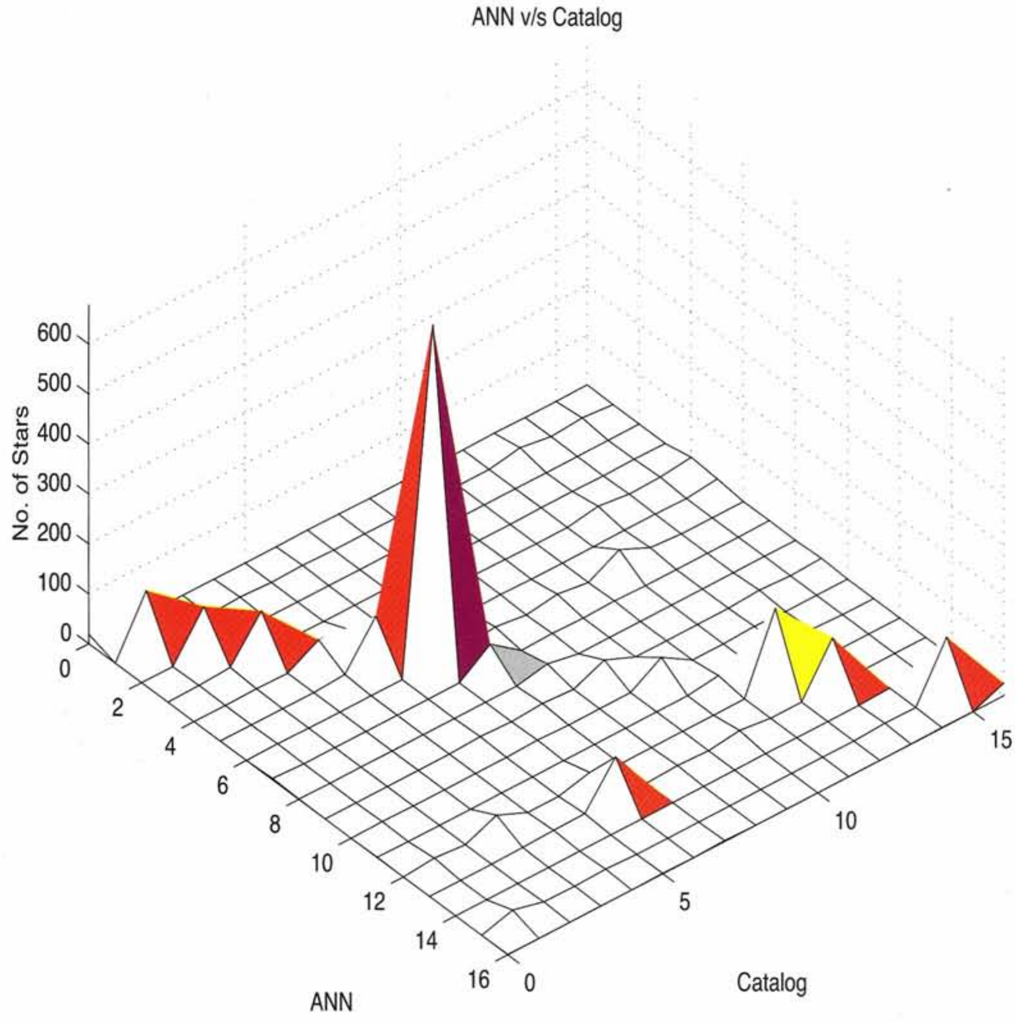

Figure 36: The 3D histogram of the same result as shown in Figure 35

Study of Young Open Star Clusters

Young open star clusters in a galaxy provide valuable information about star formation processes and are key objects for the galactic structure and evolution. For such studies, a knowledge of cluster's parameters like distance, age, reddening and stellar content is required, which can be derived from the colour-magnitude and colour-colour diagrams of star clusters. In addition to this, the distribution of stellar masses at the time of cluster formation is of fundamental importance to analysis related to evolution of galaxies. The initial mass function also plays an important role in understanding the early dynamical evolution of star clusters, because it is a fossil record of the very complex process of star formation and provides an important link between the easily observable population of luminous stars in a stellar system and the fainter, but dynamically more important, low mass stars. Another related problem is the mass segregation in star clusters in which massive stars are more concentrated towards the cluster centre compared to low mass stars. It is not clear whether the mass segregation observed in several open clusters is due to dynamical evolution or an imprint of star formation processes itself. Thus, one can say that the young open star clusters are the laboratories in a galaxy for providing answers to many current questions of astrophysics.

UBVRI CCD photometry in the region of two young open star clusters Basel 4 and NGC 7067 has been done for the first time by *R.S. Yadav* and collaborators. The observations were obtained using a 2K×2K CCD system at the f/13 Cassegrain focus of the Sampurnanand 104-cm telescope of the State Observatory, Nainital. The entire chip covers a field of 12.3×12.3 arcmin^2. The sample consists of $\sim$ 4000 stars down to $V \sim 21$ mag. Stellar surface density profile indicates that radius of Basel 4 and NGC 7067 are about 1.8 and 3.0 arcmin respectively. The $(U-B)$ versus $(B-V)$ diagrams indicate that metallicity of NGC 7067 is solar, while that of Basel 4 is $Z \sim 0.008$. *Yadav*, et.al. estimate the mean value of $E(B-V) = 0.45 \pm 0.05$ and 0.75 ± 0.05 mag for Basel 4, and NGC 7067 respectively. The analysis of 2MASS JHK data in combination with the optical data in both the clusters yields $E(J-K) = 0.30 \pm 0.20$ mag and $E(V-K) = 1.60 \pm 0.20$ mag for Basel 4 while $E(J-K) = 0.40 \pm 0.20$ mag and $E(V-K) = 2.10 \pm 0.20$ mag for NGC 7067. Furthermore, colour excess diagrams show a normal interstellar extinction law towards both the clusters.

Using the intrinsic colour-magnitude diagrams of the cluster members, they estimated the distances of the clusters as 3.0±0.2 and 3.6±0.2 Kpc for Basel 4 and NGC 7067 respectively. By fitting the proper metallicity isochrones to the bright cluster members, the age of the clusters were estimated as 200±50 and 100±25 Myr for Basel 4 and NGC 7067 respectively. The mass function slope, which is derived by applying the corrections of field star contamination and data incompleteness are 1.55 ± 0.25 and 1.68 ± 0.47 for Basel 4 and NGC 7067 respectively. The values of mass function slopes are, thus, not too different from the Salpeter's (1955) value. Mass segregation is observed in both the clusters, which may be due to the dynamical evolutions or imprint of star formation processes or both.

Solar Physics

Observations of the Sun with the Giant Metrewave Radio Telescope

Prasad Subramanian has been collaborating with S. Ananthakrishnan and others in developing the GMRT solar observing programme. They have recently published the first GMRT observations of a flare-CME event. Using radio images obtained with the GMRT, together with data at several other wavelengths, they have gathered insights into the initiation of the flare-CME phenomenon. This work has provided some of the first observational evidence for the formation of an intense current sheet during the acceleration phase of the flare-CME phenomenon. The formation of a current sheet under the erupting magnetic field arcade is a key ingredient of several competing models for CME initiation.

Subramanian has been interacting closely with Monique Pick and other members of the Solar Radiophysics group of the Observatoire de Paris, Meudon, France, with regard to joint GMRT - Nancay Radioheliograph (NRH) observations of the sun. The first results combine visibilities from the NRH and the GMRT for a couple of sample observations of the sun. This combination exploits the advantages of both the instruments: the dense coverage at short baseline spacings given by the NRH with the superior spatial resolution offered by the GMRT owing to its large baseline spacings. This is expected to yield solar maps of unprecedented dynamic range at meter wavelengths. Apart from the technical acomplishment of producing such maps, these are very useful for several aspects of cutting edge research into the nature of the solar corona. The superior spatial resolution of such combined maps will yield information on the smallest structures in the solar corona observable at metre wavelengths. This in turn, will reveal the fibrous nature of the solar corona, and impose constraints on the scattering of radio waves due to coronal imhomogenieties. When observing the sources of radio noise storms, such observations will also yield useful constraints on their brightness temperatures, thereby, constraining parameters of the electron acceleration processes that give rise to these phenomena. Solar noise storms are ubiquitous phenomena on the sun at meter wavelengths. Thus, they are ideally suited for study with a telescope like the GMRT, which is only occasionally available to study the sun. More importantly, they are representative of other astrophysical situations, where quasi-continuous electron acceleration processes are operative, and for which such detailed data are not available. *Subramanian* has initiated a study with Peter A. Becker on the efficiency of the electron acceleration process in generating noise storms.

Instrumentation

NIPI - Near-Infrared PICNIC Imager

The necessity of being able to make observations at near-IR wavelengths with the IUCAA telescope has been realized from an early stage of the project. To meet this requirement, work on building a near-IR camera to cover J, H and K bands have undertaken at IUCAA since 2001. A major milestone in the development of this new instrument was achieved last year with the testing of the silicon multiplexer on the final circuit board, using the IR-controller and the core version of the observation software. The silicon multiplexer is physically and electrically exactly identical to the PICNIC detector, but does not carry the IR-light sensitive HgCdTe layer. With these tests on the bare multiplexer, *A. Deep*, *A. N. Ramaprakash* and *S. N. Tandon* and other members of the instrumentation group, have now mastered the technique for data acquisition with PICNIC IR-detectors. The silicon multiplexer has a very limited sensitivity to visual light and by exploiting this, images of bright objects like incandescent lamp filaments, etc. were obtained (see Figure 37). These tests allowed the estimation of various performance parameters of the system, like readnoise, bias level, speed of operation, robustness of the system, etc. In this detector system, the necessary clock and bias signals for data acquisition are encoded in the form of a state-time table, called the waveform table. Such a table allows easy configuration of the data acquisition system to cater to different observing scenarios, which varies in their demands in terms of speed of operation, regions of interest, data minning, multiple exposures, nondestructive readouts, etc. A number of these operational variables were explored to fully understand the behaviour of the system.

The next step is to replace the bare multiplexer with the actual IR detector and carry out tests. Since, the IR-detector has to be cooled to very low temperatures in order to keep the dark current neglible, while conducting the tests, a suitable test set-up is being prepared. Apart from the physical and electro-static fragility of these detectors, there is an upper limit on the rate at which they can be cooled from room temperature to the operating temperature of about 80K. The experimental set up should take care of these restriction as well as allow a controlled amount of IR-light to reach the detector.

It was reported last year that the optical design of the instrument was complete and orders had been placed for procuring the lenses, mirrors, filters and dewar window. These components have now been received from the vendors. Suitable mechanical mounting arrangements for these components are currently being designed. The mounting arrangements should be such that the elements do not suffer excessive stresses/deformation at the operating temperature of about -100^0C. The optical components will be aligned and tested at room temperature and they should maintain the alignment to a large extent at the working temperature also.

The optical components and the detector will be housed inside a cryogenic dewar cooled by liquid nitrogen. In order to prevent water from condensing on the optics/detector when cooled as well as to reduce the heat load, the dewar has to be evacuated to reasonably low vacuum. The cryogenic dewar will have two parts. One part will carry the liquid nitrogen flask and the ports to fill liquid nitrogen as well as to evacuate the dewar. The other part will house the optical components and the detector on a table, which is directly attached to the cold plate of the liquid nitrogen flask. Since, the detector has to operate at temperatures close to that of liquid nitrogen, the detector mount will have extra conductive paths to the cold face of the nitrogen flask. The first part of the dewar has been already procured from Infrared Systems, USA (see Figure 38). Work on the design of the second part of the dewar, which has to form a vacuum chamber along with the first part, is currently underway. Once the design is finalized, the chamber will be manufactured with the help of local industry. The work on designing, fabricating and assembling an embedded instrument controller is approaching completion. This controller will accept instructions from the instrument control computer and carry out operations like changing filters, monitor tem-

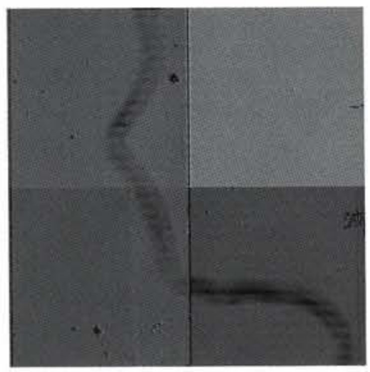

Figure 37: The image of incandescent lamp filament acquired through multiplexer. The filament was focused on the multiplexer using a lens.

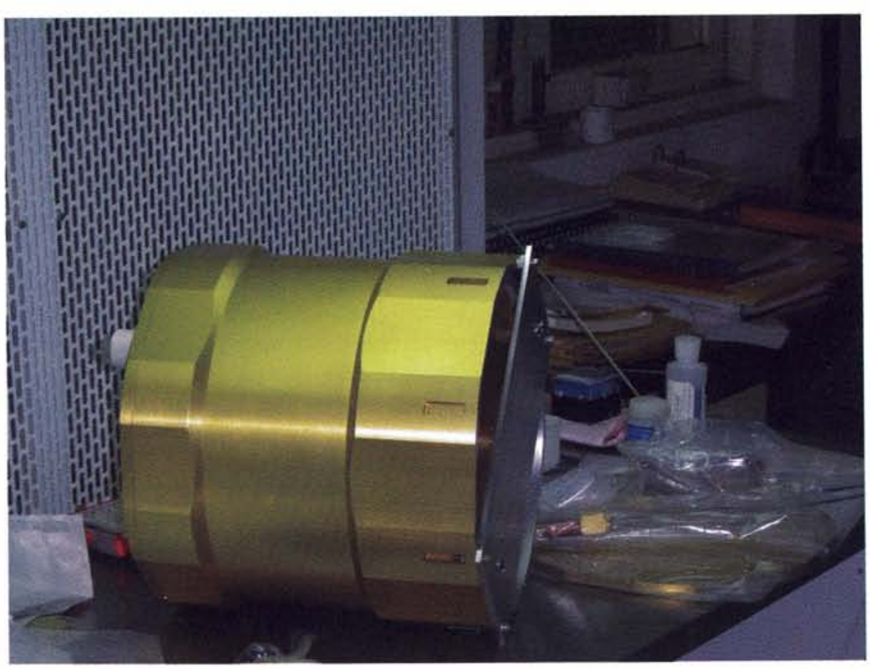

Figure 38: A snapshot of liquid nitrogen dewar procured from Infrared Labs, Arizona.

peratures inside the dewar, turn on and off lamps and fans, etc. This system is undergoing tests in the laboratory.

Cambridge Infra-Red Panoramic Survey Spectrograph

Continuing his collaboration with the instrumentation group at the Institute of Astronomy, Cambridge, UK, *A. N. Ramaprakash* joined a team from the UK at the Gemini South Telescope on Cerro Pachon, Chile in June-July 2003 for observations. During the commissioning run in 2002 on the same telescope, a number of improvements were identified to enhance the performace and efficiency of the instrument. Most of these were implemented and tested during the above observation run. The operation of the instrument was fine-tuned to work seamlessly with the telescope and observatory control system. The latter part of the run was utilized for collecting scientific observational data on a wide range of galactic and extra-galactic targets. The quality of data obtained during these observations amply demonstrated the effectiveness of fibre-imaging spectroscopic technique in collecting spectra with high spatial resolution over a two dimensional area of the sky even at near-IR wavelegnths.

Ultra Violet Imaging Telescope

It has been proposed to launch an Indian Astronomy Satellite (ASTROSAT) for observations in X-ray, and UV-visible bands. The instrumentation for UV-visible observations, is proposed to be developed through collaborative effort of several institutions from India including IUCAA, and National Research Council of Canada, and *Shyam Tandon* has been coordinating this effort. This instrument, called Ultra Violet Imaging Telescope, consists of two telescopes, each of diameter 380 mm. One of the telescopes is used for imaging in 1200 - 1800 A band, and the other in 1800 - 3000 A and 3500 - 6000 A bands. A wide field of 30 arcmin is imaged simultaneously in all the bands with an angular resolution of 1.5 arcsec. A set of 7 filters is available in each band for wavelength selection.

A particularly attractive feature of the mission is the possibility of simultaneous time variation studies in a very wide range of wavelength from hard X-rays to visible band.

The design of the Ultra Violet Imaging Telescope is now defined in some details and the main optics of the telescope is under fabrication at ISRO. The detectors are under development in Canada through an agreement between ISRO and Canadian Space Agency. Facilities for testing, calibration and assembly are being designed, and a laboratory for this pupose is being constructed at IIA, Bangalore. It is expected that the satellite would be ready for launch by end of year 2007.

Photon Counting Detectors

In the Ultra Violet Imaging Telescope described above, intensified imagers with CCD/CMOS read out devicess would be used. 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, in order to get a high overall resolution, it is required that centroids of the intensified spots on the devices be measured with an accuracy < 0.1 pixels. *Shyam Tandon* and *Abhay Kohok* have made tests with an intensifier coupled to a CMOS readout device to find means of achieving < 0.1 pixel accuracy on the centroids, and have found that: (a) coordinates of the calculated centroids of the intensified spots have a bias, i.e., an error which depends on how far or near the real centroid is from centre of the pixel, (b) this bias is an one dimensional function to a good approximation, i.e., bias in X- direction is not related to that in Y- diection and vice versa, and (c) the bias, which can be 0.1 pixel, can be found by demanding that for a uniform exposure the centroids should be uniformly distributed over face of the pixels. Similar procedures would be used to process data from UVIT.

Title of the Project and IUCAA Investigators	**Funding Agency**	**Duration of the project**
Gravitational Wave Data Analysis for Laser Interferometric Space Antenna (LISA) *S. Dhurandhar*	IFCPAR (Indo - French)	2000 - 2003
LIGO project (US) Extracting Gravitational Wave Signals of Inspiraling Compact Binary Stars from Laser Interferometric Data *S. Dhurandhar*	Indo - US DST-NSF	2002 - 2005
Gravitational Wave Data Analysis for TAMA *S. Dhurandhar*	Indo-Japanese DST-JSPS	2002 -
A Comprehensive Digital Library of Stellar Spectra *Ranjan Gupta*	Indo-US DST-NSF	2001 - 2003
Galaxy Formation : The AGN-Spheroid Connection *A. K. Kembhavi, A.N. Ramaprakash*	IFCPAR (Indo-French)	2003 - 2006
Morphological properties of the Supercluster-Void Network in the Universe *Varun Sahni*	Indo-US DST-NSF	2001 - 2004
An investigation into: Problems of Modern Cosmology *Varun Sahni*	Indo-Ukrainian	2001 - 2003
Probing the remote Universe with QSO absorption lines *R. Siranand*	IFCPAR (Indo-French)	2003 -2006
Modeling of physical conditions in the high z protogalaxies *R. Siranand*	Indo-US DST-NSF	2003 -2005

(II) RESEARCH BY VISITING ASSOCIATES AND LONG TERM VISITORS

General Relativity and Gravitational Waves

Banerjee, Asit

In 4 dimensional spacetime, there are several cases of gravitational collapse where naked singularities may occur. Comparatively, much less is known about the naked singularities in higher dimensional spacetime. Asit Banerjee along with his collaborators studied naked singularities in the region close to the centre for a spherically symmetric inhomogeneous dust collapse in higher dimensions and concluded that for a marginally bound case naked singularities do not appear in the spacetime of more than five dimensions. The role of shear in the formation of naked singularities is studied even for non-marginally bound collapse.

A. Banerjee and S. Chatterjee constructed a vacuole model with higher dimensional Schwarzschild like interior in the background of an inhomogeneous Tolman- Bondi universe. A new five dimensional exact solution was obtained and the Israel juncion conditions were used to study the dynamical behaviour of the vacuole boundary. The calculation of the frequency shift of radiation coming from the boundary shows that there exist the possibilities of both red shift and blue shift in the above model.

Hoyle and Narlikar's C-field cosmology has been extended to five dimensional spacetime and a new exact solution has been obtained in five dimensions. It is interesting to see that in line with the physical requirements, the above model admits a decelerating phase in the early era followed by an accelerating expansion in the later period.

Classical Gravity

Chaudhuri, Sarbeswar

An exact relativistic treatment on the exterior gravitational field of an accretion disk formed around a blackhole is of much importance in astrophysics. During the time of formation of accretion disk around a blackhole, material particles are highly compressed due to the intense gravitational field of the blackhole and a high temperature is created. As a result, ionisation of material particles occur and a large amount of energy is released, which explains the fueling mechanism inside massive blackholes.

S. Chaudhuri is now engaged in search for some new solutions on the exterior gravitational fields produced by accretion disks with or a blackhole at the core. A Schwarzschild blackhole is taken as the central object and for simplicity, the disk is assumed to be static. A static disk may be considered as composed of equal number of counter-rotating particles so that the total angular momentum of the system becomes zero. The disk energy density and pressure shows that the presence of the blackhole stabilizes the disk system. It is interesting to note that the velocity of counter rotation of the disk particles assume tachyonic speed near the event horizon. A number of such solutions with different potentials are considered in our analysis.

Secondly, S. Chaudhuri, in collaboration with D. Bhattacharyya considered a Kuzmin disk with a Curzon blackhole at the centre. The field equations of the disk and disk-blackhole combination are derived. The energy density and pressure of the disk and the combined system, and the velocity of counter-rotation of the disk particles are to be evaluated. A possible interpretation of the results obtained from the system can then be available.

Ghosh, S. G.

A singularity occurs when the quantities in a theory "blow up" or become infinite and, therefore, is a sign that the theory does not work. In effort to protect the applicability of general relativity, Penrose conjectured that such singularities might be hidden by an event horizon, and thus, invisible to an asymptotic observer, i.e., they cannot be globally naked. This constituent in essence, what has become known as weak cosmic censorship conjecture (CCC)? However, it is quite possible for an observer to penetrate the event horizon and live a rather normal life inside a blackhole. This motivated the strong cosmic censorship conjecture, which broadly states that time like singularities cannot occur in nature, i.e., they cannot be visible even locally. Comparatively, much less is known about singularity formation in higher dimensions (HD) that are being currently considered very important in view of recent developments in string theory and other field theories. S.G. Ghosh and N.K. Dadhich have showed that the effect of extra dimensions appears to be a shrinking of the naked singularity initial data space (of 4D) or an enlargement of the blackhole initial data space in spherical collapse. Recently, Dadhich, Ghosh and Deshkar have found exact solution of the Einstein equation in HD for a fluid with radial pressure and vanishing tangential pressure and then analyzed the tug of war between a blackhole and a naked singularity. The most remarkable result that emerges from this analysis is the interplay between the dimension D of spacetime and the equation of state parameter γ. It turns out that the outcome of the collapse for dust in D and fluid with $\gamma = -1$ in D+1 dimensions is the same.

Ghosh and A. Beesham have studied the development of strong curvature naked singularities in the charged Vaidya-de Sitter spacetime. An interesting feature of their model is that naked singularities always occur for any values of the parameters. Further, they inferred that the occurrence of a naked singularity does not depend upon whether the asymptotic spacetime is expanding or not.

In order to study gravitational collapse, it is necessary to describe adequately the geometry of interior and exterior regions and to give conditions, which allow matching of them. Ghosh in collaboration with Deshkar derived the junction conditions for non-spherical collapsing radiating star consisting of a shearing fluid undergoing radial heat flow with outgoing radiation. Radiation of the system is described by non-spherical Vaidya solution.

Ibohal, Ng

After the application of Newman-Janis algorithm to a spherically symmetric 'seed' metric, Ng. Ibohal has presented the general formulae for the spin coefficients, the Ricci scalars and the Weyl scalars in Newman-Penrose (NP) formalism for the metric, which is a function of three variables. From these NP quantities, he has given examples of rotating solutions of Einstein's field equations: (i) rotating Vaidya-Bonnor solution, (ii) rotating de Sitter solution, (iii) rotating Kerr-Newman-Vaidya and (iv) rotating Kerr-Newman-Vaidya-de Sitter solution. The rotating Kerr-Newman-Vaidya solution represents the Kerr-Newman blackhole to be embedded into the rotating Vaidya null radiating universe. Similarly, in the case of Kerr-Newman-Vaidya-de Sitter solution, it can be understood as a Kerr-Newman blackhole in embedded into the rotating Vaidya-de Sitter universe or Kerr-Newman-Vaidya blackhole is embedded into the rotating de Sitter universe. These embedded solutions can be expressed in Kerr-Schild forms describing the extension of Glass and Krisch superposition, which is further extension of Xanthopoulos superposition. It is also shown that the energy momentum tensor of Kerr-Newman-Vaidya-de Sitter solution will reduce to the Guth's modification of energy momentum tensor for the early inflationary universe when the rotation parameter vanishes. These embedded solutions are also applied to study the Hawking's radiation of blackholes showing the changes of masses of electrically radiating blackholes.

Nandi, K. K.

K.K. Nandi, is carrying out a study into the possibility of Lorentzian traversible wormholes in the string theory. Wormholes are handles that connect two otherwise disjoint distant regions of space. As contemplated by Morris, Thorne, and Yurtsever, such objects can be used for interstellar travel. Preliminary investigations reveal that, while massive wormholes exist in the string theory, massless ones do not. Classical and quantum constraints on traversible wormholes are also calculated. The work is being done in collaboration with Yuan-Zhong Zhang of the Institute of Theoretical Physics, Chinese Academy of Sciences, Beijing.

Paul, B. C.

A class of relativistic solution of compact star, which is in hydrostatic equilibrium is obtained in higher dimensions considering a spherically symmetric spacetime. A (D - 1) spheroid immersed in a D-dimensional Euclidean space is assumed and solutions are obtained, which for D = 4 reduce to that obtained by Mukherjee, Paul and Dadhich (1997). It is found that a higher dimensional spacetime accommodates a more massive compact object for a given size compared to that in the usual four dimensional spacetimes. The effects of dimensionality on other physical parameters of compact stars are also explored.

Ray, Saibal

"Electromagnetic mass" models have been studied by S. Ray for the charged particle electron and charged star under general relativity.

Ray, in collaboration with S. Bhadra, has considered a static spherically symmetric charged anisotropic fluid source of radius $\sim 10^{-16}$ cm by introducing a variable lambda dependent on the radial coordinate r. From the solution sets, a possible role of the cosmological constant is investigated, which indicates the dependency of energy density on it.

Ray and B. Das have revisited the class of astrophysical solutions in static spherically symmetric Einstein-Maxwell spacetime in connection to the phenomenological relationship between the gravitational and electromagnetic fields. It is qualitatively shown that the charged relativistic stars of Tolman and Bayin type are of purely electromagnetic origin. The existence of this type of astrophysical solution is a probable extension of Lorentz's conjecture that an electron-like extended charged particle possesses only 'electromagnetic mass' and no 'material mass".

Sarmah, B. P.

The oscillations of relativistic stars have been considered to contain wealth of information that can be extracted through the gravitational wave window. The different modes of oscillations, e.g., f-mode, p-mode, g-mode, w-mode, etc. can throw light on the internal characteristics of relativistic objects from different angles. The recently discovered r-mode has been found to satisfy CFS instability criterion in relativistic stars at all rotations. In particular, gravitational radiation drives CFS instability in the r-mode of young, rapidly rotation neutron stars. In case of inviscid relavtistic fluid material, this instability is expected to carry away most of the angular momentum of the star by emission gravitational radiation, leaving the star at fairly low rotation rate within months of its formation. But the role of viscosity, superfluidity and magnetic fields are yet to be clearly spelt out for deciding a critical rotation speed below which, the said dissipative agents are expected to annul the instability.

Bhim Prasad Sarmah is presently studying the instabilities of r-mode in neutron stars and the effect of weak magnetic field and superfluidity in them.

Quantum Cosmology, Brane World and Quintessence

Banerjee, Narayan

Narayan Banerjee is involved in the so-called quintessence problem, where a possible explanation for the present accelerated expansion of the universe is explored. He is also exploring the possibilty of finding an explanation of an alleged periodicity in the distribution of galaxies in terms of a variation of the Newtonian 'constant' of gravitation.

Chaudhuri, Sarbeswar

Recently, S. Chaudhuri has been engaged in research on brane cosmology. It is supposed that the standard model particles are confined in a hypersurface called the brane, embedded in a higher dimensional space, called the bulk. Randall and Sundrum suggested a brane model in which the standard model particles are confined in a brane with constant negative tension and the bulk is a part of the spacetime with negative cosmological constant. Chen, Harko and Mak presented exact solutions of gravitational field equations for an anisotropic brane with Bianchi type I and V geometry, with perfect fluid and scalar fields as matter sources. S. Chaudhuri in collaboration with S. Chakraborti is in search for cosmological solutions with anisotropic brane using different scalar fields in different conditions. The expansion scalar, evolution of volume scale factor, deceleration parameter and anisotropy are being studied.

Chakraborty, Subenoy

The cosmic censorship conjecture is one of the unresolved problems in general relativity. It states that in all generic situations, the singularities will be covered by event horizon and hence, not visible to outside observers. A well known example contradicting this conjecture is the spherical dust collapse in four dimension. Subenoy Chakraborty and his collaborators have extended this study to higher dimensional spherical dust collapse and have shown that using realistic initial condition naked singularity is not possible above five dimension. Subsequently, Chakraborty and his associates have extended these studies for quasi spherical model and have concluded that formation of naked singularity depends strongly on the initial conditions and dimension of spacetime.

Chakraborty, in collaboration with U. Debnath and N. C. Chakraborty has studied quintessence problem in Brans-Dicke theory and the recently developed controversial issue namely, the varying speed of light with cosmological consequences. Also, Chakraborty has addressed the cosmic no-hair conjecture in brane scenarios and has shown that the validity of this conjecture in brane scenarios follows from general relativity with some realistic examples.

Paul, B. C.

Linde's chaotic inflationary scenario in the brane world model is explored considering matter described by a minimally coupled self-interacting scalar field. We studied the era before inflation, where the kinetic energy of the field dominates in addition to inflation, when potential energy of the field dominates. It is found that a very weakly coupled field is required in this case compared to Einstein gravity. Linde has shown that a sufficient inflation may be obtained from a distribution of the inflation field if initial field satisfies $\phi \geq 3M_P$. At a very early time, $t = t(P)$, Planck time, one has pick up values satisfying $V(\phi) \leq M_P^4$ and $\delta_i\phi \leq M_P^2$, in model building. Consequently, it is unrealistic to consider a model with initial $\phi \geq 3M_P$ and use only quartic type potential. In brane, it is found that a sufficient inflation may be obtained even with an inflation field having $\phi < M_P$.

Sami, M.

The recent advances in observational astrophysics support the inflationary paradigm and confirm the current acceleration of universe. The inflationary scenario, not only successfully addresses the problem of initial conditions of the hot big bang, but also gives important clues about the origin of structure in the universe. It is puzzling that the realization of cosmological inflation is ad hoc. As inflation is operating around the Planck's scale, the needle of hope points towards string theory, a possibly consistent quantum theory at this scale. The current acceleration of universe implies the existence of an exotic form of energy (dark energy), which constitutes up to 70 percent of the total energy in the universe at present. So far, there is no satisfactory explanation of this phenomenon supported by a fundamental theory. The answer to the mentioned puzzles could come from string theory. Needless, to say, string theory has its own problems. The process of compactification in string theory, which relates the higher dimensional theory to the four dimensional real world, is not yet well understood. Cosmology is expected to play an important role here and it is believed that the synthesis of the two theories will lead to the true picture of nature. M. Sami with collaborators, M. R. Garousi and Shinji Tsujikawa studied the cosmological evolution of the massive DBI (Dirac-Born-Infeld) scalar field on the ant-D3 brane of KKLT vacua. They have shown that this scenario satisfies the observational constraint coming from the Cosmic Microwave Background anisotropies and other observational data. They have shown that the model can account for observed late time acceleration of universe and may lead to successful reheating. The other area of theoretical cosmology inspired by string theory, Sami has been working on with collaborators, is related to brane world cosmology *a la* Randall-Sundrum (RS). This scenario enhances the prospects of inflation. Sami, with collaborators (*V. Sahni, N. Dadhich* and T. Shiromizu) has investigated the possibility of unification of inflation with quintessence in the frame work of brane worlds. It was, recently, shown by Sami and *Sahni* that these concepts can be synthesized successfully in brane world cosmology provided, reheating is implemented by "*instant preheating mechanism*". However, the recent measurements of CMB anisotropy by WMAP places very strong constraints on the brane world inflation.

The study of perturbations in brane worlds is a challenging problem at present. Recently, Sami, with collaborators J. Francis, R. Maartens and J. Lidsey has been involved in the study of cosmological perturbations from brane inflation with a Gauss-Bonnet term. He is currently studying the observational constraints on the Gauss-Bonnet brane world inflation. Ha has also investigated the theoretical models of Phantom energy with *Dadhich* and *P. Singh*.

Cosmology and Structure Formation

Ahmed, Farooq

The problem of non-linear gravitational galaxy clustering can also be studied using the statistical mechanical approach. The statistical mechanics of N-body systems is based on N-body Hamiltonian. From this Hamiltonian, partition function is formed as a function of N-dimensional integral, which incorporates the effects of interactions among all particles. To evaluate such an integral analytically is generally very complicated. However, it is possible (Ahmad, Saslaw and Bhat 2002, Ap.J. 571, 576) to evaluate partition function for cosmological many- body problem analytically with some simple approximation. Cosmological many-body systems generally satisfy the time scale criterion of quasi-equilibrium statistical mechanics. Since, macroscopic global variables such as average temperature, density and the ratio of gravitational correlation energy to thermal energy change on time scales at least as long as the Hubble time, whereas, local dynamical time scales in regions of clustering are shorter. Once many-body partition function is known, there is no difficulty in evaluating the grand canonical partition function which represents the exchange of both particles and energy. From grand partition function, the distribution function of galaxies follows directly. One can start with the formalism of classical statistical mechanics of an ensemble of co-moving cells containing gravitating particles (galaxies) in an expanding universe.

Farooq Ahmad and Manzoor A. Malik have extended the method of statistical mechanics of cosmological many-body problem developed earlier by Farooq Ahmad, William Saslaw and N.I. Bhat to higher order clustering. They have extended the method based on the evaluation of grand-partition function by cluster expansion developed by Mayer and his collaborators to cosmological many body problem. The usual cluster expansion drops third or higher order product terms in the expansion. However, these higher order terms actually represent the interaction of more than two particles simultaneously . The inclusion of third order and higher order expansion terms can change the form of the partition function. As a result, all the thermodynamic functions and distribution function of galaxies can be affected. The evaluation of partition function for higher order cluster expansion terms is generally quite complicated. However, they have used two methods namely, Fourier transform and spherical harmonics of legendre polynomials. They derive analytical expression for partition function of such complicated system. Further, they are investigating the consistency of partition function derived earlier for lower order clustering. This will particularly help in solving the problem of higher order gravitational clustering of galaxies from the statistical mechanical point of view, which may have important consequences on understanding the large scale structure of the universe.

Biswas, S.

S. Biswas, along with Indrani Chowdhury, is working on particle production in inflationary cosmology. At the end of inflation, the universe is empty and extremely cold, and undergoes periodic oscillation, and is dominated by the homogeneous coherent mode of inflation. The coherent oscillations of inflation produce particles, which interact with each other, to attain a thermal equilibrium with a temperature T. This temperature is called the reheating temperature.

To understand the heating mechanism in early universe Biswas and Chowdhury have studied both boson and fermion particle production in FRW background with time dependent periodic potential. In the literature, there are contradictory results on both fermion and boson production. It is, therefore, necessary to test the existing results through another independent method. They applied the CWKB method developed by Biswas and others to study both boson and fermion production at the end of inflation.

In dealing with the wavefunction of the universe, there is a debate on the various proposals about the boundary condition of the wavefunction of the universe. Recently, it has been argued that the operator ambiguity factor has a decisive role in deciding the consequences of the various wavefunction at the zero scale factor region. Biswas, Chowdhury and Misra have discussed the role of operator ordering in the light of wormhole dominance proposed by Biswas and have given an interpretation of operator ordering as a contribution of some sort of matter fields and discussed the role of complex WKB paths in avoiding the initial singularity.

Jain, Deepak

Recent observations of Type Ia supernovae provide strong evidence that the universe may be accelerating. These results when combine with measurements of CMBR anisotropies and dynamic estimates of matter in the universe, suggest that universe is flat and dominated by smoothly distributed exotic component endowed with large negative pressure, called dark energy. One of the most difficult challenges that cosmology faces is to understand the origin and nature of dark energy.

Deepak Jain, along with Abha Dev, N. Panchapakesan, S. Mahajan and V. B. Bhatia, uses gravitational lens statistics to constrain equation of state of the dark energy ($P = w\rho$). They use image separation distribution function of lensed quasars as a tool to probe eqation of state. They find that for observed range of $\Omega_m \sim 0.2 - 0.4, w$ should be $-0.8 < w < -0.4$.

Assuming general time dependence of the scale factor, $R \propto t^{\alpha}$, Jain, Dev and Jailson S. Alcaniz have investigated observational constraints on the dimensionless parameter, α, from measurements of angular size for a large sample of milliarc second compact radio source. They find that a strictly linearly evolution, i.e., $\alpha = 1$ is favoured for data, which is also in agreement with limit obtained from other independent cosmological tests.

At present, Jain, Dev and Alcaniz are using cosmological data on Sne, CLASS radio sources, galaxy cluster x- ray data, etc. to constrain parameters in various dark energy models.

John, Moncy V.

The apparent magnitude-redshift data of SNe Ia call for modifications in the standard model energy densities. Under the circumstance that this modification cannot be limited to the addition of a mere cosmological constant, a serious situation has emerged in cosmology, in which the energy densities in the universe have become largely speculative. In this situation, an equation of state of the form $p = w\rho$ itself is not well-motivated. Moncy V. John argues that the reasonable option left is to make a model-independent analysis of SNe data, without reference to the energy densities. In this basically kinematic approach, the observationally justifiable assumptions of homogeneity and isotropy; i.e., to the assumption that the universe has a RW metric. This cosmographic approach is historically the original one to cosmology. The analysis is performed by expanding the scale factor into a polynomial of order 5, which assumption can be further generalised to any order. The present expansion rates h, q_0, r_0, etc. are evaluated by computing the marginal likelihoods for these parameters. These values are relevant, since any cosmological solution would ultimately need to explain them.

Lohiya, Daksh

Standard big bang cosmology uses a host of precision measurements to measure parameters arising out of conjectures and paradigms that are far from satisfactorily realized within the framework of any respectable particle physics model. Daksh Lohiya has been exploring the possibility of realizing a problem free cosmology within the framework of a host of so called "pre - big - bang" models. In these models, the gravitational constant dynamically vanishes at an earlier epoch. The canonical value arises as a result of a first order phase transition. What results is a Friedmann-Robertson-Walker cosmology with a linear evolution of the scale factor right from the creation event. This turns out to be an excellent fit to a host of cosmological observations. These observations are: (i) the Hubble diagram for both small and the large red-shift objects, (ii) early universe nucleosynthesis, (iii) the age of the universe, (iv) gravitational lensing statistics, (v) Cosmic microwave background anisotropy, (vi) structure formation, and finally (vi) bounds on matter density deduced from galactic flows.

The cosmological constant dynamically vanishes in these models. Nucleosynthesis constraint in a linearly coasting cosmology closes mass estimates from large clusters. There is, thus, no room for non - baryonic dark matter. Non - baryonic dark matter is needed in standard big bang model to generate non linear density perturbations leading to halos, where baryons could fall in and make galactic structures. Surprisingly, in a linearly coasting cosmology, tiny perturbations in baryons alone are sufficient to drive baryonic density perturbations to a non-linear regime.

Lohiya claims that his efforts lead to a falsifiable cosmological theory, which he feels has the potential of relegating the needs of dark matter, the cosmological constant (along with all its corrupted associates like quintesscense, etc.) to the archives, in the company of concepts like ether, phlogiston, etc.

Mittal, A. K.

A. K. Mittal and Daksh Lohiya had earlier proposed an idealized expanding fractal dust model of the universe. This model is motivated by the claims of some investigators that the observed number of galaxies in a sphere of radius R, centred on any galaxy is proportional to R^D, where D is approximately equal to 2 and not 3 as would be expected of a homogeneous distriubution. It incorporates Mandelbrot's conditional cosmological principle within the framework of general theory of relativity. It is free from Hubble-deVaucouleurs paradox and consistent with SNe1a observations. Attempts are being made to put the model on more rigorous footing. Implications of chaos for N-body simulations are also being explored.

Mukherjee, S.

Recently, Ellis and Maartens have suggested the possibilities of cosmological models in which there is no singularity, no beginning of time and no horizon problem. The universe starts out in the infinite past as an almost static universe and expands slowly, eventually, evolving into a hot big bang era. An example of this scenario is a closed model with a minimally coupled scalar field, with a special self-interaction potential. Ellis, Murugan and Tsagas noted that this potential is just the negative of the potential that one gets when one considers a suitable conformal transformation of the R^2 theory. In this context, a detailed study of relevant theories has been undertaken by S. Mukherjee, Paul B. C., Beesham A. and Maharaj S. D. considering (1) the Starobinsky model and (2) the higher derivative models. The field equations are analysed to determine the general features of the evolution and some quantities of cosmological interest are calculated and compared with those of the model of the emergent universe

Pandey, Sanjay

To quantify large scale structures (LSS) at high redshifts is an important problem of modern cosmology. The study of fluctuaions in the redshifted 21 c.m. emission line from neutral hydrogen (HI) at early epoch can be used to probe LSS at these redshifts. HI density in the range $1 \leq z \leq 3.5$ is known from absorption studies. The HI distribution is expected to be inhomogenous in the gravitational instability picture. This inhomogenity leads to anisotropy in the redshifted HI emission, which may be detected using a low-frequency interferometric instruments like GMRT Sanjay Pandey and Somenath Bharadwaj have calculated visibility-visibility cross-correlations at different frequencies and baselines as these correlations directly probe the power spectrum of the density fluctuations at the redshift, where the radiation originated. They have also made detailed estimates of the expected signals from the redshifted HI emission at two frequency bands centred at 610 and 325 MHz. These will be useful in planning observations and deciding the optimal strategy for detecting this signal.

The next higher order statistics, i.e., 3 point correlation function characterizes the clustering in further detail. This statistics and its Fourier counterpart, the bispectrum, can be used to check non-Gaussianity (if any) in the primordial fluctuations. Pandey and Bharadwaj have calculated analytic expression for 3 point visibility correlation function, which can be used to find bias of HI with respect to the dark matter distribution. The work on these things and related issues is under progress. They also plan to compare the analytic results with N-body simulations.

Pradhan, A.

The study of cosmological models is of interdisciplinary relevance. An exact solution of Einstein's field equations is known as cosmological if it can reproduce an FLRW metric when its arbitrary constants or functions assume certain limiting values. Cosmological models, which are not FLRW have also been studied in the past, particularly in recent years. This study was motivated partly by (i) the need to explore the consequences of Einstein's theory of gravity and (ii) because the FLRW cannot explain several features of enigmas of the present universe, A. Pradhan and G.P. Singh have investigated higher dimentional cosmological models and plane symmetric domain walls in Lyra geometry. They have also investigated inhomogeneous cosmological models which includes dissipative process, cosmological and gravitational constants to explain the formation and evolution of the early universe.

Cosmological constant problem is one of the most important problems in particle physics and cosmology. According to recent observations, our universe is acceleratingly expanding at present. The observed relation between luminosity distance and redshift for extragalactic Type Ia supernovae (SNe) favours accelerating universe, where almost two-thirds of the critical energy density may be in the form of a component with negative pressure. However, neither present data nor the theoretical models require cosmological constant (Λ) to be exactly constant. To explore the possibility that Λ- like term (e.g., quintessence) is time-dependent. So, we can use a model for it that mimics the simple variant of the inflationary scenario of the early universe. Pradhan and coauthors have investigated cosmological models with variable cosmological constant and they have shown that this class of solutions is consistent with recent observations of supernovae Ia.

Pradhan, A. and Jotania, K.

Inhomogeneous cosmological models play an important role in understanding some essential features of the universe such as the formation of galaxies during the early stages of evolution and process of homogenization. Models with a relic cosmological constant Λ have received considerable attention recently among researchers for various reasons. The special interest is of the ansätz $\Lambda \propto S^{-2}$. The occurrence of magnetic fields on galactic scale is well-established fact today, and their importance for a variety of astrophysical phenomena is generally acknowledged.

As a natural consequences, one should include magnetic fields in the energy-momentum tensor of the early universe. The choice of anisotropic cosmological models in Einstein system of field equations leads to the cosmological models more general than Robertson-Walker model.

A. Pradhan and K. Jotania, in collaboration with S.K. Srivastava have focused upon the problem of establishing a formalism for studying the general relativistic evolution of magnetic inhomogeneities in the presence of bulk viscous in an expanding universe by including an electrically neutral bulk viscous fluid as the source of matter in the energy-momentum tensor. They also deal with the solution of the field equations in presence of bulk viscous fluid assuming supplementary condition between metric potentials given by parameter K and unit change in derivative of ratio of metric potential α. They obtain a new class of cylindrically symmetric inhomogeneous cosmological models with electro-magnetic bulk viscous fluid as the source of matter. In all these models, they find that they do not approach isotropy for large values of time. It is concluded that (i) if $\alpha > 0$ then for the cases $K > 0$ or the values of K tending to 0, the models have point type singularity at the time of maximum expansion, and (ii) if $0 < \alpha < 1$ then they have infinite singularity. Whereas, the case $K < 0$ is just opposite of the case $K > 0$. In all the cases, the spacetime is conformally flat for large values of T and at the time of minimum expansion, matter density dominates over expansion. For $K = 0$ the material energy is more dominant over magnetic energy. The cosmological constant in all models are decreasing function of time and they all approach a small value as time increases (i.e., the present epoch) except the case $K < 0$. The values of cosmological "constant" for these models are found to be small and positive, which are supported by the results from recent supernova observations obtained by the High - z Supernova Team and Supernova Cosmological Project. Thus, with their approach, they obtain a physically relevant decay law for the cosmological constant unlike other investigators, where *adhoc* laws were used to arrive at a mathematical expressions for the decaying vacuum energy. Thus, their models are more general than those studied earlier. A strong point of this model is that it incorporates matter density naturally and so makes feasible model, which can be in-cooperates the physical constraints.

Seshadri, T. R.

T.R. Seshadri, with K. Subramanian has studied the effect of tensor modes due to cosmological magnetic fields on the polarization of the Cosmic Microwave Background Radiation. This is being worked out both in the standard recombination model as well as in the models with reionization. The latter is of particular significance after the indications from WMAP results that the universe could have undergone a period of reionization. Incorporating the effects of vector type perturbations in CMBFast code is also under progress.

Singh, G. P.

Recently, a number of observations have suggested that the universe is dominated by an energy component with an effective negative pressure. One possibility for such component is the cosmological constant. The role of dissipative effects in the evolution of the universe, particularly during its early stages, is also a subject of importance. It has also been proposed that causal bulk-viscous thermodynamics can be modeled on a phenomenological level matter creation in the early universe. In attempts to explain the formation and evolution of the early universe, a number of cosmological models which include dissipative process, cosmological and gravitational 'constants' have been extensively investigated. G. P. Singh and his coworkers have studied the higher dimensional dissipative cosmology with varying G and Λ, in the presence of bulk viscosity within the framework of general relativity and Lyra's geometry. It has been observed that the new models obtained in these investigations generate several known models, and results are well within the range of observational limits.

The other possibility of an energy component with an effective negative pressure is quintessence, a slowly varying scalar field φ with an appropriate potential $V(\varphi)$. Quintessence suggest a possible explanation for the observed acceleration of the universe. There are a number of quintessence models, which have been investigated by several researchers. They involve a scalar field rolling down its potential, scalar tensor theories of gravity and dilation in context of string theory. The simplest generalization of Einstein's theory of gravity are scalar-tensor theories. Most of the work that can be found in the literature on solutions of scalar-tensor theories concerns the particular case of Brans-Dicke theory, in which parameter ω, is constant. Motivated by above studies, Singh and his coworkers are studying the effect of quintessence in the presence of dissipative cosmic fluid under the framework of scalar-tensor theories.

Galaxies and Quasars

Chakraborty, D. K.

Stark has shown that a triaxial model, wherein the density is stratified on coaxial, coaligned ellipsoids, does produce any isophotal twist and ellipticity variation in its projection. On the other hand, elliptical galaxies show ellipicity variations and twists, and further, exhibit high order residuals. The triaxial models studied by Schwarzschild, de Zeeuw and Carollo, reproduce the observed characterstics of ellipticity variations and the twist, but do not exhibit enough high-order residuals to explain the observed data. D.K. Chakraborty and Das modified these models by introducing terms with fourth order spherical harmonic terms in the density distributions. The projcted density was found to exhibit sufficient amount of boxiness or pointiness, depending upon the viewing angle, and can be compared against the data. The host of triaxial models may be used to constrain the intrinsic shape of the elliptical galaxies.

Chatterjee, Tanuka

Globular clusters are valuable tools for understanding the formation and evolution of galaxies, but their formation is still poorly understood. So, if there are some evidences that at least some young star clusters (age < 1 Gyr) are young GCs then we will have a better opportunity to understand their formation process. One way to find such clusters is, to study their luminosity function (LF) and to construct any satisfactory model, which describes that whether the LF of these systems is evolving towards a characteristic form of an old GC system in the next Hubble time in spite of destruction mechanism originating from tidal field of their host galaxy. In this connection, a statistical model of the evolution of GCs LF is being developed, taking into account different destructive phenomena, like dynamical friction, disc and bulge shocking, evaporation and formation scenario due to tidal force using Monte Carlo simulation technique. To investigate the formation process of galaxies in other ways, a model is being in the process using cluster analysis technique 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 time unsuitable for a multivariate set up. These histograms show bimodality with respect to colour in bright elliptical galaxies, while cluster analysis shows multimodality. So, detail investigation is needed for a firm conclusion. The work is being carried out in collaboration with A. K. Chattopadhyay.

Jog, Chanda

The sudden drop in the surface brightness seen in the outer regions of a galactic disk is generally believed to denote a physical cut-off, although its origin is not understood. The radial truncation of the disk has been a long-standing paradigm. C.J. Jog, with C.A. Narayan has argued that this drop does not represent a physical truncation of the disk. Instead, the observed drop in brightness could easily be accounted for by a small (0.5 %) overestimate in sky brightness or due to a minor deviation of the disk from a perfect exponential. They have shown that this idea is confirmed by the recent observational data in the literature.

Khare, Pushpa

Pushpa Khare, along with her collaborators has observed 11 damped Lyman α absorption systems at intermediate redshifts ($0.6 < z < 1.5$), in the spectra of 8 QSOs with the 6.5 m Multiple Mirror Telescope in Arizona, USA. The data were analyzed to determine the chemical abundances of elements such as Zn, Cr, Si, Fe, Al, Ti, Co, Mn, Ni and Ca. These measurements have more than doubled the Zn and Cr measurements at redshifts < 1. The measured average relative abundances of various elements in these systems were found to be very similar to those found for high redshift damped Lyman α absorbers reported in the literature. The dust content of the absorbers as measured by the Cr/Zn ratio was found to be almost independent of redshift. The global mean metallicity is found to increase weakly with decreasing redshift.

She, along with a team of astronomers from the University of Chicago, continued to work on the preparation of a catalog of absorption lines in the QSO spectra observed by the Sloan Digital Sky Survey. The Data Release 1 consists of several thousand QSO spectra and the continuum fitting, line finding and identification has to be automated.

She has observed $\simeq 40$ QSOs with the GMRT to determine the radio spectral index of these quasars. The observations will determine the presence/absence of a correlation between the radio properties and the absorption properties of QSOs, and will help to discriminate between the associated and intervening absorbers. The data analysis is in progress.

Kuriakose, V. C.

In collaboration with A. Kembhavi, and C. D. Ravikumar, Kuriakose has carried out detailed near infra-red surface photometry of 33 early type galaxies from two rich clusters, Abell 2199 and Abell 2634, to extract the morphological parameters using modified χ^2 minimization algorithms involving simulation of two dimensional images of galaxies. The Abell galaxies were observed at the United Kingdom Infra-red Telescope (UKIRT) during August 7-9, 1995 by B. Mobasher. The galaxies were compiled from the sample in Lucey, et al. (1997) taking care that reliable velocity dispersion measurements were available for the selected galaxies.

They have obtained the global photometric parameters for the Abell galaxies in the sample applying de Vaucouleurs' and Sersic laws separately to the surface brightness profiles. They have found that Sersic law always fits better the observed profiles than de Vaucouleurs' law.

They have also explored various correlations existing between the global morphological parameters with special attention given to the comparison of scaling relations for the parameters extracted from the two different intensity profiles, and found that even though the Sersic law fits better to the observed profiles, there is no noticeable change in the famous Kormendy, Faber-Jackson and fundamental plane relations by moving from de Vaucouleurs' to Sersic fits.

By studying the scatter in the fundamental and photometric plane relations, they have demonstrated the existence of a four dimensional hyper plane for galaxies. The well-known three dimensional fundamental and photometric planes are projections of this hyper plane. Using the hyper plane relation, they analyzed the dependence of M/L on the structural parameters.

The observed tightness in the fundamental and hyper plane relations is used to estimate the central velocity dispersion σ of different Hubble types of galaxies in the sample. The measurement of σ becomes extremely challenging and difficult across the galaxy sequence and especially when the galaxies are at high redshifts, and hence this method provides a cheaper and reliable way of estimating the central velocity dispersion. Finally, the masses of supermassive blackholes assumed to be located at the centres of all galaxies have also been calculated.

Interstellar Matter and Star Formation

Indulekha, Kavita

Kavita Indulekha, has been studying the formation of bound open clusters. It is found that the new born cluster should have lost either energy or a fraction of its members, for a bound stellar system to remain after gas removal. Estimates of the necessary energy loss are obtained and compared with the energy that would be taken away by stars with higher velocity escaping the system.

Chandra, Suresh

Suresh Chandra is working on asymmetric top and diatomic molecules of astronomical interest. Recently, he investigated transfer of radiation through CS molecules in atmosphere of a carbon star. It was found that in the absence of external IR field, high density and high temperature in the region could not support formation of lines in the vibrationally excited state of the molecule. Hence, the lines in the vibrationally excited states cannot be found unless external IR field is in progress.

He along with his student, has calculated Einstein A-coefficients for rotational transitions in the ring-chain isomer of C_5 H_2.

Kumbharkhane, A. C.

The space between stars in the galaxy is filled with gas containing hydrogen, helium, oxygen, carbon, calcium and many other elements. In a thermal plasma, when the electrons and ions interact, they may pass close enough to each other that the electron gets bound to the ion in excited state, losing some of its energy, known as recombination process. The recombination electron cascade down towards the ground state, giving rise to narrow band line radiations. The line which are radiated as the electron cascade down the energy level are known as recombination line, and those emitted at radio wavelength are called as radio recombination line.

Radio recombination lines are useful for studying morphology and physical condition in the low density ionized region. A.C. Kumbharkhane is analysing the hydrogen and carbon recombination emission from ionized hydrogen region using the Giant Metrewave Radio Telescope (GMRT) in the L-band and P-band in collaboration with Nimisha Kanthari.

Rastogi, Shantanu

Astronomical spectroscopic observations have established the presence of a large number of carbonaceous organic molecules in space. Among them, Polycyclic Aromatic Hydrocarbon (PAH) molecules belong to the most stable and probably the most abundant species. Their presence is indicated by the infrared emission features at 3050, 1610, 1310, 1165 and 885 cm^{-1}(3.28, 6.2, 7.7, 8.6 and 11.2 mu m). These Aromatic Infrared Bands (AIB) are found to be ubiquitously present in a variety of regions viz., Planetary Nebulae, Proto-Planetary Nebulae, Reflection Nebulae, H II regions and even in extra galactic sources. 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) observed in the visible and near infrared spectral ranges. The general features of the interstellar IR spectra are attributed to aromatic species, and yet identification of individual molecules is complex and no specific PAH molecule has yet been identified. To put constraints on the size distribution of PAHs in the ISM, Shantanu Rastogi has performed vibrational analysis on infinite polymeric graphene sheet models. The normal modes and their dispersion unravel simultaneously the features of oligomers (finite lengths of the basic unit) viz., Naphthalene, Pyrene, Anthanthrene, Phenanthrene, Ovaline, etc. The density of state lead to Heat Capacity, which compares well with graphite and is useful in obtaining the PAH cooling times by IR fluorescence. Intensity and band position corelation of AIB is better with PAH cations, so a systematic study of several PAHs and their cations has been done by Amit Pathak and Shantanu Rastogi using ab-initio density functional method. The intensity of C-H stretch mode is drastically reduced in cations while the C-C stretch intensity increases by several orders. These variations in intensity of IR bands upon ionization are related to the changes in charge distribution within the molecule. Linear catacondensed PAHs show systematic variations in spectra with size, while non-linear catacondensed PAHs show no regular variation.

X-ray Binaries

K. Shanti

X-ray binaries consist of a compact object (such as a neutron star or a blackhole) accreting matter from a companion star. A majority of the X-ray binaries contain neutron stars and exhibit different temporal and spectral characteristics depending on the strength of the magnetic field of the neutron star and accretion rates. Some of these systems exhibit Gaussian like features in their power spectra, which are called Quasi Periodic Oscillations

(QPO). Kilohertz quasi periodic oscillations have now been detected for more than twenty sources. The high frequencies of these QPO, imply that they are generated close to the neutron star, where general relativistic effects are expected to play a major role.

K. Shanthi and R. Misra have analyzed the RXTE data of the atoll source 4U-1636-53, which exhibits such strong KHz QPO. They had previously obtained the complete available data (about 5 years nearly $1.32*10^6$ sec) for this source and had done a systematic automated search for KHz QPO. A follow-up of this work was undertaken, where a detailed study of the correlation between the properties of the QPO and the averaged spectra was done. Such studies give insight on the structure of the accretion disk when a QPO is present. This in turn will enhance our understanding of this phenomenon and X-ray binaries in general.

Singh, K. Y.

X-ray binaries constitute the brightest class of X-ray sources in the sky. The primary factors that determine the emission properties of an accreting compact object are: (1) whether the central object is a blackhole or a neutron star, (2) if it is a neutron star, the strength and geometry of its magnetic field, and (3) the geometry of the accretion flow from the companion These determine whether the emission region is the small magnetic polar cap of a neutron star, a hot accretion disc surrounding a blackhole, a shock heated region in a spherical inflow, or the boundary layer between an accretion disk and a neutron star. Two more factors are the mass of the central object, and the mass accretion rate; these influence the overall luminosity, spectral shape and time variability of the emission.

Study of the periodic and aperiodic variability and spectral characteristics of X-ray binaries provides information about the nature of the sources and physical processes responsible for X-ray emission in them. For instance, the spectral type of the companion determines the mode of mass transfer to the compact object and the overall environment in the vicinity. Many X-ray binaries are transient sources that appear on a time scale of a few days, and then decay over many tens or hundreds of days. These transient sources can, for a few weeks, be amongst the brightest in the sky, before they fade away. They are particularly important in the study of X-ray binaries, since they cover an enormous dynamic range in luminosity (typically $10^4 - 10^5$).

The power spectrum of several X-ray binaries often displays Quasiperiodic Oscillations (QPO). A sinusoidal signal in the light curve may give rise to such features in the power spectrum if the frequency of the signal varies during the time of the observation. Time scale variations range from milliseconds as seen from kilohertz quasi-periodic oscillations (QPOs) in low-mass X-ray binaries (LMXBs) to seconds and minutes as indicated by low-frequency QPOs and pulsations in X-ray pulsars. Chaotic variability, flickering and QPOs are common features of most stellar-mass blackhole sources. X-ray variability serves as a powerful tool to probe details of the accretion process very close to the compact objects.

K .Y. Singh has studied some X-ray binaries (Cygnus X-3, GX 1+4) using the data of Indian X-ray Astronomy Experiment (IXAE) and Rossi X-ray Timing Explorer (RXTE) satellite available in the public domain.

Recently, the Department of Science and Technology (DST), Government of India has entrusted to K. Y. Singh a research project entitled *"Development of Stellar Photometric Observation facility at Manipur University"* to be implemented within a period of three years (from January 2004 to January 2007).

Compact and Exotic Stars

Chakrabarty, Somenath

In a recent work, Somenath Chakrabarty along with Soma Mandal, has studied the flattening and collapse of hadronic bags in presence of strong quantizing magnetic fields.

It is found that in the presence of ultra-strong magnetic field, a neutron star flattens in the classical general relativistic model whereas, the inclusion of microscopic quantum mechanical effects, the same system collapses. Both these strange phenomena occur in the transverse to the magnetic field direction. Somenath Chakrabarty and Mandal have shown using MIT type bag model of confinement that the same phenomena may occur in the microscopic level, i.e., in the case of hadrons (neutrons, protons, etc., the constituents of neutron stars) in the presence of ultra-strong magnetic fields.

In an investigation, Somenath Chakrabarty along with Sutapa Ghosh and Soma Mandal have developed an exact and new general formalism to obtain the equation of state of dense stellar plasma in the presence of ultra-strong magnetic field. This formalism is applied by them to study the transport properties of dense stellar electron-proton plasma. They have found that such a plasma behaves like a super-fluid insulator. They have further studied the neutrino emissivities and neutrino opacities in neutron stars. They have shown that neutron stars cool rapidly in the presence of strong magnetic fields.

Chandra, Deepak

Deepak Chandra, along with Meenu Dahiya and Ashok Goyal has studied chiral symmetry structure at finite density and temperature in the presence of external magnetic field and gravity, a situation relevant in the early universe and in the core of compact stars. They have investigated the phase structure of the Nambu-Jona-Lasinio model in curved spacetime in the linear curvature approximation, and found that in the presence of external gravity with positive R, the chiral symmetry restoration is first order even as in flat spacetime, the transition is second order with temperature and becomes first order in the presence of density. Chandra along with Goyal has continued his work on the dynamics of first-order cofinement-deconfinement phase transition through nucleation of hadronic bubbles in an expanding quark gluon plasma in the context of heavy ion collisions for interacting quark and hadron gas and by incorporating the effects of curvature energy. They find that the interactions reduce the delay in the phase transition, however, the curvature energy has a mixed behaviour. Also, lower values of surface tension increases the supercooling and slows down the hadronization process unlike the case in the early universe phase transition. Higher values of bag pressure tend to speed up the transition. Another interesting feature they find is the start of the hadronization process as soon as the QGP is created.

Goyal, Ashok

Ashok Goyal, with his colleagues V. K. Gupta, Deepak Chandra and Chandrika Devi continues to investigate the possibility of phase transition at high densities in the core of neutron stars. They have argued that strange quark matter is in the color superconducting state and that at high densities, such matter would be in a colour-flavour-locked phase. This leads to the exciting possibility of the entire neutron star converting itself into a pure quark star with matter in such an exotic phase or a hybrid star. Recent developments in the measurement of mass-radius relation of compact objects is likely to throw light on the existence and properties of such objects. A study of radial oscillation frequencies, mass-radius relation , neutrino emission is being undertaken.

Goyal with S.R.Choudhury, Naveen Gaur and Sukanta Dutta has been investigating phenomenon and processes likely to point towards new physics beyond the standard model. $K_0 - \bar{K}_0$ mass difference, lepton number violation in meson decays and in neutrino factory, triple vector-boson anamolous coupling are some of the phenomenon under consideration.

Mukherjee, S.

An exact and analytically solvable model for a class of static configurations of self-interacting complex scalar fields, minimally coupled to gravity, has been studied by S. Mukherjee, R. Sharma and S. Karmakar Assuming that these configurations describe compact objects of VaidyaTikekar class, generalized to accommodate anisotropic pressure distributions, the radial dependence of the effective potential can be determined. For given mass and radius of the compact object, the model may be used to determine the coupling constants if the functional form of the effective potential is assumed. Thus, assuming a quartic expression for the effective potential, for a star of mass equal to 0.88 solar mass and a radius of 7.7 km, the scalar field mass is found to be about 4 times 10^{-10} ev, which is of the order of the typical mass of an axion. However, the effective potential here also has a constant term, which needs an explanation. In the early universe, the presence of this constant, considered as a cosmological constant, would have favoured the formation of such boson stars. Further, work is in progress, which considers more complicated effective potentials. The possibilities of supermassive Boson stars as well as of mini-stars are also studied by making use of the scaling properties of the model.

Tikekar, Ramesh and Jotania, Kanti

Adopting an ansatz similar to that suggested by Vaidya-Tikekar for the variation of matter density in the interior of a superdense spherical star, a general solution of the Einstein's field equations is presented, which is useful in describing a three parameter family of physically viable models of superdense star. The family provides two classes of models. The physical viability of the models of the two classes is investigated using numerical techniques. If the information about physical parameters such as matter density at the star surface, its ratio to the central density and compatification parameter (*i.e.*, mass to star radius ratio) is available, the ansatz is found to admit viable models of compact and ultra-compact objects of astrophysical relevance. The ansatz prescribing pseudo-spheroidal geometry for the 3-space of a star, is also found to be suitable to describe superdense configurations of strange-matter stars too.

Usmani, A. A.

Though the conventional many-body theories have been successfully used to study dense systems like neutron and nuclear-matter and quantum liquids, the microscopic and realistic treatment of infinite-body systems like neutron stars is still developing starting from nucleon and hyperon degree of freedom. The equation of state has been a focus of study since more than a decade. The subject is still growing with better state-of-art many-body tools. The phase transition from hadronic to quark matter and a possible kaon condensation have triggered a great deal of interest in the scenario, where a strange hyperon may coexit with nucleons in a neutron star. This is important to understand the early evolution and cooling scenario of the star. One has to have a better knowledge of baryon-baryon and three-baryon forces as basic ingredients. The nucleon-nucleon (NN) and three-nucleon (NNN) forces are very well known these days. But in the strange sector, the various key questions regarding hyperon-nucleon (HN) and hyperon-nucleon-nucleon (HNN) forces have to be addressed. One inevitably studies the hypernuclear physics to extract precise informations about these forces as a prerequisite for any realistic treatment of dense systems like neutron stars. Such a study is required to know what amount of strange matter a neutron star may sustain. He, therefore, studies s-shell hypernuclei in order to pin down the strengths of both HN and HNN forces. Besides the above work, progress has been made in formulating the Fermi-hypernetted-chain technique with the three-body correlation to study the dense infinite-body systems.

Sun and the Solar System

Badruddin

Coronal mass ejections (CMEs) are powerful eruptions in which, as much as ten billion tons of sun's atmosphere can be blown off in to interplanetary space. There is considerable interest in investigating CMEs, their interaction with earth, their propagation and evolution from sun to the earth and beyond. Considering CMEs, halo CMEs and partial halo CMEs and their interplanetary manifestations (magnetic clouds, ejecta and shocks) observed by instruments onboard SOHO and Wind spacecraft, Badruddin and Y. P. Singh have studied their role and relative effectiveness in modulation of galactic cosmic rays in the heliosphere.

The polarity state of the heliospheric magnetic field is known to reverse every $\sim$ 11 year near the solar maximum period. This polarity reversal should have a significant influence on the motion of charged galactic cosmic rays if the particle drift due to gradient and curvature of the heliospheric magnetic field plays an important role in modulation. They have also studied the effects of gradient and curvature drifts on transient modulation of cosmic rays (Forbush decreases).

Heliosphere current sheet divides the heliosphere into two polarity regions above and below it. Badruddin and A. G. Ananth have studied the cosmic ray intensity variation during different polarity states of the heliosphere, with day-to-day changes in the angular distances from the earth to the current sheet. Their findings are in good agreement with 3-D model calculations including large-scale particle drift in the heliosphere with a wavy current sheet.

Narain, Udit

Udit Narain, and his co-workers are working on mechanisms responsible for maintaining the million degree temperature of the outer solar atmosphere, namely corona.

At present, they are working on heating of solar and stellar coronae by transients, namely nanoflares/microflares, and flares. In a single large flare, the energy released by sun is equivalent to the energy obtained by burning all the coal and petrol deposits on the earth.

In a nanoflare, the energy released by the sun is about one-billionth of the large flare, whereas in a microflare the energy released is roughly one-millionth of a large flare. This energy comes from the annihilation of magnetic fields, which takes place when two oppositely directed magnetic fields come very close to each other to form a current sheet, in which the current density is extremely high. In spite of very small resistivity of solar coronal plasma, electromagnetic energy is converted into thermal energy, which goes to heat the solar atmosphere via conduction and radiation.

The process by which magnetic energy is converted to heat, is known as magnetic reconnection. According to Parker, a nanoflare is the smallest unit of energy which the sun releases. When many nanoflares occur simultaneously we have a microflare. A flare occurs if an extremely large number of nanoflares occur simultaneously.

It is now considered that such processes occur in planetary atmospheres (including our earth), on stars and galaxies also. Thus, it is one of the most important problems in astrophysics, particularly solar physics. Their efforts in this direction are continuing.

Prasad, Lalan

There are severel mechanisms to explain the solar coronal heating. Micro and nano flare solar coronal heating mechanisms are the approaches towards the problem. Another method is phase-mixing process to explain the heating of solar coronal loops. Lalan Prasad discusses the non-linear mode of phase mixing by

Alfven waves. However, Heyvaert Priest model gives a good explanation of phase mixing in a class of coronal loops. Under typical coronal heating condition by ohmic dissipation due to phase mixing, coronal heating can attain a hot coronal loop. In this case, he assumed the magnetic field to be static and associated with only in inhomogeneities plasma density. Heating of coronal loops by linear resonant Alfven waves excited by the foot-point motions in the photosphere has been studied. The analysis of single layer heating is extended to multilayer heating in semiempirical treatment.

Sahijpal, Sandeep

Our solar system formed around 4.6 billion years ago by gravitational collapse of a molecular cloud core. Was the collapse triggered by shock waves from a nearby supernova, or alternatively by conventional scenario that involves ambipolar diffusion of magnetic field support of molecular cloud core, thereby leading to its gravitational collapse? The riddle can be addressed considerably by understanding the source of several short-lived nuclides, (^{7,10}Be, ^{41}Ca, ^{26}Al, ^{36}Cl, ^{53}Mn, ^{60}Fe; $\tau \leq 5$ million years) found to be present in the earliest formed solar system grains that survived in primitive meteorites. Presence of these short-lived nuclides in the early solar system indicates either their *fresh* production by stellar nucleosynthesis just prior to the formation of the solar system or due to their 'local' production in the early solar system by irradiation of solar nebula dust by energetic particles from the pre-main sequence sun going through T Tauri phase. To understand the origin of the solar system, it becomes essential to decipher the source of these short-lived nuclides. S. Sahijpal has been investigating both the scenarios. The stellar nucleosynthetic production scenario was discussed last year and the present work deals with detailed numerical simulations of production of short-lived nuclides by irradiation of solar nebula dust by energetic particles produced by magnetic flaring associated with pre-main sequence sun.

Conventional theories of low-mass star formation involve, formation of an accretion disc around a proto-star. Matter accretes on the disc that in turn feed the proto-star. The proto-star develops a strong magnetosphere that actively interacts with the accretion disc and results in the formation of a *magnetic reconnection ring*. Observations in X-rays, radio and γ-rays of these stellar environments show elevated levels of magnetic activity due to violent MHD magnetic reconnection events (flares). These energetic flares accelerate ambient protons, ^{3,4}He nuclei to MeV/n energies, thereby, creating an environment conducive for spallation reactions in the ambient dust. In the numerical simulations for the production of short-lived nuclides by irradiation, the magnetic reconnection ring at a distance 12 $R_\odot$ from the proto-sun's centre was opted as the irradiation site. Dust grains (5μ m - 2cm) with cosmic composition were introduced into Keplerian orbits with a coronal plasma viscous drag. Recent X-rays observations of Orion's low mass proto-stars made by Chandra X-ray satellite indicate intra-day variations in X-rays flare luminosities in the range 10^{29-32} ergs/s were used to model flare characteristics (e.g., ambient temperature, energetic particle flux, flare area) for simulations. Impulsive and gradual flares were generated randomly according to Chandra X-ray flare luminosity data. Composition of grains at different flare temperatures was modeled according to thermo-dynamical criteria. A power law energy distribution, dN $\alpha E^{-\gamma}$ dE was assumed with $\gamma \rightarrow 3$ - 4 and 2 - 3 for impulsive and gradual flares, respectively. All the proton, ^{3,4}He induced nuclear reactions with dust that can produce the short-lived nuclides were considered. ^{3}He/H ratio for impulsive flares was taken to be 0.1 - 0.5 with ^{4}He/H ratio of 0.1. Simple thermodynamical models were formulated for grain condensation and coagulation during flares. Simulations were run for a period of five years with a time step of hour. Preliminary results indicate that all the short-lived nuclides (except ^{60}Fe) can be produced by impulsive flares with ^{3}He/H ≥ 0.3.

Sen, Asoke K.

Comets are known to exhibit high amount of polarisation, caused by scattering of solar radiation from grains. However, it has been observed that this polarisation varies widely from one comet to another. Due to this property, comets are sometimes grouped into two or three distinct classes. During the last apparition of Halley's comet in 1985-86, in situ, measurements were made by six spacecrafts and some grain model was arrived at. Subsequently, this grain model was used for the interpretation of polarimetric data of many other comets. However, it was later observed that the same grain model is unable to explain the thermal re-radiation from cometary grains. Asoke K. Sen has refined the earlier grain model (derived from in situ space measurements) on the basis of recent IR observations on comets, which could successfully explain the polarisation as well.

Further using Mie theory, Sen has analysed the observed polarisation data of all such comets, with an aim to understand its variation. Based on other evidences it was assumed that the composition of grains does not differ between comets. As a result, while fitting the observed data to Mie theory, the complex refractive index (n, k) of grains was kept fixed. The individual grain size distribution functions so obtained for various comets suggest different values for the 'relative abundance of coarser grains' (g, say). It was observed that the relative abundance of coarser grains in a comet has a dependence on some of the orbital elements of the comet and for non-periodic comets he has found that it is related to perihelion distance (q) by the relation $g = 2.5q^{2/3}$. From this relation, he has further concluded that, comets whose grains are processed more by the solar radiation contain relatively larger number of coarser grains. For the periodic comets, a refinement of above mathematical relation is required to include the dependence of 'g' on the time period of comets.

Nonlinear Dynamics

Ambika, G.

G. Ambika, has analyzed the occurrence of Stochastic Resonance (SR) in cubic bimodal maps with a bistability window, together with K. P. Harikrishnan. By coupling two such systems, an enhancement of SR and an improvement of signal to noise ratio (SNR) are observed for an optimum value of the coupling strength. For composite but weak signals or signals of multiple frequencies, SR is found useful in isolating the combining frequencies. The analysis is repeated for a typical practical situation like the Josephson junction. This system also supports SR between its oscillatory and escape modes, when a proper resetting mechanism is imposed.

She is also working on Coupled Map Lattices (CML), where the spatial fractal dimensions are computed for the frozen patterns and cluster pattern formations along the lattice for temporal periodic sites.

The rotation and reflection symmetries underlying the Mandelbrot set and the conjugate Mandelbar set are analyzed by considering iterations of a generalized complex polynomial as the generator of the sets. The fractal patterns for some inverse functions are also being investigated.

Ambika has extended the work on the intensity variations of a variable star like CYAquarii started in collaboration with M. Takeuti, and A. K. Kembhavi. The full Lyapunov spectrum, Singular Value Decomposition leading to reconstruction of attractors in the phase space are now done for five different data type viz. the raw data, processed data, model data from multiperiodic fit, data with equivalent Gaussian noise and pure Gaussian. A comparison of the results establishes low dimensional chaos in the system. This is being done for the X-ray data from the blackhole system GRS 1915+105 in collaboration with Kembhavi, R. Misra and Harikrishnan. Out of the 12 temporal states analyzed, 4 clearly indicate low dimensional chaotic behaviour while 3 shows stochastic nature.

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

M. K. Das, and L. M. Saha have mainly confined themselves to the simulation of trajectories of an infinitesimal mass in the gravitational and radiation field of a binary system. The numerical investigation of stability of the trajectories has been studied. They consider only planar motion. The stability analysis has been studied using the method of Poincare surface of section and also using the correlation method. Further, analytical method has also been developed to study the finite amplitude motion around L4 in the above system. The perturbation method used incorporates finite eccentricity of the elliptical orbit of the primaries.

Hallan, Prem

Existence and stability of equilibrium points have been studied in Robe's circular problem when the primary other than the spherical shell is an oblate spheroid. It is proved that for certain values of the mass and density parameters, and the oblateness factor, there are (i) two equilibrium points on the line joining the centres of the primaries, (ii) two equilibrium points in the x-z plane equidistant, and forming triangles with the line joining the centres of the primaries, (iii) infinite number of equilibrium points in x-y plane lying on a circle. Further, it is proved that circular and triangular points are unstable, and equilibrium points on the line joining the centres of the primaries are stable, if mass and density parameters satisfy certain inequalities.

Hasan, S. N.

His research interests include the study of dynamical systems ranging from the three-body problem, three-body scattering problem and galaxy interactions, and n-body simulations.

He is involved in a problem on galaxy ejection in collaboration with K.S.V.S. Narasimhan and S.M. Alladin. He is also engaged in the application of Clifford Algebras to celestial mechanics.

Kuriakose, V. C.

V. C. Kuriakose, and Ganapathy have analyzed coherent soliton pulse interaction in an erbium doped fibre system associated with the higher order dispersion, self-steepening, and self-induced transparency effects. Using auto-Backlund-transformation, one- and two-soliton solutions with and without the continuous wave background have been generated. As usual, it is observed that there is an exact balancing between higher-order perturbation terms and self-induced transparency effects.

Next, the soliton solution when the erbium-doped fibre system is driven by a constant pumping source is considered. In this case, the soliton solution has a constant value equal to that of pumping source even at infinity, a phenomenon which differs from the case, where the soliton solution asymptotically decreases to zero at infinity. This is depicted as the soliton in a continuous wave background. The interaction scenario is also studied in detail for both the cases. Vinoj and Kuriakose have studied pulse propagation through dispersion decreasing fibres and found that high quality ultrashort soliton pulses can be generated when light propagates through a dispersion decreasing fibre with fibre loss. Another area in nonlinear optics, where soliton finds applications is in photo refractive and photonic crystals. Jisha and Kuriakose have began studying photo refractive solitons from the point of photonic switching applications. Shaju and Kuriakose have proposed a simple method to create a double-well potential in an annular 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.

Mittal, A. K.

A. K. Mittal, and Dwivedi investigated the forced Lorenz model, which was introduced by Palmer as a conceptual model for discussing long-range monsoon predictability. Time series data was analyzed using techniques from chaotic dynamics. Applications of neural network and genetic algorithm techniques for atmospheric studies are also being explored.

Plasma Physics

Khan, Manoranjan

Study of the dust acoustic shock wave at high dust density, i.e., the dust electroacoustic (DEA) or dust Coulomb (DC) shock wave is an important area of investigation in a complex plasma. Manoranjan Khan in collaboration with his colleagues M.R. Gupta, S. Sarkar, S. Ghosh and collaborator K. Avinash, has investigated the shock strength incorporating the nonadiabatic dust charge variation. It has been shown that nonlinear DEA shock is governed by the K-dV Burger equation, in which the Burger term is proportional to the nonadiabatically generated dissipation. In collaboration with M.R. Gupta, S. Sarkar, S. Ghosh, numerical results for the propagation of large amplitude dust acoustic stationary shock wave are obtained for a complete set of nonlinear dust fluid equations coupled with dust charging equation and Poisson equation. It is seen that the DA shock transition to its far downstream amplitude is oscillatory in nature due to dust charge fluctuation, the oscillation amplitude and shock width depending on the ratio w_{pd}/v_{ch} and other plasma parameters.

A capacitively coupled radio-frequency discharge plasma in a discharge tube of cylindrical topology with low cost component has been designed and fabricated in a plasma laboratory in collaboration with Abhijit Bhattacharyya. In the plasma laboratory, argon plasma at 10^{-5} mbar pressure has been produced and the electron density and plasma conductivity has been estimated using an analytical model.

Using the analytical instruments like atomic force microscope (AFM), atomic resolution imaging of seeds has been conducted in the USIC Laboratory in collaboration with R. Bhar and others. Approximately, 1.5 Å structures have been resolved on the surface of mung bean, cumin and mustard seeds. These results are likely to be the first imaging of atoms of a biological sample with the help of AFM.

Kumar, Nagendra

Nagendra Kumar, in collaboration with V. Kumar, K.M. Srivastava and H. Sikka, has studied the Kelvin-Helmholtz instability in sheared magnetohydrodynamic flow of an ideally conducting rotating inhomogeneous compressible plasma. The asymptotic behaviour in x of the Kelvin-Helmholtz eigen functions for the case of finite compressibility in the presence of rotation is discussed and instability condition is derived. In the incompressible limit, a dispersion relation is derived, which has been solved numerically and discussed in detail. It is found that the inhomogeneous system is unstable in an incompressible plasma. The behaviour of the Hall-MHD sausage and kink waves in the presence of steady flow has been studied by Kumar in collaboration with H. Sikka and Ivan Zhelyazkov. The influence of the flow, both inside and outside the plasma slab is taken into account. The plasma in the environment is considered to be cold and moves with the different flow velocity outside the slab. Dispersion relation is derived to discuss the propagation of both the modes. Numerical results for the propagation characteristics are obtained in the limit of parallel propagation. It is found that the dispersion curves, for both the sausage and kink modes in cold plasma consists of the pieces of curves, which merge at a point and follows the same propagation pattern for the higher values of the flow parameter too, indicating the complex behaviour of the waves due to the flow in the environment.

Mondal, K. K.

Over the last few decades, plasma physicists have made investigations on various nonlinear structures, viz., ion-acoustic solitary waves, shocks, double layers, etc., in plasmas as these have been found to have relevance with regard to some experimental observations and astrophysical phenomena. In the experimental observations made with a double plasma device on the properties of the ion-acoustic solitary waves, it is found that the wave velocity is larger and the width is narrower than those predicted theoretically, i.e., by the solution of K-dV equation. In order to remove or rather minimize this discrepancy, several renowned workers like, Ichikawa, Kodama, et al., have made investigations on the effect of higher order nonlinearity on the ion-acoustic solitary waves for cold ions by reductive perturbation method.

K.K. Mondal,e t al., have made an exhaustive study on the combined effects of ion-temperature, negative ions and higher order corrections to ion-acoustic solitary waves in a multicomponent plasma containing warm, relativistic positive ions and negative ions, two-temperature and nonisothermal electrons, etc., and observed that both the amplitude and width of the solitary waves get considerably modified. Actually, they have developed a general theory incorporating various probable situations and compared their results with those obtained by others, who developed their theories separately for particular situation.

Beginning with the work of Bliokh on waves in Saturn rings, a good deal of work, theoretical as well as experimental, has been done on waves in dusty plasma, because of its relevance in various astrophysical scenarios. At the outset of the last decade of the last century, existence of very low velocity low frequency dust acoustic (DA) waves excited in dusty plasma has been theoretically demonstrated.

They have studied the effect of higher order nonlinearity on dust acoustic solitary waves using the higher approximations in the reductive perturbation technique, which was firstly formulated by Ichikawa, et al. In their analysis, they have taken a simple model of charge variation, viz., Ie+Ii = 0, where Ie and Ii denote the electronic and ionic currents respectively. They have noticed that the higher order correction modifies the amplitude and the width of the DA soliton to an appreciable extent.

Paul, S. N.

i) From the experimental observations, it is found that theoretically predicted values of the amplitude, width and velocity of the solitary waves do not obey the experimental results. To remove the discrepancy between the theoretical and experimental results, S. N. Paul and his co-workers S. K. Chattopadhyay and S. K. Bhattacharya have considered higher order nonlinearity and dispersive effect for the study of ion-acoustic solitary waves and doublelayers in multicomponent plasma consisting of positive ions, negative ions and isothermal electrons using the pseudo-potential methods. The effects of drift motion of the ions and the electron inertia have been taken into consideration and the structure of solitary waves and double layers including width and amplitude are shown graphically and discussed for different values of the plasma parameters. It is seen that drift motion, negative ions and the electron inertia have important contribution on the amplitude and width of the ion-acoustic solitary wave in the plasma. The first-order K-dV equation gives rarefactive solitons, where as second-order modified K-dV equation gives compressive solitons. It is also observed that when the mass-ratio of negative ion and positive ion is small, the doublelayers are more prominent. Moreover, it is seen that the potential of double layers is negative which predicts that only rarefactive doublelayers exist in the negativeion plasma in presence of electron-inertia.

Considering a multicomponent plasma consisting of positive ions, negative ions and two-temperature-electrons, Paul, in collaboration with his co-workers, A. Roychowdhury and S.R. Majumdar, has studied ion-acoustic solitary wave taking third-order nonlinear and dispersive terms. The variations of potential, width, and Mach number against amplitude of first-, second- and third-order solitary wave are shown graphically. It is seen that both compressive and rarefactive solitary wave may be excited when negative ions and two-temperature-electrons are present in the plasma. Moreover, the potential of first-order K-dV solitons is greater than the third order modified K-dV (mK-dV) solitons. The width of lower order K-dV soliton is greater than the second and third order mK-dV soliton. It is found from the potential structure of double layers for different values of the density of negative ions and two-temperature-electrons that the widths of double layers are greater for large values of 'Q' (mass ratio of negative ions and positive ions). Ion acoustic solitary waves in a plasma bounded in finite geometry and consisting of positive ions, negative ions and nonthermal electrons have been theoretically investigated by Paul and his co-workers K.K. Mondal and Bhattacharya, using the pseudo-potential method. They have shown that the amplitude and width of the solitary waves depend on the concentration of negative ions, nonthermal parameter of electrons and the radius of the cylindrical geometry of the bounded plasma. In presence of non-thermal electrons and negative ions, both compressive and rarefactive solitons will be excited. But, solitons will not exist in a bounded plasma in the absence of negative ions for any value of nonthermal parameter of electrons.

ii) In plasmas, some atoms remain neutral, but their valance electrons are weakly bound to their respective nuclei in partially ionized plasmas, for example, in plasmas in the ionosphere, in the cosmic spaces of the chromosphere, solar photosphere, and cool interstellar clouds, etc. Paul, in collaboration with his co-workers B.Ghosh, S.R.Majumdar and Bhattacharya, has investigated the collective behaviour of a plasma when the plasma is considered to be as mixture of compressible fluids of free electrons, free ions, weakly bound electrons and neutral atoms. It is found that the Poynting theorem for energy conservation and the Maxwell stress elements have some new terms due to the collective effect of all the plasma constituents. Particle dynamics of bound electron in the presence of applied wave fields, in the classical limit, exists and gives useful results in the Larmour precession effect, in the scattering theory of light of Rayleigh and Thomson. iii) Paul, in collaboration with his co-workers B. Chakraborty and Bhattacharya, has investigated the nonlinear propagation of surface waves in a cold homogeneous electron plasma half-space. Using the method of Multiple Scales, they have derived a nonlinear Schrodinger equation describing the nonlinear evolution of surface waves. From this equation, the criteria of instability are obtained. Numerical computations are presented, which show that surface waves are modulationally unstable throughout the whole electro-magnetic region of its existence when one disregards ion motion. The growth rate of this instability and existence of solitary waves has been discussed. The electric field associated with a finite amplitude surface wave can take the form of an envelope soliton, which propagates along the plasma-vacuum interface with a velocity independent of the soliton height.

Theoretical Physics

Gangal, Anil D.

Recently, a formulation of calculus on fractal subsets of the real line and of fractal differential equations was developed. During the period of report further progress was made in the corresponding techniques and applications. Anil D. Gangal, together with Abhay Parvate, developed a correspondence between fractal differential equations and ordinary differential equations. This development provides a tool for study of models involving fractal-time evolution processes. Simple examples of these include (i) streched exponentials associated with fractally-slow relaxations, (ii) motion of a particle in a fractal medium and (iii) anomalous diffusion, etc.

Further, Taylor expansions for a class of fractal functions were developed. They provide a tool for approximations for that class of fractal functions.

Kaushal, R. S.

In recent years, a variety of scalar field potential models have been advanced and used to understand the existence of an exotic form of energy, called "dark" energy in the universe. An explanation of this feature of the universe is sought in terms of various scalar field potential models. R. S. Kaushal has been pursuing model independent studies of these features in cosmologial dynamics with regard to phantom field, and phantom with Born-Infeld type Lagrangian field. The possibility of occurrence of attractor(s) in the solutions for a certain class of scalar field potentials has been demonstrated in a very general manner.

Kaushal, with his collaborators, has also been pursuing the study of Schrödinger quantum mechanics and supersymmetric quantum mechanics of one-dimensional non-Hermitian Hamiltonian systems in an extended complex phase space characterized by $x = x_1 + ip_2, p = p_1 + ix_2$. In this context, the concepts of "shape invariance" of potentials and that of "quasi parity" are generalized.

Malik, Usha

It has been shown that the confining term in the widely used Cornell form of QCD potential is derivable from the gluon superpropagator for an exponential form of gluon self-interaction. For this purpose, it has been assumed that the gluon-gluon coupling constant has the character of a running coupling constant. As is well known, the form of the above mentioned potential is based on the belief in an underlying gauge theory of hadrons, salient features of which are asymptotic freedom and infrared slavery. In physical terms, the latter feature meets the phenomenological requirement that free quarks be unobservable, but from the point of view of field theory, the origin of the confining part has remained obscure. The present work deals with this puzzle.

Usha Malik has also conducted a study of high Tc superconductors. It has been suggested that the highTc 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.This work was presented by her collaborator at the 24th Riso International Symposium on Superconductivity and Magnetism held in Denmark (September 2003).

As a follow up of the above approach in superconductivity, the results of ab-initio 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. This work is currently available on Science Direct.

The entire research work has been done in collaboration with G P Malik.

Pandita, P.N.

The Standard Model (SM) of electroweak interactions is a great success. However, it suffers from the naturalness problem, which makes the Higgs sector so crucial for its internal consistency, unstable under radiative corrections. Supersymmetry is at present the only known framework in which the Higgs sector of the SM is stable under radiative corrections. Furthermore, the minimal supersymemtric standard model (MSSM), when embedded in a grand unified theory (GUT), provides a framework for understanding the relative strengths of the three gauge couplings of the SM gauge group $SU(3)_C \times SU(2)_L \times U(1)_Y$.

P. N. Pandita, in collaboration with B. Ananthanarayan, has carried out an analysis of the non-universal supersymmetry breaking scalar masses arising in $SO(10)$ supersymmetric unification. By considering patterns of squark and slepton masses, a set of sum rules for the sfermion masses have been derived. These are independent of the manner in which $SO(10)$ breaks to the SM gauge group via its $SU(5)$ subgroups. The phenomenology arising from such non-universality is unaffected by the symmetry breaking pattern, so long as the breaking occurs via any of the $SU(5)$ subgroups of the $SO(10)$ 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.

Rahaman, Farook

Over the last two decades, the developments in cosmology and particle physics (also in condense matter physics) were marked by a close interaction between the two fields. Some characteristic parts of the early universe have analogous in condensed matter physics. The particle physicists are trying to verify their theories at the early universe, while the cosmologists are taking ideas from particle physics to understand the large-scale structure of the universe. Interestingly, the topological defects are the common ideas in cosmology and condensed matter physics. Farook Rahaman has studied different topological defects in alternative theories of gravity based on Lyra geometry. He has also studied global monopoles in Kalb-Ramond background.

Verma, R. C.

The Standard Model of fundamental particle interactions has achieved remarkable success in understanding electromagnetic and weak interactions in leptonic and semileptonic sector. However, non-leptonic weak processes have posed serious challenges to the model, as these processes experience interference due to the strong interactions. Even though quantum chromodynamics provides a reliable description of the strong interactions at high-energy scale, relationship of quarks with their hadron bound states still eludes. Experimentally, measurements on heavy flavour baryons are still in infancy, as their production requires large energies. Only singly charmed and isosinglet bottom baryons have been observed. After the development of B-factories in the last decade, measurements on their decays have now come under active experimental investigations and more data are expected in near future.

(i) Theoretical progress on heavy baryons has been rather slow due to the complexity of their three-quark structure. Whereas the investigation of inclusive decays and lifetimes of heavy flavour baryons has now matured, their exclusive decays are difficult to be explained. Initially, it was expected that the dynamics of nonleptonic weak decays of charm baryon might become simple as the decaying quarks are heavy. However, the available experimental information, through meagre, has already started showing discrepancy with such nave expectations. Since, these baryons are very heavy, they can decay through numerous channels, which we have studied. Using the QCD modified weak Hamiltonian based on the Standard Model, R. C. Verma has investigated two-body weak nonleptonic decays of charm baryons emitting $J^P = 1/2^+$ baryons and pseudoscalar mesons using the SU(3) flavour symmetry. He has derived the decay amplitudes in terms of the reduced matrix elements of corresponding irreducible representations, which lump all the weak dynamical processes including the strong interaction effects. Assuming sextet dominance of the weak nonleptonic Hamiltonian, he has obtained several sum-rules among decay amplitudes in Cabibbo favoured, Cabibbo suppressed, and Cabibbo doubly suppressed models. Determining the reduced matrix elements from the available branching ratios and asymmetry parameters of a few decays of the isosinglet charm baryon, he has made predictions for several decays in these modes. A consistent agreement with experimental values has been achieved.

(ii) Though measurements of hyperon magnetic moments have now become more precise, there exist serious discrepancies between experiment and quark model predictions. Various theoretical efforts have been made to improve the situation but with partial success. Verma has shown that a good agreement can be obtained for baryon moments using the concepts of effective quark mass and effective quark charge. He has then employed these considerations to calculate magnetic moments of charmed baryons also. He has first determined the effective quark masses from the charmed baryon mass spectra by including spin-dependent interaction 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 moments. The obtained values are expected to be test soon as serious efforts are underway to measure charmed baryon moments.

Observational Astronomy and Image Analysis

Pandey, S. K.

(i) Inter-Stellar Medium All components of (ISM) known to exist in spiral galaxies have been detected, although in different proportion, in early-type galaxies too. However, nature of different forms of ISM in early-type galaxies, unlike the situation in spiral galaxies, is not well understood. As a part of an ongoing collaborative research programme with an objective of studying dust and other forms of ISM in a large sample of early-type galaxies, a detailed surface photometric analysis in optical as well as near-IR bands for a rather heterogeneous sample of 29 early-type galaxies, which have been classified as dusty galaxies, was completed during the year. Starting with the techniques of detecting dust, which allows one to examine distribution and morphology of dust in extended objects, the extinction curves from extinction maps of all the sample galaxies were derived. The work show a very remarkable result: the extinction curves of all the galaxies, in general, run parallel to that of the Milky Way, implying the dust extinction properties in extragalactic environment are very similar to that found in our own galaxy. Dust mass estimates using total optical extinction as well as using IRAS fluxes reveal that the two differ significantly, as has been found from earlier studies! The optical broad band imaging data showing dust absorption, the H-α narrow band photometry which traces the ionized gas, and X-ray emission maps extracted from Chandra archive for several galaxies in the sample were used to examine interrelationship between different forms of ISM. The results seem to indicate a close physical connection between various forms of ISM in early-type galaxies, and needs further investigation to obtain a better understanding of the origin and evolution of multiphase ISM in early-type galaxies. This forms a major part of thesis work of M.K. Patil. Observations of some more dusty elliptical were carried out in BVRI and H-α bands using the 60" telescope at Palomar Observatory during the period July - September 2003, and analysis of the data is in progress.

(ii) Analysis of BVR photometry of the RS CVn binary star HD 61396 identified by the research group during the year 2000 as a new active binary star, was carried out using the new photometric observations of the system during the period February-March 2001.The new photometry reveals significant evolution is the shape and amplitude of its light curve. The traditional two-spot model has been used to obtain the spot parameters from the observed light curve to note significant changes in the spot area and their location on the stellar surface as compared to the earlier results. Likewise, BVRI photometric observations of HD52452, one of the shortest period(0.42304 days) non-eclipsing chromospherically active binary star taken during the period 2000-2001 was analyzed and compared with previous data reported by Messina, *et al.* to find noticeable change the shape of its light cure and the location of the light minima. Low resolution spectra of several suspected RS CVn stars were obtained during February and March 2004, and analysis of the data was in progress. Sudhanshu Barway has been involved in this research programme.

Rao, Vivekananda

The light curves of the RS CVn type eclipsing binary UV Piscium were analysed and their absolute elements were derived. From the derived elements, the evolutionary status of the system was determined using Schaller's models and compared with other members of the group. It is found that in most of the systems, the less massive component is more evolved. This indicates that the models need revision as they depend on many parameters.

The intermediate age open cluster NGC 6791 is found to have many WUMa binaries. Vivekananda Rao has been analysing the light curves of these binaries. It is found that the components of these binaries are more evolved compared to the field ones indicating evolutionary effects.

Srivastava, P. K.

HII regions are associated with hot stars, where all the hydrogen is believed to be completely ionized. In our galaxy, one of the largest and most complex emission nebula W51 comprises of multitude of HII regions of varying compactness and morphologies. P. K. Srivastava, in collaboration with A. Pramesh Rao has observed (as reported previously) radio continuum emission from W51 at frequencies 240, 610, 1060, 1400 MHz using GMRT. Eleven prominent HII regions in W51 were analyzed, and physical properties like kinetic electron temperatures and emission measures were derived. The observed spectra show that emission from all these regions is thermal. It has also been found that electron temperatures in above regions lie between 2100-5600 K. The radio recombination line studies of these regions give higher kinetic temperatures ($\sim 10000K$). Srivastava and Rao have found that high resolution low frequency data conclusively show that electron temperatures in HII regions of W51 are low. Moreover, the observed diffused HII sources show higher flux at 240 MHz than predicted by single component thermal source. They have proposed that the observed flux and derived properties can be satisfactorily explained by regarding all the regions consisting of a dense optically thick (below 1 GHz) core enveloped by a hot ionized medium, which is optically thin down to 240 MHz. The discrepancy between low frequency continuum values of electron temperature and RRL derived values, however, seems to be a generic problem of HII regions and to investigate it further, a proposal to observe a sample of ten other nebulae is in progress.

Srivastava, in collaboration with A. K. Kembhavi and others, have also observed four fields at 325 MHz at GMRT to look for extended features around ultra-high frequency flat-spectrum radio sources. These fields have been observed by Kembhavi and his collaborators at 30 GHz using OVRO 40 m telescope and is expected to include nearly 125 AGNs with flux >6mJy. The complimentary observations at low frequency were taken and all the four fields were mapped. Unfortunately, due to high ionospheric activity during the period of observation, the primary flux and band-pass calibrator data was found to be bad and hence, no reliable results could be obtained.

Radio Astronomy

Srivastava, D. C.

D. C. Srivastava has recently started research in radio astronomy. He, alongwith his research student and in collaboration with S. Anantha Krishnan, studying nearby galaxies using Giant Metre Radio Telescope (GMRT). Nearby galaxies may be defined as those galaxies, which are at distances of less than about 100 Mpc. These include elliptical/SO Seyfert/Spiral galaxies. The study of these objects using GMRT is interesting, because of three reasons; firstly, these are the galaxies for which the most detailed optical information can be obtained, secondly, these are examples of most common forms of active galaxies, and thirdly, their nuclei are bright, but beyond a few arc minutes, the emission is very diffuse and hence, require high sensitivity arrays like GMRT for its investigation. In these galaxies, due to the star formation taking place in the disk, there is large outflow of matter and this creates radio halos. Such radio haloes are more easily observed at low radio frequencies due to steep spectral indices that arise from the synchrotron radiation in these galaxies. The presence and properties of such radio haloes are found to be associated with the degree of star formation in the galaxy disks, although such correlations have been questioned. These haloes in the nearby galaxies extends to a few kilo parsecs from their plane. The gaseous haloes appear to contain both termal and nonthermal plasma, warm emitting filaments, neutral hydrogen, cool molecular gas, and radio emitting synchrotron plasma.

Due to high sensitivity required, only as small sample of edge on galaxies have been studied in detail. The objective of these investigations will be to get a better understanding of diffusive and convective transport of relativistic plasma moving outward from the centre of these galaxies. Such studies will also elucidate the disk versus halo interaction.

Cluster Computing for Machine Learning

Philip, Ninan Sajeeth

One of the growing demands that is never satisfied is the demand for computational power. Supercomputers are prohibitively expensive, while most huge databases are publicly available. The only feasible solution to this is to develop low-cost supercomputers known as Cluster Computers. Cluster computers are built around ordinary personal computers that are interconnected through a fast local area network. Special software packages are used to enable the system of computers in the network to collaborate as if they are part of a single virtual machine. The major difference between a local area network (LAN) and a high performance cluster (HPC) computer is that clusters allow sharing of CPU and memory power in the entire network, while LAN is basically a file resource sharing system in which CPU and memory resources are localised, and are often wasted. In Unix systems, running the top command gives a quantitative estimate of the CPU resource utilisation by a system.

Although, cluster computing is over two decade old, it is still in its development stage. The initial ten years of development in the eighties and early nineties resulted in incompatible and non portable system tools. A common standard known as the Message Passing Interface (MPI) was, thus, developed to write portable and efficient cluster programmes. The first draft of MPI standard was released in May 1994. As the name suggests, MPI communicates in a cluster by exchanging messages between the nodes (machines) in the cluster. A slightly different interface in which automated CPU load balancing is addressed by the OpenMosix cluster environment. In a study conducted at St. Thomas College, N. S. Philip found that a cluster built using both the techniques simultaneously produces a better throughput in machine learning problems. A cluster of 6 Pentium machines was built by Philip and five M.Sc. students from St. Thomas College to experiment the concept. Since, identical working environment of Red Hat Linux 9.0 was required for the project, they had to build a diskless cluster of five nodes that shared the master node's file system using the open Mosix File System (oMFS). The code development and building of the 6 node cluster was done by the students as part of their M.Sc. project. An extension of the work was done in collaboration with IUCAA by the same team members and Ajit Kembhavi. A diskless cluster of 16 Pentium 4,2.4 GHz nodes was built this time at a cost of about 6 lakhs. Various benchmarking tests and scientific computations are being done on the system to identify and debug its limitations.

In earlier studies, Philip, Y. Wadadekar, Kembhavi, and K. B. Joseph had shown that a powerful machine learning tool called DBNN can be used for the automated star-galaxy separation with more accuracy and speed as compared to other popular tools. In another study, Stephen Odewahn, S.H. Cohen, R.A. Windhorst and Philip had extended the usage of the tool for classifying galaxy types based on their morphology. DBNN has also been used by other researchers as an efficient tool for spectral classification, rainfall analysis, etc. Redesigning the DBNN code for parallel architecture can improve classification speed, especially when the data set is huge. Since, the computational part and the communication parts in DBNN can be well separated, the theoretical speed improvement can be as large as 3 to 4 times the number of nodes in the cluster. They are in the processes of developing an MPI version of DBNN for the 16 node cluster at IUCAA. A prototype version of parallel DBNN run on a two node cluster of old PCs showed 2 - 2.5 times speed advantage.

Philip has also developed an optimal training data selection algorithm for the efficient training of a DBNN using minimum number of training data. In a collaborative paper with Shaukat N. Goderya the usefulness of the tool for galaxy morphology classification has been evaluated. The new tool produced an increase in classification accuracy from $68\% to 100\%$ as compared to other neural network tools on the same data.

Instrumentation

Bhatnagar, S. P. and Umesh Dodia

S.P. Bhatnagar, and Umesh Dodia, have been working with a 14" Automated Photoelectric Telescope (APT). Photometric data on HIPPARCOS suspected variables (IN HYA, TV UMA, PSI1 AURIGA, FY LIBra, FP VIRGO) have been taken with a photometer built at IUCAA. Data analysis is under process. Due to earthquake, the top floor of the Physics Department was damaged, and the observatory constructed on the top floor has been removed. At present, the APT has been dismantled. The construction of a new observatory is still awaited. Dodia has replicated IUCAA designed CCD camera (Competible to ST-6, with TC 241 CCD Image Sensor 754(H) × 244(V) active elements) under UGC Minor Research Project by using IUCAA's in house facilities, in the instrumentation lab. The photometry of stars fainter than 10th magnitude will become possible with this CCD camera.

(III) IUCAA-NCRA GRADUATE SCHOOL

Four IUCAA Research Scholars, Archana A. Pai, Tarun Deep Saini, Niranjan Sambhus, and S. Shankaranarayanan, have defended their thesis submitted to the University of Pune during the year of this Report. The abstracts of the same are given below :

(i) Data Analysis Strategies for Detection of Gravitational Waves with a Network of Detectors.

Archana A. Pai

The existence of gravitational waves (GW) has been indirectly established by the timing observations of Hulse-Taylor binary pulsar, PSR 1913+16. However, direct detection of such waves with the man-made instruments is a grand scientific and technological challenge for the experimentalists. GW from typical astrophysical sources are extremely weak and thus, demand highly sensitive instruments. However, due to the advancement of interferometric techniques over the last decade, the goal of detection is not far from reach. Various interferometric projects such as LIGO, VIRGO, TAMA and GEO, with arm-lengths ranging from few hundred metres to few km are being constructed and will be in operation in 3 - 4 years, and are expected to reach the required sensitivities.

Inspiraling compact binaries are one of the prime candidates for these earth-based interferometers. The compact binary systems are comprised of two compact objects, such as blackholes or neutron stars, in a binary orbit. General relativity predicts emission of GW from such orbiting binaries. The back-reaction of radiated GW results in an inspiral with eventual merger of two members of this binary system. The emitted GW from such sources carry important astrophysical information about binary parameters, the geometry of strongly nonlinear spacetimes, the equation of state of compact objects, etc. Current estimates show a significant number of coalescence binary events per year up to cosmological distances and the resulting waves emitted during the inspiral phase can be detected with upcoming interferometers when they will reach their desired sensitivities. The inspiral waveform typically enters the bandwidth of interferometric detectors few minutes before the coalescence. Inspiraling compact binaries are relatively easy to model amongst the possible GW astrophysical sources. The emitted GW waveform can be obtained to the desired accuracy by using successive post-Newtonian (PN) approximations. (A PN approximation is a Taylor expansion in the parameter v^2/c^2, where the v is the relative velocity of the two stars and c, the speed of light.) Since the waveform can be predicted adequately and accurately, special detection techniques of template matching, such as matched filtering can be employed to extract the signal from the noisy data.

In this thesis, we address the problem of detection of gravitational waves from inspiraling compact binaries using a network of laser interferometric gravitational wave detectors having arbitrary orientations and locations. Searching for inspiral waveforms using a network of detectors is advantageous over a single detector because : (i) it has better sensitivity as compared to its single constituent detector, (ii) it can be used to pinpoint the source location by triangulating the source, and (iii) more information about the binary can be obtained by solving for more binary parameters.

Detection with a detector network requires combining the data from various detectors. Broadly speaking, there are two ways of combining data from the network of detectors, (a) coincidence approach, and (b) coherent approach. In the coincidence approach, the data is processed separately in the individual detectors and conclusions are drawn about the presence or absence of a signal. In the coherent approach, the network is treated as a single detector, where the phase information is crucially used in combining the data. In this thesis we take the coherent approach. The advantage here is that since, the phase information is used, the approach tends to be optimal. We use maximum likelihood detection (MLD) method which naturally leads to a coherent analysis.

Goals of this thesis are as follows:

(i) *To formulate the detection problem for the network of detectors* by the maximum likelihood approach. We assume the noise in the detector to be mainly Gaussian and stationary, interspersed with occasional non-Gaussian events. Under this assumption of Gaussian stationary noise, the MLD method reduces to matched filtering.

(ii) To obtain a *single* likelihood ratio (LR) for the entire network. To reduce the computational costs involved in searching over the multidimensional parameter space. The LR, in general, depends on 8 parameters for the Newtonian signal and 9 for PN waveform. Searching over all of the parameters will be a Herculean computational task. We save on the computational cost in two ways:

(iii) To analytically maximize over 4 of the parameters, namely, the distance, the initial phase, and angles specifying binary orbit orientations.

(iv) Use the Fast-Fourier-Transform (FFT) algorithm to efficiently scan over the time of arrival and the time delay window corresponding to an all sky search.

(v)To estimate the computational costs for various network configurations.

The thesis is organized as follows:

Chapter 1: Introduction to Gravitational Wave Astronomy

We begin with historical development of gravitational wave astronomy. Comparative features between electromagnetic waves and gravitational waves are mentioned. Since, gravitation is the weakest force in nature, gravitational waves interact weakly with matter, the detection of GW is an extremely difficult task. A brief overview of various projects being undertaken for detecting GW is mentioned. We review the linearized theory of gravity and the effects of GW on test particles – the test masses in the detectors. A discussion on various astrophysical sources of GW, such as supernovae, coalescing binaries, rotating neutron stars, etc. is included. We then describe briefly the two main types of detectors of gravitational radiation, in vogue namely, the resonant bar detector and the laser interferometric detector.

Chapter 2: Inspiraling Binary Signal

In this chapter, we qualitatively describe a model of a coalescing binary system to compute the time evolution of an emitted gravitational waveform in an inspiral phase. In the inspiral phase, it has been shown that tidal effects can be ignored and we can treat the binaries to be point masses. The time scale for circularization is much smaller than the coalescence time-scale, and therefore, when the signal enters the bandwidth of a detector, the orbit is almost circular. In short, eccentricity, tidal effects, *etc.*, do not play any significant role in the evolution of the binary during its inspiral phase. Thus, they are relatively clean systems to model, described essentially by the dynamical parameters; the masses and spins of the two stars. Typically, a binary spends most of its time in the inspiral phase (~ 10000 cycles) when it enters the detector bandwidth as compared to merger phase (one cycle), and thus the inspiral waveform contains substantial amount of the total energy emitted during coalescence. The accurate phase evolution of the binary is computed with the PN approximation scheme, which involves calculating the relativistic corrections to the Newtonian theory. We give a brief discussion of the above mentioned model and discuss restricted PN waveform up to 2.5 order.

Chapter 3: The Theory of Signal Detection

A brief discussion on the theory of signal detection is included, which involves classical theory of hypothesis testing and optimal decision strategies. We concentrate on the Neyman-Pearson decision criterion, which is more relevant for detection of GW. We discuss the maximum likelihood detection technique in detail. We show that in the case of Gaussian noise, maximum likelihood detection amounts to matched filtering.

Chapter 4 and onward the thesis reports original work.

Chapter 4: Formulation of the Network Problem

We give a brief introduction to network problem followed by basic mathematical framework required for developing the formalism. This formalism allows us to pose the network problem in an elegant manner. The dependence of the signal on orientation angles such as binary orbit orientations and detector orientations can be expressed in a systematic way, which is then further amenable to convenient mathematical manipulations. This is achieved by available machinery of symmetric trace free (STF) tensors and Gel'Fand functions. We express the wave tensor and detector tensors in terms of the STF tensors and thus, obtain a new representation of signal at the detector. The signal carries information of binary parameters, which are 8 in the case of Newtonian waveform and 9 in case of post-Newtonian waveform. We elaborate the role of each physical parameter influencing the waveform. Also, statistical properties of the noise of the detector are enlisted. We construct a network statistic by *coherently* combining the signals from each detector.

Chapter 5: Efficient Maximization of the Network Likelihood Ratio

In this chapter, we show how the detection problem can be optimally addressed by using the maximum likelihood method. We obtain a single likelihood ratio for the entire network pertaining to the inspiral signal. It has a very simple form, owing to our use of the new representation for the signal. This likelihood ratio is analytically maximized with respect to the distance, the initial phase, and the orientation angles describing the binary orbit. The initial phase is maximized by the method of quadratures. The maximization over the orientation angles of the binary orbit is performed using the symmetry properties of the Gel'Fand functions. The FFT can be used to maximize efficiently over the time of arrival at each detector. Thus, searching over the direction to the source or equivalently the time-delay window can be efficiently carried out by using the FFT.

Chapter 6: General Analysis of Computational Costs

In this chapter, we construct a template bank for the Newtonian waveform to scan over chirp mass and direction angles to the source by extending Owen's differential geometrical approach. We estimate the number of templates by calculating the volume of the parameter space of interest, obtained by the computing metric on the manifold and dividing the size of each template. We conclude the chapter with a discussion on computational costs involved in Fourier transforms and computing the network statistic. The metric also has information about errors on estimates of the parameters and thus, we determine the resolution in direction to the source, etc.

Chapter 7: Computational Costs for detector Networks:
Several detector configurations involving idealistic networks and realistic networks consisting of interferometers under construction, such as LIGOs and VIRGO are studied. First, the results for the simple waveform, namely, the Newtonian waveform are obtained. Then the computational costs for more realistic signal model, namely, the 2.5 PN waveform are estimated. If we consider constituent masses to be above a solar mass, then the online computational speed requirement to detect inspiraling compact binaries varies from few Gflops for a single detector to a few tens of Tflops for LIGO-VIRGO network.

Chapter 8: Statistical significance of detection

In this chapter, we discuss the statistical properties of the network statistic. We calculate the false-alarm and the detection probabilities associated with the network statistic, and obtain a relation between the network sensitivity and the number of detectors in a network. We also discuss the case, where the detector noise is contaminated by occasional non-Gaussian noise events and suggest a vetoing criterion based on the χ^2 - test.

Chapter 9: Summary of Thesis :
In this chapter, we summarize the main results of the thesis.

Publication list:

1. *Computational cost for detecting compact binaries using a network of laser interferometric detectors* , **A. Pai**, S. Bose, S. V., Dhurandhar to be published in Class. Quantum Grav., proceedings of the Edoardo Amaldi 4 meeting held in UWA, Australia.

2. *A data-analysis strategy for detecting gravitational-wave signals from inspiraling compact binaries with a network of laser-interferometric detectors*, **A. Pai**, S. V. Dhurandhar and S. Bose, Phys. Rev. D., **64**, 042004, (2001) (gr-qc/0009078).

3. *Detection of gravitational waves from inspiraling, compact binaries using a network of interferometric detectors*, S. Bose, **A. Pai**, and S. V. Dhurandhar, Int. J. Mod. Phys. D, **9**, 325 (2000) (gr-qc/0002010) .

4. *Detection of gravitational waves using a network of detectors*, Sukanta Bose, Sanjeev V. Dhurandhar, and **Archana Pai**, Pramana, **53**, No. **6**, 1125-1136 (1999).

5. *Radiation pressure induced instabilities in laser interferometric detectors of gravitational waves*, **A. Pai**, S. V. Dhurandhar, P. Hello, J-Y Vinet, Eur. Phys. J., D **8**, 333-346 (2000).

Archana Pai has done the research work under the guidance of S.V. Dhurandhar.

(ii) Cosmology with Supernovae and Gravitational Lensing

Tarun Deep Saini

This thesis contributes to the field of gravitational lensing (GL) and observational cosmology.

Gravitational Lensing as a cosmic telescope: We first investigate the usefulness of the magnifying power of gravitational lensing in the detection of distant supernovae and the damped Lyman-α clouds.

Supernovae (SNe) in distant galaxies that are gravitationally lensed by foreground galaxy clusters make excellent cosmological candles for measuring quantities like the density of the universe in its various components and the Hubble constant. We show that gravitational lensing can magnify distant supernovae by > 40 fold (which translates to about $3 - 4$ in magnitude), provided the SNe occur inside the giant arcs. This would enable even modest size telescopes to observe SNe beyond $z \simeq 1$. We show that in the case of the lens cluster Abell 2218, the detectability of high-redshift supernovae is significantly enhanced due to the lensing effects of the cluster. One shortcoming of this approach is that the number of detections per year is substantially smaller than what one has in the other observational schemes. But this problem can be rectified to some extent by observing several clusters at the same time. We also show that the signal-to-noise ratio of the SNe occurring inside the arcs could be an order of magnitude better than in the case when they are not lensed. This happens because the image of the host galaxy in which the SN event occurs is stretched in one direction. Since, the SN is a point object, its image is essentially the seeing disk of the telescope. The amount of light from the galaxy going into this seeing disk is diluted by the stretch factor and therefore the signal-to-noise ratio in this case is better than if the host galaxy was unlensed and unresolved. We recommend monitoring well-modelled clusters with several known arclets for the detection of cosmologically useful SNe around z = 1 and beyond.

We also investigate the possibility of detecting HI emission from gravitationally lensed HI clouds, which are similar to the damped Lyman-α clouds at high redshift by carrying out deep radio observations in the fields of known cluster lenses. Such observations will be possible with present radio telescopes only if the lens substantially magnifies the flux of the HI emission. While at present this holds the only possibility of detecting the HI emission from such clouds, it has the disadvantage of being restricted to clouds that lie very close to the caustics of the lens.

We show that observations at a detection threshold of 50 μJy at 320 MHz, which is possible with the Giant Metrewave Radio Telescope (GMRT), have greater than 20% probability of detecting an HI cloud in the field of a cluster, provided the clouds have HI masses in the range 5×10^8 M$_\odot \le M_{\rm HI} \le 2.5 \times 10^{10}$ M$_\odot$. We have also shown that the probability of detecting a cloud increases if they have larger HI masses, except in the cases where the number of HI clouds in the cluster field becomes very small. The probability of a detection at 610 MHz and 233 MHz is comparable to that at 320 MHz, though a definitive statement is difficult owing to uncertainties in the HI content at redshifts corresponding to these frequencies. Observations at a detection threshold of 2 μJy (possible in the future with the SKA) are expected to detect a few HI clouds in the field of every cluster provided the clouds have HI masses in the range 2×10^7 M$_\odot \le M_{\rm HI} \le 10^9$ M$_\odot$. Even if such observations do not result in the detection of HI clouds, they will be able to put useful constraints on the HI content of the clouds.

Lens Mapping Algorithm: We develop an algorithm for the reconstruction of the two-dimensional mass distribution of a gravitational lens from the observable distortion of background galaxies. We obtain the lens mapping directly from the measured reduced shear, from which a mass distribution is derived. This is unlike other methods, where the convergence ("kappa") is directly obtained.

This algorithm works the best for a sub-critical lens, where the reduced shear is given on a large field. If the data is available only in a finite field then the method has a *mass sheet degeneracy,* which is mathematically equivalent to the one present in the other methods as well. We also show that the algorithm works equally well for data which is noisy and where the sampling of reduced shear is discrete. The algorithm also quantifies the reconstructed noise in a very straight forward fashion. This algorithm does not depend on the shape of the field in which the data is given and in principle it works the same way for any given geometry of the data field. The computational time is also comparable to the other methods of reconstruction.

Reconstructing the Cosmic Potential: Observations of high redshift Type Ia supernovae indicate that they are fainter than they would be in a flat, matter dominated universe. This strongly suggest that the universe is accelerating at the present epoch, fuelled by a cosmological Λ-term, which is either a constant or weakly time varying. The observed relation between luminosity distance and redshift for extragalactic Type Ia supernovae (SNe) appears to favour an accelerating universe, where almost two thirds of the critical energy density may be in the form of a component with negative pressure. Although, this is consistent with $\Omega_m < 1$ and a cosmological constant $\Lambda > 0$ at the theoretical level, a constant Λ runs into serious difficulties, since the present value of Λ is $\sim 10^{123}$ times smaller than predicted by most particle physics models.

However, neither the present data nor the theoretical models require Λ to be exactly constant. To explore the possibility that the Λ-like term (e.g., quintessence) is time-dependent, we use a model for it that mimics the simplest variant of the inflationary scenario of the early universe. A variable Λ-term is described in terms of an effective scalar field with some self-interaction $V(\phi)$, which is minimally coupled to the gravitational field and has little or no coupling to other known physical fields.

By using a fitting function for the luminosity distance, we have reconstructed the potential that such a scalar field has to satisfy, if it is consistent with the geometry of the universe at low redshift. We find that a moderate evolution of the cosmological term is consistent with observations of high redshift supernovae. However, an unevolving Λ-term also agrees with the data.

Tarun Deep Saini has done the research work under the guidance of Somak Raychaudhury and Varun Sahni.

(iii) Stellar Dynamics in Galactic Nuclei

Niranjan Sambhus

This doctoral thesis addresses some aspects of the dynamics of dense clusters of stars in the nuclei of galaxies. A few billion years ago, highly energetic sources filled the universe with their light. Decades of study suggests that regions not much larger than the solar system were as luminous as an entire galaxy of stars. These compact, energetic regions are thought to reside in the centres of galaxies, and are hence commonly referred to as Active Galactic Nuclei (AGN). The most luminous of these are the Quasi–stellar radio sources (Quasars). Their high luminosity and small size suggest that a quasar engine derives its power from the release of gravitational energy, when matter accretes onto a compact, massive body such as a blackhole; this process is expected to be far more efficient than, say, nuclear burning. The estimated masses of these blackholes, as obtained from quasar luminosities, are in the range $10^6 - 10^9\,\mathrm{M}_\odot$. Once the supply of fuel ceases, the nuclear activity shuts down. It is believed that most galaxies went through at least one active phase during their lifetime. Quasars were 10,000 times more abundant a few billion years ago, than they are today. Estimates suggest that supermassive blackholes (SMBH) exist at the centres of many nearby, inactive galaxies. There is increasing support for this notion, from kinematical observations and dynamical modeling.

Galaxies of widely different morphological types appear to harbour SMBH in their nuclei. It was realised quite early that the presence of a central SMBH can have a direct effect on the global structure of a galaxy. Stars on orbits that had a close encounter with the SMBH would suffer significant deflections. In particular, the "box" orbits, that are thought to contribute significantly to the structure of a triaxial elliptical galaxy, would be rendered chaotic. This could result in a reduction of the triaxiality of a significant part of the elliptical galaxy. Hubble Space Telescope observations of the central regions of several disc, as well as elliptical galaxies reveal that the surface brightness profiles (of stellar light) rise in a cuspy fashion toward the centre. The distribution of cusp profiles seems to be bimodal, and there are several correlations between properties of the nuclear region, and the spheroidal component of a galaxy. Here, "spheroidal component" refers to the bulge of a disc galaxy, or the entire galaxy in the case of an elliptical galaxy. Furthermore, the mass of the SMBH is correlated with the velocity dispersions of stars in the spheroidal component. Our understanding of the origins of these correlations is incomplete, but it is clear that they must reflect the physical conditions governing galaxy formation, galaxy mergers, and the growth of the SMBH.

The cuspy brightness profiles imply that the nuclei of galaxies contain dense agglomerations of stars; it is not uncommon to estimate that there could be in excess of a million stars in a cubic parsec. Over the last three decades, there have been several theoretical investigations, seeking to understand the dynamical influence that a SMBH exerts on stars in its vicinity. A star that approaches too close to the SMBH is likely to be tidally disrupted, or swallowed whole; the SMBH could be thought of as a sink of stars. A slowly growing SMBH would offer an adiabatically changing gravitational potential for stellar orbits. During galaxy mergers, binary blackholes could violently scatter stars in the central regions. Simple models suggest that each of these processes leads to a different prediction for the slope of the central brightness profile. Unfortunately, for most nearby galaxies, even the spatial resolution of the Hubble Space Telescope is inadequate to resolve the structure of galactic nuclei. However, there are a few exceptions, of which two are noteworthy: the Milky Way Galaxy (our Galaxy), and the nearby spiral galaxy called Andromeda (or M31). The centre of our Galaxy has been modeled as a spherically symmetric distribution of stars, in orbit about a SMBH of mass $\sim 3 \times 10^6\,\mathrm{M}_\odot$; the model seems consistent with a cuspy density profile, and isotropic velocity dispersions. On the other hand, photometry of the nucleus of M31 shows two peaks, one centrally located and the other displaced by a few parsecs. The stars in this lopsided nucleus are thought to orbit a SMBH of mass $\sim 3.3 \times 10^7\,\mathrm{M}_\odot$. The two cases, for which we possess detailed photometric and kinematic observations, are quite unlike each other!

A major focus of this thesis concerns the development of a stellar dynamical model for the lopsided nucleus of the Andromeda galaxy. In the second part of the thesis, we undertake a general study of the orbital structure, within the sphere of influence of the SMBH. In all cases, we consider the SMBH to be a point mass, exerting an inverse square force on stars, which are also considered to be point masses. This approximation is valid when stellar orbits are well outside the Schwarzschild radius of the SMBH, as is the case in all observations to date. Below, we present a chapterwise summary of the contents of the thesis.

Chapter 1: Introduction to Stellar Dynamics in Galactic Nuclei

This chapter provides a brief introduction to the phenomenology of galactic nuclei. We present a well known argument, based on the energy output of quasars and galaxies, that nearly all galaxies in the nearby universe should possess a SMBH. The correlations between nuclear and global properties of galaxies are described. We discuss stategies that are commonly used to detect SMBH in galactic nuclei. These involve observing the motions of stars and/or gas. The motions of stars are governed only by gravitational forces, whereas, non-gravitational forces (due to, say, thermal pressure gradients, and magnetic fields) can act on gas. However, stellar systems are often collisionless, and may be described by quite complicated phase space distribution functions. Significant amount of dynamical modeling is often necessary, before an estimate of the mass of the SMBH can be extracted. The central brightness profiles of many galaxies are apparently cuspy. We discuss some theoretical ideas on different origins of density cusps, in the vicinity of a SMBH. These processes have been considered for only the simplest models of nuclear star clusters. A major block in the consideration of more complicated models is the lack of detailed photometric and kinematic observations of the nearest large galaxies. Two noteworthy exceptions, the Milky Way Galaxy and the Andromeda galaxy (M31), are briefly described. The latter has a remarkable nucleus, whose structure is the subject of the next chapter.

Chapter 2: Dynamical Modeling of the Stellar Nucleus of M31

Here we focus attention on a specific but special galaxy, *Andromeda.* This galaxy is thought to possess a central SMBH of mass $\simeq 3.3 \times 10^7\,\mathrm{M}_\odot$, about 10 times more massive than the SMBH in our Galaxy. Observations from ground, as well as, space-based telescopes show a lopsided nucleus with two peaks in the brightness distribution. We review the history of observations and ideas about the structure and origin of this dense stellar system. This subject attained maturity, with Tremaine's proposal of an eccentric disc of stars in orbit about the SMBH. The goal of this chapter is to present a stellar dynamical model of the eccentric disc. To this end, we use Hubble Space Telescope photometry, to derive the surface density distribution of a (model) razor–thin disc in the disc plane. We then calculate the stellar self-gravitational potential, and approximate it by a high–order polynomial function of the Cartesian coordinates in the disc plane. To this, we add the gravitational potential of the SMBH. We assume that the pattern of the stellar disc, and the SMBH are in steady rotation, at a rate that is to be determined. We integrate orbits of test particles in the rotating frame, for a range of pattern speeds. Of the many families of orbits, we select two – the prograde and retrograde loop orbits – to build a library of orbits. Each orbit belonging to the library consists of a set of test particle positions and velocities, the positions on the orbit chosen so as to make the mass density along the orbit approximately time independent (in the rotating frame). All the test particles on a given orbit may be assumed to have the same mass, which is the unknown quantity of interest. The masses are determined, by iteratively invoking consistency between model and photometry (in a central rectangle), using the Richardson-Lucy algorithm (which is based on Bayes' theorem). After convergent iteration, we compute two dimensional maps of the mean line of sight velocities and line of sight velocity dispersions. These are then compared with the available data, and the best–fit model is estimated. We note that the best-fit photometric model also provides the best-fit kinematic maps; this lent confidence to the models. Our numerical dynamical models are self-consistent, in the sense that the observed light distribution, used to compute the disc potential and the orbit families, is well reproduced by populating orbits with non-negative masses. A feature unique to our models is the presence of stars moving in counter rotating streams. The mass in these stars is equivalent to that of a globular cluster, and we speculate that an infall of such a cluster, on retrograde orbit might have excited lopsided instability in an originally axisymmetric stellar disc. This speculation is motivated by recent investigations of instabilities in counter rotating, nearly Keplerian stellar discs. We review the assumptions underlying our models, and discuss their limitations. We conclude with a mention of future investigations of dynamical stability using N–body simulations.

Chapter 3: Pattern Speed of Nuclear Disc of M31

We present a method of estimating the pattern speed of the lopsided nucleus of M31. Our procedure is a variant of the kinematic method, proposed originally by Tremaine and Weinberg (TW). As mentioned in the previous chapter, Tremaine interpreted the observed double peaked nucleus of M31, as an eccentric disc of stars orbiting a SMBH. The eccentric distortion, arising due to the alignment of the apoapsides of the stellar orbits, might be maintained by the self-gravity of the disc, with the entire configuration being a discrete, non-linear eigenmode, characterised by a pattern speed, which is equal to the common apsidal precession rate. The TW method of estimating the pattern speed requires measurements of the surface brightness and the radial velocity along a strip parallel to the line of nodes (defined as the line of intersection of the sky and disc planes). It uses the equation of continuity of the underlying tracer stellar population, and has been applied to barred galaxies. In the case of the nucleus of M31, the radial velocity measurements are available only along strips that do not coincide with the line of nodes (as estimated from the galactic disc of M31). Hence, we propose a modification of the original method, that exploits the basic feature of the eccentric disc model, to extract estimates of the pattern speed from Hubble Space Telescope spectroscopic data, taken along the line joining the two brightness peaks. Within limitations imposed by the data, we estimate that the eccentric disc pattern rotates in a prograde manner. We estimate Ω_p to be less than 35 $\mathrm{km\,s^{-1}\,pc^{-1}}$, exact value being dependent on the disc inclination (which is uncertain). Our results are supplemented tion functions. Significant amount of dynamical modeling is often necessary, before an estimate of the mass of the SMBH can be extracted. The central brightness profiles of many galaxies are apparently cuspy. We discuss some theoretical ideas on different origins of density cusps, in the vicinity of a SMBH. These processes have been considered for only the simplest models of nuclear star clusters. A major block in the consideration of more complicated models is the lack of detailed photometric and kinematic observations of the nearest large galaxies. Two noteworthy exceptions, the Milky Way Galaxy and the Andromeda galaxy (M31), are briefly described. The latter has a remarkable nucleus, whose structure is the subject of the next chapter.

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Chapter 4: Slow Dynamics in Centres of Galaxies

With this chapter we begin the second part of the thesis, which is a study of the stellar orbital structure in the vicinity of a SMBH. Dynamical phenomena in the central regions of galaxies are strongly influenced by the nuclear SMBH. Cuspy brightness profiles in the nuclear regions of galaxies containing SMBHs, indicate the presence of dense star clusters. Individual stars in such clusters move under the combined gravitational influence of the SMBH and the surrounding stars. On timescales smaller than the two-body relaxation period, the dynamics is in the collisionless limit, and the self-gravity of the cluster can be approximated by a mean field potential, whose strength relative to the black hole potential is proportional to the ratio of the mass of the cluster and the SMBH. We consider physical scales that are much larger than the Schwarzschild radius of the SMBH, thus treating the SMBH as a point mass that exerts a Newtonian $1/r^2$ force. We also restrict attention to scales on which the mass of the star cluster is less than the mass of the SMBH (the sphere of influence of the SMBH). Stars orbit the SMBH on nearly Keplerian ellipses that precess slowly due to the gravitational perturbation of the star cluster. The precessional times are larger than the orbital times by a factor of order the inverse of the mass ratio mentioned above. Thus, the orbits of stars can be imagined as ellipses that precess and deform on timescales much larger than the orbital period. Using this natural separation of timescales, we formulate a method to investigate the study the secular evolution of such orbits. Writing the (test particle) Hamiltonian in terms of the action-angle variables of the Kepler problem (the *Delaunay* variables), and using secular perturbation theory, we identify the fast angle in the system (which is the orbital phase in the Kepler ellipse). Averaging over this fast angle results in an averaged Hamiltonian that describes the slow dynamics of the precessional motion. This procedure leads to an extra integral of motion, which we identify with the Kepler energy. Thus, orbit averaging increases the regularity of motion near the SMBH. We show that such a slow dynamics description is accurate to the first order in the perturbation parameter (equal to the ratio of mass of the cluster and the SMBH). We present the consequences of orbit averaging, and conclude the chapter by mentioning the regimes of validity, and some limitations of the averaging procedure.

Chapter 5: Orbit Averaged Dynamics of Nearly Keplerian Discs

Here, we apply the technique of slow dynamics to study stellar orbits in razor-thin, two dimensional discs around a SMBH. Orbit averaging results in a new secular integral of motion, namely the Kepler energy (or equivalently, the semi-major axis of the Kepler ellipse), in addition to the total energy. Hence, slow dynamics in two dimensions is always integrable. Much of the information about the orbits can be ascertained analytically by inspecting the Hamiltonian. We systematically explore orbital structure in model harmonic disc potentials that allow for non-axisymmetric, lopsided, as well as rotating configurations. Using Hamiltonian dynamics, we identify different orbital families, such as loops and lenses, and provide analytic descriptions of fixed point orbits. Motivated by our dynamical modeling of the nucleus of M31, we present orbital structure in rotating, non-axisymmetric discs. Rotation distinguishes between prograde and retrograde moving orbits, and hence, is useful in classifying orbital families. Finally, as an application to data, we orbit-average the gravitational potential of the eccentric nuclear disc of M31, as obtained from the observed image, and discuss the resulting orbital structure.

Chapter 6: Orbit Averaged Dynamics of Nearly Keplerian Triaxial Clusters

In this chapter, we extend the techniques of slow dynamics to three dimensions. Observations indicate that elliptical galaxies, or spheroids in general, display a triaxial mass distribution. Though, this in not clear for the nuclear regions, lopsided and elongated nuclei are known to exist. We undertake a detailed study of the orbital stucture in highly triaxial (oblate as well as prolate), harmonic clusters. These are qualitatively similar to flat core profiles, and we expect the orbital structure to be generically similar in more realistic cores. Since averaging introduces an extra integral of motion, we show that dynamics in spherical as well as axisymmetric three dimensional clusters is completely integrable, and hence, the orbital structure is regular. We present a comparative, analytic description of the motion in oblate and prolate axisymmetric potentials. Detailed classification of various orbital families is obtained by using the technique of Poincaré surfaces-of-sections. The study is then generalised to the triaxial case, where, we find a high degree of regularity, due to extra integral of motion, the product of the mass of the BH and the size of the stellar orbit. Thus, chaos is found to be limited, even for highly triaxial clusters. Wherever possible, we support the numerical integrations by analytic estimates of the extra integral of motion (the third integral). Interpreting the results through secular perturbation theory, physical explainations are provided to describe these new integrals. We also present real space, major axis projections of stellar orbits, and consider the possibility of these orbits reinforcing the potential distribution. There are several results of this exploration of orbital structures in triaxial harmonic clusters. Of particular interest are those orbits that reinforce triaxiality, as well as oblateness/prolateness of the potential. We conclude this chapter by listing all such structures, and provide a list of relevant figures at the end.

Chapter 7: Summary of Thesis

The last chapter summarises the thesis work, and describes possible future explorations of stellar dynamics in galactic nuclei.

• List of Publications:

1. Dynamical Modeling of the Stellar Nucleus of M31, **Niranjan Sambhus**, S. Sridhar, A & A, 388, 766 (2002).
2. Stellar Orbits in Triaxial Clusters around Blackholes in Galactic Nuclei, **Niranjan Sambhus**, S. Sridhar, Ap J, 542, 143 (2000).
3. The Pattern Speed of the Nuclear Disk of M31, Using a Variant of the Tremaine-Weinberg Method, **Niranjan Sambhus**, S. Sridhar, Ap J L, 539, 17 (2000).

Niranjan Sambhus has done the research work under the guidance of S. Sridhar.

(iv) Field Theoretic Methods of Gravity

S. Shankaranarayanan

The fundamental interactions at present known to physics can be divided into three classes: strong, electro-weak and gravity. Quantum field theory has been successful as a theory describing the behaviour of the first two interactions up to energy scales of the order of 100 GeV. The electroweak interactions is successfully described by the Weinberg-Salam theory, while the strong interaction is described by quantum chromodynamics. Attempts in the direction of grand unified theory to incorporate strong interaction into a wider gauge theory have also led to some success. However, we still lack a quantum description of the gravitational interaction – quantum gravity.

The past century has seen a large number of theoretical attacks on the problem of quantum gravity. Even though these approaches have had some successes, none of them has given a complete theory that works at Planck energy scales. The difficulties on the way to quantum gravity are of different kinds. First of all, the detection of quantum gravitational effects is by itself extremely difficult due to the weakness of the gravitational interaction. In addition one encounters technical problems in quantizing gravity resulting from basic, and peculiar, properties of general relativity such as the non-linearity of the Einstein equations and the invariance of the theory under the group of diffeomorphisms. Further, the fact that gravity couples via a dimensional coupling constant $G_{\rm N}$ makes the theory intrinsically non-renormalisable. For sometime, it was believed that the supergravity theories might overcome the non-renormalisabilty of general relativity, but detailed calculations has led to the conclusion that they also suffer from the same problem. The modern viewpoint is that the non-renormalisability is a natural feature of a theory for which, the action is not fundamental but arises as an effective action in some energy limit.

In spite of the fact that we are yet to have a quantum theory of gravity, there exist compelling reasons to believe that quantum gravitational effects will be important only at energy scales of the order of Planck energy ($\sim 10^{19}\ GeV$). There exist a domain of 17 orders of magnitude between the Planck energy and the energy scale of the order of 100 GeV, where the gravitational field can be assumed to behave classically and the matter fields can be assumed to have a quantum nature. Though, there exist other contesting theories to describe the classical gravitational field, observations have pointed towards Einstein's general theory of relativity as a theory describing classical gravity. Thus, adopting general relativity as a theory describing classical gravity, one is led to the subject of quantum field theory in curved spacetimes which has been an area of active research during the past couple of decades.

Quantum field theory in curved spacetime is a semiclassical theory, in which the gravitational field is retained as a classical background, while the matter fields are quantised according to the conventionl quantum field theory. This theory describes the system propagating in a background curved spacetime based on the covariant version of the flat spacetime Lagrangian for the field. The formalism of quantum field theory in flat spacetime can be generalised to a curved spacetime in a straight forward manner. The quantisation of the field proceeds by defining a set of canonical commutation relations for the field operators. The evolution of the quantum field is governed by the behaviour of the normal modes of the field equation in the spacetime of interest.

The vacuum state of a quantum field develops a non-trivial structure in a classical gravitational background. As a result, three different types of phenomena occur in a classical background: (i) polarization of the vacuum, (ii) production of particles corresponding to the quantum field, and (iii) the concept of a particle turns out to be coordinate dependent. In particular, quantum field theory predicts particle production in the gravitational fields of blackhole and various cosmological models. In the case of a body collapsing to a blackhole, of mass M, quantum field theory predicts radiation of particles, at late times, in all modes of the quantum field, with characteristic thermal spectrum at a temperature equal to $(1/8\pi M)$.

One of the aims of this thesis, is to understand Hawking radiation in the Schwarzchild spacetime as a tunneling phenomena and show that Hawking radiation is covariant. The second aim of the thesis is to incorporate quantum gravitational effects in standard field theory and to quantify the low energy effects of quantum gravity. As we have mentioned, there is no viable complete theory of gravity as yet. The conceptual difficulties of integrating gravity into a quantum mechanical framework have proved formidable so far. With no experimental evidence to guide the construction of such a theory, only selfconsistent frame works can be made. As mentioned in an earlier paragraph, the quantum gravitational effects are significant only at energies of the order of the Planck length $L_P = (G\hbar/c^3)^{1/2}$. Such energies were available in the universe at times $t < t_{\rm Planck} = 5.4 \times 10^{-44} sec$ and may not be obtainable at the present epoch. It is possible that there are "low energy" ($E \ll M_{\rm Planck}$) physical effect that could be experimentally tested. As a step in the direction to quantify low energy effects of quantum gravity, we use three basic *field theoretic* methods: (i) Hypothesis of path-integral duality, (ii) Dispersive field theory models, and (ii) Large extra dimension models. A chapter wise summary of the thesis is given below.

In chapter (1), we introduce the basic terminology and the mathematical framework, that is used to study the evolution of quantum fields in curved spacetime. Some of the essential results that serve as a background for the chapters to follow are reviewed. The chapter begins by illustrating the crucial differences in quantisation of fields between flat and general curved spacetime. We also introduce effective action and Euclidean path-integral approach. Subsequently, Hawking radiation in a Schwarzschild spacetime is considered and three different well known methods of obtaining Hawking radiation are described. These different approaches illustrate the semi-classical approach usually taken when dealing with scalar fields in curved spacetime. Finally, we discuss the three *field theoretic* approaches – path-integral duality, dispersive field theory model, and large extra dimension models – which we use to quantify the low energy effects of quantum gravity.

Chapter (2) is concerned with the covariance of Hawking radiation in three different coordinate systems of the Schwarzschild spacetime, using the method of complex paths. The motivation for this approach is the method of complex paths used in standard non-relativistic semi-classical quantum mechanics to calculate transmission and reflection coefficients. We show that even though the two coordinate systems – Lemaitre and Painlevé– do not possess a coordinate singularity, the action integral develops poles at the horizon. The method of complex paths, gives a suitable complex contour in order to regularise the singularity. This prescription takes into account the following: (i) the one-way nature of the horizon surface, (ii) the multiple mapping of the coordinates. Using Novikov's R and T regions analysis of the spacetime manifold, the standard Hawking temperature is recovered.

In chapter (3), we use the modified propagator for quantum field based on a *principle of path integral duality* to investigate several results in quantum electrodynamics. This procedure modifies the Feynman propagator by the introduction of a fundamental length (Planck length) scale. We use this modified propagator for the Dirac particles to evaluate the first order radiative corrections in quantum electrodynamics. We find that the extra factor of the modified propagator acts like a regulator at the Planck scales thereby, removing the divergences that otherwise appear in the conventional radiative correction calculations of quantum electrodynamics. We also find that: (i) all the three renormalisation factors Z_1, Z_2, and Z_3 pick up finite corrections, and (ii) the modified propagator breaks the gauge invariance at a very small level of $\mathcal{O}(10^{-45})$. The implications of this result to the generation of primordial seed magnetic fields are discussed.

Chapter (4) is concerned with the effects of the trans-Planckian dispersion relation on the spectrum of primordial density perturbations during inflation. In contrast to the earlier analyses in the literature, we do not assume any specific form of the dispersion relation and allow the initial state of the field to be arbitrary. We obtain the spectrum of vacuum fluctuations of the quantum field by considering a scalar field satisfying the linear wave equation with higher spatial derivative terms propagating in the De Sitter spacetime. We show that the power spectrum *does not* depend on the dispersion relation strongly and that the form of the dispersion relation does not play a significant role in obtaining the corrections to the scale invariant spectrum. We also show that the signatures of the deviations from the flat scale-invariant spectrum from the cosmic microwave background radiation observations due to quantum gravitational effects *cannot* be distinguished from the standard inflationary scenario with an *arbitrary* initial state.

In chapter (5), we generalize the results of Randall and Sundrum to a wider class of four-dimensional spacetimes including the four-dimensional Schwarzschild background and De Sitter universe. We solve the equation for graviton propagation in a general four dimensional background and find an explicit solution for a zero mass bound state of the graviton. We find that this zero mass bound state is normalisable only if the cosmological constant is *strictly* zero, thereby, providing a dynamical reason for the vanishing of cosmological constant within the context of this model. We also show that the results of Randall and Sundrum can be generalized without any modification to the Schwarzschild background.

The details of the calculations of the work presented in the thesis are given in the *Appendices A – D*. Some of the appendices also provide some background material that may be useful in appreciating the issues involved in the thesis.

Finally, in chapter (6), we present our conclusions and the future outlook. This thesis is mainly based on the following publications:

1. T. Padmanabhan and **S. Shankaranarayanan**, *Vanishing of the cosmological constant in nonfactorizable geometry*, *Phys. Rev. D* **63**, 105021 (2001); [hep-th/0011159].

2. **S. Shankaranarayanan**, and T. Padmanabhan, *Hypothesis of path integral duality: Applications to QED*, *Int. Journ. Mod. Phys. D* **10**, 351 - 365 (2001); [gr-qc/0003058].

3. **S. Shankaranarayanan**, K. Srinivasan, and T. Padmanabhan, *Method of complex paths and general covariance of Hawking radiation*, *Mod. Phys. Lett. A* **16**, 571-578 (2001); [gr-qc/0007022].

4. **S. Shankaranarayanan**, T. Padmanabhan and K. Srinivasan, *Hawking radiation in different coordinate settings: Complex paths approach*, *Class. Quant. Grav.* **19**, 2671-2688 (2002); [gr-qc/0010042].

5. **S. Shankaranarayanan**, *Is there an imprint of Planck scale physics on inflationary cosmology?*, *Class. Quant. Grav.* **20**, 75-83 (2003); [gr-qc/0203060].

S. Shankaranarayanan has done the research work under the guidance of T. Padmanabhan.

(IV) PUBLICATIONS

by IUCAA Academic Staff

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

(a) Journals

Alam, Ujjaini, Varun Sahni, and Alexei Starobinsky (2003) Can dark energy be decaying?, JCAP, **0304** 002.

Alam, Ujjaini, Varun Sahni, Tarun Saini and Alexei Starobinsky (2003) Exploring the expanding universe and dark energy using the statefinder diagnostic, MNRAS, **344**, 1057.

Chand, H., R. Srianand, P. Petitjean, and B. Aracil (2004) Probing the cosmological variation of the fine-structure constant: Results based on VLT-UVES sample, A &A, **417**, 853.

Choudhury, T. Roy, and **T. Padmanabhan** (2004) Quasi normal modes in Schwarzschild-De Sitter spacetime: A simple derivation of the level spacing of the frequencies, Phys. Rev. **D69** 064033.

Anandan, Jeeva, **Naresh Dadhich,** and **Parampreet Singh** (2003) Action based approach to the dynamics of extended bodies in general relativity, Int. J. Mod. Phys. **D12,** 1651, (*Honorable Mention in the 2003 Gravity Research Foundation Essay Competition*).

Anandan, Jeeva, **Naresh Dadhich, and Parampreet Singh** (2003) Action principle formulation for motion of extended bodies in general relativity, Phys. Rev., **D68** 124014.

Visser, Matt, Sayan Kar, and **Naresh Dadhich** (2003) Traversable wormholes with arbitrarily small energy condition violations, Phys. Rev. Lett., **90** 201102.

Das, H. K., Abhay Kohok, and **S.N. Tandon**, (2004) An implementation of transfer-pupil in a spectrograph on optical telescopes, Bull, Astr. Soc. India, **32**, 121-131.

Abbott, B., **S. V. Dhurandhar**, et.al. (2004) First upper limits from LIGO on gravitational wave bursts, (The LIGO Science Collaboration), Class. Quant. Grav., **21**, S677.

Hajian, Amir, and **Tarun Souradeep** (2003) Measuring statistical isotropy of the CMB anisotropy, ApJL, **597**, L5-L8.

Bagla, J. S., **H. K. Jassal**, and **T. Padmanabhan** (2003) Cosmology with tachyon field as dark energy, Phys. Rev. D **D 67**, 063504.

Bhattacharyya, S. N. Bhatt, **R. Misra**, and C. L. Kaul (2003) A continuous injection plasma model for the X-ray/radio knots in kiloparsec-scale jets of active galactic nuclei, The effect of nonthermal protons on the high-energy spectra of blackhole binaries, ApJ, **595**, 317.

Sahayanathan, S., **R. Misra**, **A. K. Kembhavi** and C. L. Kaul (2003) A continuous injection plasma model for the X-ray/radio knots in kiloparsec-scale jets of active galactic nuclei, ApJ, **588**, L77.

Narlikar, **J. V.**, David Lloyd, N. C. Wickramasinghe, Melanie J. Harris, Michael P. Turner, S. Al-Mufti, Max K. Wallis, M. Wainwright, P. Rajaratnam, S. Shivaji, G.S.N. Reddy, S. Ramadurai, and F. Hoyle (2003) A balloon experiment to detect microorganisms in the outer space, Ap. Sp. Sc., **285**, 555.

Narlikar J. V. (2003) Action at a distance and cosmology: A historical perspective, Annual Review of A&A, **41**, 169.

Nayak, K. Rajesh, A. Pai, **S. V. Dhurandhar,** and J-Y. Vinet (2003) Improving the sensitivity of LISA, Class. Quant. Grav. **20**, 1217.

Nayak, Rajesh., **S. V. Dhurandhar**, A. Pai, and J-Y. Vinet (2003) Optimising the directional sensitivity of LISA, Phys. Rev., **68**, 122001.

Padmanabhan T. (2003) Cosmological constant - the weight of the vacuum, Physics Reports, **380**, 235-320.

Padmanabhan, T., and **T. Roy Choudhury** (2003) A theoretician's analysis of the supernova data and the limitations in determining the nature of dark energy, MNRAS, **344** 823-834.

Padmanabhan, T. (2003) Gravity from spacetime thermodynamics, Ap. Sp. Sc., **285**, 407.

Saini, Tarun Deep, **T. Padmanabhan**, and Sarah Bridle (2003) Response of distance measures to the equation of state, MNRAS, **343**, 533.

Padmanabhan, T., and T. P. Singh (2003) A note on the thermodynamics of gravitational radiation, Class. Quant. Grav., **20**, 4419.

Padmanabhan, T. (2003) Why gravity has no choice: Bulk spacetime dynamics is dictated by information entanglement across horizons, Gen. Rel. Grav., **35**, 2097-2103 [*Fifth Prize: Gravity Research Foundation Essay Contest 2003*].

Padmanabhan, T. (2003) Topological interpretation of the horizon temperature, Mod. Phys. Rev. Letts., **18**, 2903.

Padmanabhan, T. (2004) Quasi normal modes: A simple derivation of the level spacing of the frequencies, Class Quan. Grav., **21** L1.

Ray, Subharthi, Manuel Malheiro, Jos'e P. S. Lemos, and Vilson T. Zanchin (2004) Charged polytropic compact stars, Brazilian Journal of Physics, **34** 310-314.

Shtanov, Yuri, and **Varun Sahni** (2003) Bouncing braneworlds, Phys. Lett., B **557** 1-6.

Sahni, Varun, and Yuri Shtanov (2003) Braneworld models of dark energy, JCAP, **11** 014.

Sahni,Varun, Tarun Deep Saini, A. A. Starobinsky, and **Ujjaini Alam** (2003) Statefinder a new geometrical diagnostic of dark energy, JETP Lett., **77** 201-206.

Sami M., and **T. Padmanabhan** (2003) A Viable cosmology with a scalar field coupled to the trace of the stress-tensor, Phys. Rev., **D 67** 083509.

Sami, M., **N. Dadhich**, and Tetsuya Shiromizu (2003) Steep inflation followed by Born-Infeld reheating, Phys.Lett., **B 568** 118-126.

Sengupta, A., S. V. Dhurandhar, and A. Lazzarini (2003) Faster implementation of the hierarchical search algorithm for detection of gravitational waves from inspiraling compact binaries, Phys. Rev., **D 67**, 082004.

Sheth, Jatush V., Varun Sahni, Sergei F. Shandarin, and B. S. Sathyaprakash (2003) Measuring geometry and topology of large scale structure using SURFGEN: Methodology and preliminary results, MNRAS, **343** 22.

Singh, Parampreet, *M. Sami*, and **N. Dadhich** (2003) Cosmological dynamics of phantom field, Phys. Rev., **D 68** 023522.

Lambiase, Aetano, and **Parampreet Singh** (2003) Matter-antimatter asymmetry generated by loop quantum gravity, Phys. Lett., **B 565**, 27.

Mukherjee, Pia, Kim Coble, Mark Dragovan, Ken Ganga, John Kovac, Bharat Ratra and **Tarun Souradeep** (2003) Galactic foreground constraints from the Python V cosmic microwave background anisotropy data, ApJ, **592**, 692-698.

Mukherjee, Pia, **Tarun Souradeep**, Bharat Ratra, Naoshi Sugiyama and Krzysztof M. Gorski (2003) OVRO CMB anisotropy measurement constraints on flat-lambda and open CDM cosmogonies, Mod. Phys. Lett. A, **18**, 1145-1155.

Mukherjee, Pia, Ken Ganga, Bharat Ratra, Graca Rocha, **Tarun Souradeep**, Naoshi Sugiyama, and Krzyszt of M. Gorski (2003) CMB anisotropy constraints on flat- Λ and open CDM cosmogonies from DMR, UCSB South Pole, Python, ARGO, MAX, White Dish, OVRO and SuZIE data, Int.J.Mod. Phys., **A18**, 4933.

Ledoux, C., P. Petitjean, and **R. Srianand** (2003) The VLT-UVES survey of molecular hydrogen in high redshift damped Lyman α systems, MNRAS, **346**, 209.

Gupta, N., **R. Srianand**, P. Petitjean, and C. Ledoux (2003) Chemical enrichment in the outflowing material from z_em = 4.92 QSO SDSS J160501.21-011220.0, A & A, **406**, 65.

Ellison, S., R. Iebta, M. Pettini, G. Lewis, P. Petitjean, B. Aracil, and **R. Srianand** (2004) The size and kinematic structure of high and low ionization absorption systems towards the lensed quasar APM 08279+5255, A & A, **414**, 79.

Srianand, R., H. Chand, P. Petitjean, and B. Aracil (2004) Limits on the time variation of the electromagnetic fine-structure constant in the low energy limit from absorption lines in the spectra of distant quasars, Phys. Rev. Letts., **92**, 121302.

Subramanian, K. (2003) Hyperdiffusion in non-linear, large and small-scale turbulent dynamos, Phys. Rev. Letts., **90**, 245003-1 - 245003-4.

Subramanian, K., T. R. Seshadri, and J. D. Barrow (2003) Small-scale CMB polarization anisotropies due to tangled primordial magnetic fields, MNRAS, **344**, L31-L35.

Subramanian, P., S. Ananthakrishnan, P. Janardhan, M. R. Kundu, S. M. White, and V. I. Garaimov (2003) Giant Meterwave Radio Telescope observations of an M2.8 flare: insights into the initiation of a flare-coronal mass ejection event, Solar Physics, **218**, 247.

Yadav, R. K. S., and Ram Sagar (2004) UBVRI CCD photometric study of the open clusters Basel 4 and NGC 7067, MNRAS, **349**, 1481-1492.

(b) Proceedings

Philip, Ninan Sajeeth, Wadadekar, Yogesh, **Ajit Kembhavi,** and Babu Joseph, K. (2003) A new tool for automated classification of astronomical images, statistical challenges in astronomy. Third Statistical Challenges in Modern Astronomy (SCMA III) Conference, Eric D. Feigelson, and G. Jogesh Babu (eds.). New York: Springer, ISBN 0-387-95546-1, 469.

Ambika, G., M.Takeuti, and **A. K. Kembhavi,** (2003) Chaotic pulsations in irregular variables in mass-losing pulsating stars and their circumstellar matter, eds. Y.

Nakada, M. Honmam, and M. Seki. Kluwer Academic Publishers, ISBN 1-4020-1162-8, 95.

Ambika, G , M.Takeuti, and **A.K. Kembhavi,** (2003) Low dimensional chaos in a short period pulsating star, Proceedings of the first National Conference in Nonlinear Systems and Dynamics NCNSD, 65.

Alladi, Vagiswari, Christina, Birdie, **Nirupama, Bawdekar, Ajit, Kembhavi,** and Geetha Sheshadri, (2003) Virtual Observatory - India : Information support for remote users library and information services in astronomy IV (LISA IV), Emerging and preserving: Providing astronomical information in the digital age. Proceedings of a conference held at Charles University, Prague, Czech Republic. Edited by Brenda G. Corbin, Elizabeth P. Bryson, and Marek Wolf. Washington.

Patil, Madhav K., S.K. Pandey, D.K. Sahu, , **A. K. Kembhavi,** (2003) Multi-wavelength study of dust properties in early-type galaxies. Astrophysics of Dust, Estes Park, Colorado, Edited by Adolf N. Witt.

Kembhavi, Ajit (2003) The International Virtual Observatory Alliance, Large Telescope and Virtual Observatory: Visions for the Future, 25th meeting of the IAU, Joint Discussion 8, Sydney, Australia.

Jassal H. K. (2004) Proceedings of the IX international Symposium on Particles, Strings and Cosmology Tachyon field in Cosmology (PASCOS'03), T.I.F.R., Mumbai, Pramana 62, 757 .

J.V. Narlikar (2003) Working with Fred on action at a distance, Astrophysics and Space Science, **285**, 389.

Pathak, Sandeep Kumar and Neela Deshpande, (2004) Role of FORSA in astronomy and astrophysics community in India. ICDL Conference Proceeding-2004. The Energy and Resources Institute (TERI), New Delhi on the theme of Knowledge Creation, Preservation, Access and Management Pp. 312-319.

Pathak, Sandeep Kumar (2004) Astronomy and Astrophysics: A recent development in information services. SIS Conference Proceeding Indian Institute of Technology, Madras and Society for Information Science, New Delhi on the theme "Digital Information Exchange: Pathways to Build Global Information Society". Pp. 43-47.

Pathak, Sandeep Kumar (2003) Importance of online resources in special libraries: An overview of IUCAA Library. NACLIN Conference Jadavpur University, Kolkata on the theme Managing Knowledge Resources in the Digital Era Pp. 116-126.

Yuri Shtanov and **Varun Sahni** (2002) Braneworld models of dark energy. Proceedings of the 18th IAP Astrophysics Colloquium on the nature of dark energy: Observational and theoretical results on the accelerating universe", Institute d'Astrophysique de Paris, France, Frontier Group, Editors, P. Brax, J. Martin, and J-P. Uzan, page 243.

Varun Sahni (2002) Exploring dark energy using the statefinder, Proceedings of the 18th IAP Astrophysics Colloquium on the nature of dark energy: Observational and theoretical results on the accelerating Universe", Institute d'Astrophysique de Paris, France, Frontier Group, Editors, P. Brax, J. Martin, and J-P. Uzan, page 147.

Souradeep Tarun (2004) Statistical isotropy of the Cosmic Microwave Background, Proceedings of the IX International Conference on Particles, Strings and Cosmology (PASCOS 2003) - Part II Pramana, 62, 793.

Srianand R (2003) Molecular hydrogen as a probe of physical conditions in high red-shift damped L α absorbers, Shaw, G., Ferland, G., AAS,20311303.

(c) Books Authored

Narlikar, J.V. (2003) Virus, Scholastic India Pvt Ltd., Gurgaon.

Narlikar, J.V. (2003) The scientific edge, Penguin Books India (P) Ltd., New Delhi.

T. Padmanabhan

The following popular science book published by Vigyan Prasar, New Delhi, has now been translated into Hindi and Marathi: *The Story of Physics [a comic strip with figures contributed by Keith Francis and Avinash Deshpande, based on the author's ideas*], Vigyan Prasar, New Delhi, 2002.

(d) Book Review

Dadhich, N.K. (2003) Quantum leaps in the march of physics : A review of the book entitled "On the shoulders of giants" by Stephen Hawking, The Hindu, September 2, p.16.

(e) Resource Summaries in Khagol

S.V. Dhurandhar (2003) The Quest for Gravitational Waves (Issue No. 56 October).

A.K. Kembhavi (2004) Virtual Observatories (Issue No. 58 April).

J.V. Narlikar (2003) A Search for Microorganism at High Altitudes (Issue No. 55 July).

Publications by Visiting Associates and Long-term Visitors

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

(a) Journals

Badruddin, and Y. P. Singh (2003) Forbush decreases in cosmic radiation: Effects of solar flares associated with type-IV radio bursts and with different field orientations at flare sites, Ind. J. Phys., **77B**, 497.

Banerjee, A., S. Chakraborty, and U. Debnath (2003) Naked singularities in higher dimensional gravitational collapse, Int. J. Mod. Phys., **D12**, 1255.

Banerjee, A., and S. Chatterjee (2003) A generalized vacuole model in higher dimensions, Int. J. Mod. Phys., **D12**, 1035.

Chatterjee, S., and **A. Banerjee** (2003) C-field cosmology in higher dimensions, Gen. Rel. Grav., **36**, 303.

Banerjee, Narayan, Diego Pavon, and Somasri Sen (2003) Periodic distribution of galaxies in general scalar tensor theories, Gen. Rel. Grav., **35**, 851.

Biswas, S., P. Misra, and I. Chouwdhury (2003) the CWKB method of particle production in periodic potential, Gen. Rel. Grav., **35(1),** 1.

Biswas, S., and I.. Chouwdhury, (2004) Fermion particle production in periodic potential, Gen. Rel. Grav., **36 (4),** 825.

Biswas, S., I. Chouwdhury and P. Misra (2003) Does operator ordering need wormhole dominance in the wavefunction of the universe?, Gen. Rel. Grav. **35 (4),** 545.

Biswas, S., S. Kamilya, and B. Modak (2004) Induced gravity theory from Noether symmetry, Gen. Rel. Grav., **36 (4),** 661.

Debnath, U., **S. Chakraborty,** and J. D. Barrow (2004) Quasispherical gravitational collapse in any dimension, Gen. Rel. Grav., **36**, 231.

Chakraborty, S., N. C. Chakraborty, and U. Debnath (2003) The cosmology in a perfect or causal viscous fluid with varying speed of light, Physica Scripta, **68**, 399.

Chakraborty, S., N. Chakraborty, and U. Debnath (2003) Quintessence problem and Brans-Dicke theory, Mod. Phys. Lett., A. **18**,1549.

Debnath, U., and **S. Chakraborty** (2003) The study of gravitational collapse model in higher dimensional space-time, Mod. Phys. Lett., A. **18**,1265.

Chakraborty, S. (2003) Asymptotic behaviour of homogeneous cosmological models on the brane, Mod. Phys. Lett., A. **18**, 1197.

Chakraborty, S., and U. Debnath (2003) Does cosmic no-hair conjecture in brane scenarios follow from general relativity?, Class. Quant. Grav., **20**, 2693.

Chakraborty, S. and A. Ghosh (2003) Brans-Dicke cosmology- A generalization in four and five dimensional spacetime models, Physica Scripta, **68**, 98.

Chakraborty, S., N. C. Chakraborty, and U. Debnath (2003) A quintessence problem in self-interacting Brans-Dicke theory, Int. J. Mod. Phy., A. **18**, 3315.

Chakraborty, S., and S. Chakrabarti (2003) Inflation in Bianchi models and cosmic no-hair theorem in Einstein-Cartan theory, Int. J. Mod. Phys., **D12**, 833 .

Chandra, Suresh (2003) Radiative excitation of CS molecules in atmosphere of a star, Ind. J. Phys., **86 B**, 617.

Chandra, Suresh, and S.A. Shinde (2004) Einstein A-coefficients for rotational transitions in the ring-chain isomer of C_5H_2, Pramana, J-Phys., **62**, 967.

Chatterjee, Tanuka, B. Basu and A. K. Chattopadhyay (2003) Random fragmentation of molecular cloud and initial mass function – A Monte Carlo simulation study, Systems Analysis, Modelling and Simulation, **43**(12), 1697.

Chaudhuri, S. and D. Bhattacharyya (2004) Magnetovac solutions of the static Einstein-Maxwell equations, Ind. J. Phys., **78B**, 93 .

E. Saikia, **M.K. Das, H.P. Singh**, M.P. Srivastava, and K.L. Chan (2003), On characterization of turbulent stellar convection, MNRAS, **343**, 1002.

Das, M. K., P. Narang, M. Yuasa, **L. M. Saha**, Reza Tavakol, and Yasuo Tanaka (2003) On the motion of a mass element moving in the gravitational field of a radiating binary system, Bull. Fac. edu., Ibaraki Univ., (Nat. Sci), 52, 27.

Saha, L. M., M. K. Das, and Yasuo Tanaka (2003) Effect of Radiation from primaries on nonlinear stability of motion around L4, Bull. Fac. Edu., Ibaraki Univ., (Nat. Sci), 52, 21.

Dwivedi, B. N., A. Mohan and V. S. Pandey (2003) MHD seismology of the solar corona, Current Science, **84**, 1388.

Wilhelm, K., **B. N. Dwivedi,** and L. Teriaca (2004) On the widths of the Mg X lines near 60 nm in the corona, A & A, **415**, 1133.

Ghosh, S. G., and N. N. Saste (2004) Gravitational collapse of string fluids, Int. J Mod. Phys., **D 13**, 263.

Ghosh, S. G., and D. W. Deshkar (2003) Gravitational collapse of a radiating star in higher dimensions. Grav. and Cos., **9,** 325.

Ghosh, S. G., and D. W. Deshkar (2003) Gravitational collapse of perfect fluid in self-similar higher dimensional spacetimes, Int. J Mod. Phys., D **12,** 913.

Beesham, A., and **S. G. Ghosh** (2003) Naked singularities in charged Vaidya-de Sitter spacetime, Int. J Mod. Phys., D **12,** 801.

Ghosh, S. G., and **A. Banerjee** (2003) Non-marginally bound self-similar higher dimensional inhomogeneous dust collapse, Int. J Mod. Phys., D **12,** 630.

Ghosh, S. G., and ***Naresh Dadhich*** (2003) Gravitational collapse of null strange quark fluid and cosmic censorship, Gen. Rel. Grav., **35,** 359.

Goyal, Ashok, Poonam Mehta, and Sukanta Dutta, (2003) Heavy quark production via lepto-quarks at a neutrino factory, Phys. Rev., **D 67**, 053006.

Goyal, Ashok, M.Dahiya, and **Deepak Chandra** (2003) Symmetry structure and phase transitions, Pramana, **60**, 887.

Hallan, P. P., and Neelam Rana, (2003) Effect of perturbations in the Coriolis and centrifugal forces on the locations and stability of the equilibrium points in Robe's circular problem with density parameter having arbitrary value, Indian Journal of Pure and Applied Mathematics, **34(7)** 1045.

Indulekha, K., G. V. Vijayagovindan, and S. Ramadurai (2003) Dissipative collapse of a spherical cluster of gas clouds, Bull. Astron. Soc. India, **31**, 447.

Jain, Deepak, Abha Dev, and Jailson S. Alcaniz (2003) The angular size redshift relation in power-law and cosmologies, Classical and Quantum Gravity, **20**, 4163.

Jain, Deepak, Abha Dev, N. Panchapakesan, S. Mahajan and V. B. Bhatia (2003) Gravitational lensing constraint on the cosmic equation of state, Int. J. Mod. Phys. **D12**, 953.

Narayan, C. A., and **C. J. Jog,** (2003) The puzzle about the radial cut-off in galactic disks, A. & A. Letters, **407**, L59.

Parthasarathi, and **R. S. Kaushal** (2003) Quantum mechanics of complex sextic potential in one dimension, Physica Scripta, **68**, 115.

Parthasarathi, D. Parashar and **R. S. Kaushal** (2004) Complex phase space formulation of supersymmetric quantum mechanics, J. of Phys. **A:** Math & Gen, **37**, 781.

Ghosh, S., S. Sarkar, **Manoranjan Khan**, K. Avinash, and M. R. Gupta (2003) Dust acoustic shock wave at high dust density, Phys. Plasmas, **10(4)** 977.

Gupta, M. R., S. Sarkar, **Manoranjan Khan**, and S. Ghosh (2003) Dust acoustic shock wave generation due to dust charge variation in a dust plasma Pramana, **61(6)** 1197.

Khan, Manoranjan, and Abhijit Bhattacharyya (2003) Design, fabrication and characterization of a capacitively coupled R. F. discharge plasma system Ind. J. Phys., **77B**, 323.

Bhar, R., T. Guha, V. Ganesan, A. Sen, T. Modak Dhar, K. Bhattacharyya, A. K. Ghoshal, **Manoranjan Khan**, and R. L. Brahmachary (2003) AFM study of biological samples: Atomic resolution imaging of seeds, EMSI Bulletin, **4(1)** 15.

Kumar, N., and B. Roberts (2003) Ion-neutral collisions effects on MHD surface waves, Sol. Phys., **214**, 241.

Arun, K. G., Minu Joy, and **V. C. Kuriakose** (2003) Renormalised energy-momentum tensor of ë π^4 theory in curved spacetime Pramana, J. Phys., **60**, 1161.

Kuriakose, P. I. and **V. C. Kuriakose** (2003) Extremal Reissner-Nordstrom black hole in thermal equilibrium: the back reaction - change of entropy, Gen. Rel. Grav. **35**, 863.

Joy, Minu, and **V. C. Kuriakose** (2003) Field theoretic approach to structure formation in an anisotropic medium, Phys. Rev., **D 67**, 084029.

Shaju, P. D., and **V. C. Kuriakose** (2003) Josephson junction diode, Supercond. Sci. Technol., **16**, L25.

Vinoj, M. N., A. U. Seema, and **V. C. Kuriakose** (2003) Optimum dispersion profile and pedestal free soliton pulse compression in dispersion-decreasing fiber J. Nonlinear Optical Physics and Materials, **12**, 293.

Joy, Minu, and **V. C. Kuriakose** (2003) Phase transitions for a phi^6 model in curved spacetime, Mod. Phys. Lett., **A18**, 937.

Vinoj, M. N. and **V. C. Kuriakose** (2003) Generation of pedestal free ultrashort soliton pulses and optimum dispersion profile in real dispersion-decreasing fiber, Journal of Optics A: Pure and Applied Optics, **6**, 63.

Ganapathy, R., **V. C. Kuriakose**, and K. Porsezian (2003) Soliton propagation in an erbium-doped fiber with and without continuous wave background, Phys. Rev., E. **68**, 066615.

Malik, G. P., and **Usha Malik** (2003) Gluon super-propagator as the origin of QCD potential, Acta Physica Polonica, **B34**, 4073.

Malik, G. P., and **Usha Malik** (2003) High Tc super-conductivity via super-propagators, Physica, **B336**, 349.

Mittal, A. K., S. Dwivedi , and A. C. Pandey (2003) A study of the forced Lorenz model of relevance to monsoon predictability by Indian Journal of Radio and Space Physics, **32**, 209, National Institute of Science Communication and Information Resources, New Delhi.

Mehta, M. **A. K. Mittal** and S. Dwivedi, (2003) The double-cusp map for the forced Lorenz system, International Journal of Bifurcation and Chaos **13**, 3029.

Govinder, M., K. S. Govinder, S. D. Maharaj, R. Sharma, **S. Mukherjee,** and T. K. Dey (2003) Radiating spherical collapse with heat flow, Int. J. of Mod. Phys., **12**, 667.

Somnath Bharadwaj and **Sanjay K. Pandey** (2003) HI fluctuations at large redshifts: II- the signal expected for the GMRT, J. Astrophys. Astr., **24**, 23.

Huitu, K., J. Laamanen, and **P. N. Pandita** (2003)Upper bounds on the mass of the lightest neutralino, Phys. Rev., **D67**, 115009.

Patil, K. D. (2003) The final fate of spherical inhomogenous dust collapse in higher dimensional spacetime, Ind. J. Phys. **77B,** 345.

Paul, B. C. (2003) Chaotic inflationary universe on brane Phys. Rev, **D63** 127501.

Paul, S. N., S. Chattopadhyaya, B. Bera, and S. K. Bhattacharyya (2003) Contribution of electron-inertia and drift motion on soliton and double-layers in a negative ion plasma, Pramana, J. Phys., **60,** 1217.

Bhattacharya, S. K., **S. N. Paul,** and B. Chakraborty (2003) Effects of nonthermal electrons and negative ions on ion acoustic solitary wave in a bounded plasma, Ind. J. Phys.**77B**, 327.

Chakraborty, B., **S. N. Paul,** and S. K. Bhattacharyya (2003) Collective effects of bound electrons, free electrons and ions in a plasma, Ind. J. of Phys. **77B**, 335.

Ghosh, B., S. R. Majumdar, S. K. Bhattacharyya, and **S. N. Paul** (2003) Modulational instability of high frequency surface wave on a plasma half-space, FIZIKA, **A12**,127.

Majumdar, S. R., A. Roychowdhury, and **S. N. Paul** (2004) Higher-order nonlinearity effect and double layer in a multi-component plasma consisting of cold positive ions and negative ions and two-temperature isothermal electrons, Physica Scripta, **69**, 355.

Philip, Ninan Sajeeth and K. Babu Joseph (2003) A neural network tool for analyzing trends in rainfall, Computers and Geosciences, Elsevier, **29**, 2, 215.

Abraham, Ajith, **Ninan Sajeeth Philip** and P. Saratchandran (2003) Modeling chaotic behaviour of stock indices using intelligent Paradigms, International Journal of Neural, Parallel & Scientific Computations, **11**, issues 1 & 2, 143.

Pradhan, A., G. P. Singh, and S. Kotambkar, (2003) Higher dimensional cosmological models in Lyra geometry revisited, Int. J. Mod. Phys., D **12** (5) 853.

Pradhan, A., and H. R. Pandey (2003) Plane symmetric inhomogeneous cosmological models with variable Λ, Int. J. Mod. Phys., D **12** (5) 941.

Pradhan, A., and O. P. Pandey (2003) Bianchi type - I anisotropic magnetized cosmological models with varying Λ, Int. J. Mod. Phys. D **12** (6) 1299.

Pradhan, A., I. Aotemshi, and **G. P. Singh** (2003) Plane symmetric domain wall in Lyra geometry, Ap. Sp. Sc., **288,** 315.

Pradhan, A., and Abha Rai, (2003) Tilted Bianchi type I cosmological models filled with disordered radiation in general relativity revisited, Ap. Sp. Sci., **286**, 347.

Pradhan, A., S. K. Srivastav, and **Kanti R. Jotania** (2004) Some inhomogeneous magnetized viscous fluid cosmological models with varying Λ , Czech. J. Phys., **54**, 255.

Pradhan, A., and A. K. Vishwakarma (2004) A new class of LRS Bianchi typy-I cosmological models in Lyra geometry, J. Geom. Phys., **49**, 332.

Pradhan, A., Lallan Yadav, and A. K. Yadav (2004) Viscous fluid cosmological models in LRS Bianchi type V universe with varying Λ, Czech. J. Phys., **54**, 487.

Rahaman, F., S. Das, K. Maity, and M. Kalam (2003) Global texture in Lyra geometry, Nuovo Cimento, **118B,** 17.

Rahaman, F. (2003) Non-static cosmic string in Lyra geometry Nuovo Cimento, **118B,** 99.

Rahaman, F., T. Ray, O. Faruk, R. Mukherjee, K. Maity, and S. Mal (2003) Gravitational field of a global monopole in Kalb-Ramond background, Int. J. Mod. Phys., **D 12,** 1837.

Rahaman, F., P. Ghosh, S. Shekhar, and S. Mal (2003) Higher dimensional thick domain wall in Lyra geometry, Ap. and Sc. **286,** 373.

Rahaman, F., G. Bag, B. C. Bhui, and S. Das (2003) A study on Bianchi-IX cosmological model in Lyra geometry, Fizika **B 12,** 112.

Rahaman, F., S. Mandal, and B. C. Bhui (2003) Vacuumless global monopole in Einstein – Cartan theory, Fizika, **B 12,124.**

Rahaman, F., S. Das, N. Begum, and M. Hossain (2003) Higher dimensional homogeneous cosmology in Lyra geometry, Pramana, J. of Phys., **61,** 153.

Rahaman, F., S. Sur, and K. Gayen (2004) A study of global monopole in Kalb-Ramond background, Physica Scripta, **69,**78.

Ray, S., and S.Bhadra, (2004) Energy density in general relativity: A possible role for the cosmological constant, Phys. Lett., A **322**, 150.

Ray, S., and B.Das, (2004) Tolman-Bayin type static charged fluid spheres in general relativity, MNRAS, **349**, 1331.

Sahijpal, S., K. K. Marhas, and J. N. Goswami (2003) Determination of rare earth and refractory trace element abundances in early solar system objects by ion microprobe, Earth & Planetary Sciences, Indian Acad. Sci. **112**, 485.

Sami, M., Pravabati Chingangbam, and Tabish Qureshi (2004) Cosmological aspects of rolling tachyon, Pramana, **62** 765.

Singh, G. P., and S. Kotambkar (2003) Higher dimensional dissipative cosmology with varying G and Ë, Grav. and Cos. **9**, 3 (35) 206.

Usmani, A. A., and S. Murtaza (2003) Variational calculations of ${}^{5}_{\Lambda}$He hypernucleus, Phys. Rev., **C68**, 024001.

(b) Proceedings

Ambika, G., and **K. P. Harikrishnan** (2003) Multisignal amplification by stochastic resonance, Proc. of the first National Conference in Nonlinear Systems and Dynamics NCNSD, 261.

Ambika, G. and Kamala Menon (2003) Characterisation of lattice fractal sets in a coupled map lattice Proc. of the first National Conference in Nonlinear Systems and Dynamics NCNSD, 145.

Singh, Y. P., and **Badruddin** (2003) Large scale heliospheric magnetic field and drift effects during Forbush decreases, Proc. 28th International Cosmic Ray Conference (Universal Academy Press, Inc., Japan) 3605.

Badruddin, and A. G. Ananth (2003) Variation of cosmic-ray intensity with angular distance from earth to the current sheet, Proc. 28th International Cosmic Ray Conference (Universal Academy Press, Inc., Japan) 3909.

Badruddin, and Y. P. Singh (2003) CME types, their interplanetary manifestations (ICMEs) and effects on cosmic ray intensity, Proc. 28th International Cosmic Ray Conference (Universal Academy Press, Inc., Japan) 3631.

Badruddin, and Y. P. Singh (2003) Statistical procedure to test significance in the analysis of cosmic ray data by superposed epoch method-I, Proc. 28th International Cosmic Ray Conference (Universal Academy Press, Inc., Japan) 3639.

Badruddin, and Y. P. Singh (2003) Statistical procedure to test significance in the analysis of cosmic ray data by superposed epoch method-II, Proc. 28th International Cosmic Ray Conference (Universal Academy Press, Inc., Japan) 3643.

Singh, Y. P., and **Badruddin** (2003) Statistical procedure to test significance in the analysis of cosmic ray data by superposed epoch method-III: Comparison of test results from two techniques, Proc. 28th International Cosmic Ray Conference (Universal Academy Press, Inc., Japan) 3647.

Bhardwaj Rashmi (2004) Melnikov's function in rotation motion of a satellite under a third body torque in an elliptical orbit Proc. of Joint 9th National Conference of the Vigyan Parishad of India on Applied and Industrial Mathematics and 5th Annual Conference of Indian Society of Information theory and Applications, Netaji Subhas Institute of Technology, New Delhi, Ed. V.K. Kapoor, Mathematics and Information Theory: Recent Topics and Applications, Amanya Publishers, **218**.

Bhardwaj Rashmi (2004) Chaos and its Controlling. Proc.of Joint 9th National Conference of the Vigyan Parishad of India on Applied and Industrial Mathematics and 5th Annual Conference of Indian Society of Information theory and Applications Netaji Subhas Institute of Technology, New Delhi, Ed. V.K. Kapoor, Mathematics and Information Theory: Recent Topics and Applications, Amanya Publishers, **134.**

Saha, L. M., M. K. Das and Yasuo Tanaka (2003) Mass losing pulsating stars and their circumstellar matter, Eds. Y. Nakada, et.al., pp121.

Das, M. K., Manabu Yuasa, **L. M. Saha**, and Reza Tavakol (2003) Mass losing pulsating stars and their circumstellar Matter, Eds. Y. Nakada, et. al., 123.

Dwivedi, B. N. (2003) Dynamic Sun, edited by Cambridge University Press.

Dwivedi, B. N. (2003) The Solar Corona, Lectures on solar physics in Lecture Notes in Physics, eds. H.M. Antia, A. Bhatnagar and P. Ulmschneider, **619**, 281.

Goyal, Ashok, (2003) Hybrid stars, Int. Symposium on Particles, Strings and Cosmology (PASCOS-03) held in Mumbai, hep-ph/0303180.

Goyal, Ashok, (2003) Magnetised neutron stars: An overview, Int. workshop on strong magnetic fields and neutron stars, ICIMAF Havana, hep-ph/0306116.

Jog, C. J. (2003) Rotation curves of galaxies: Evidence for dark matter, Physics Education, 19(4), 281.

Kaushal, R. S. (2004) Abstraction and structural analogies in mathematical sciences in Proc. Int. Conf. On History of the Mathematical Sciences, ed. I. Grattan-Guinness, and B. S. Yadav, Hindustan Book Agency, 33.

Kumar, N., and H. Sikka, (2003) Effect of ion-parallel viscosity on the propagation of Alfven surface waves, Proc. XXVI International Conference on Phenomena in Ionized Gases (ICPIG), (eds. J. Meichsner, et al.) Greifswald, Germany, **4,** 155.

Mittal, A. K. and **D. Lohiya** (2003) Fractal dust model of the universe based on Mandelbrot's conditional cosmological principle and general theory of relativity, Fractals, World Scientific, Singapore, **11**, 145.

Verma, R.C. (2003)Reanalysis of baryon magnetic moments using effective mass and screened charge of quarks, XV DAE Symposium on High Energy Physics, University of Jammu, **1**, T1.

(c) Books

Chakraborty, D. K. and M. Das (2003) Projected properties of a family of trixial mass models; High order residuals, A&A, 402, 531,

Chandra, Suresh (2003) Computer Applications in Physics, Narosa Publishing House Pvt. Ltd., New Delhi & Alpha Science International Ltd., Pangbourne, England.

Chandra, Suresh (2003) A Text Book of Mathematical Physics, Narosa Publishing House Pvt. Ltd., New Delhi & Alpha Science International Ltd., Pangbourne, England.

Sahijpal, S. (2003) Genesis of the solar system: The role of β-unstable nuclei. Radioactive ion beams and physics of nuclei away from the line of stability Eds. I.M. Govil and R.K. Puri 292, Elite Publisher, New Delhi.

Singh, Kangujam Yugindro (2003) Variational Calculus; North East Readers, Imphal.

Singh, Kangujam Yugindro (2003) A Foundation of Special Functions for Mathematical Physics and Engineering; North East Readers, Imphal.

(d) Supervision of theses

Kaushal, R.S., (2003) A study of dynamical invariants for classical systems in two and three dimensions, University of Delhi, Ph.D. thesis of Shalini Gupta.

Narain, U., (2003) On electro-dynamic heating of solar corona, Chaudhury Charan Singh University, Meerut, Ph.D. thesis of Sushil Kumar.

MEAN IMPACT FACTOR OF PUBLICATIONS

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

As an experiment, this was done for the Members of IUCAA and Visiting Associates. Knowing the Impact Factor of various journals from the Institute for Scientific Information (ISI) for the period 2002 - 03, and assuming the same for the period 2003-04, the average Impact Factors for the journal publications of the Members of IUCAA and Visiting Associates were calculated. [As an indicator, here are the mean impact factor of a few journals: ApJ 6.19; CQG 2.12; MNRAS 4.67; PRD 4.36; PRL 7.32]. It is found that the Mean Impact Factor of an IUCAA member was 6.26 during 2002-03 and 4.08 during 2003-04. The corresponding figure for the Associates were 2.14 and 1.41. The mean impact factor of a paper by IUCAA member was 3.22 and 3.54 during the last two years and the corresponding figures for the Associates were 1.77 and 1.44.

(V) PEDAGOGICAL ACTIVITIES

(a) IUCAA-NCRA Graduate School

S.V. Dhurandhar
Methods of Mathematical Physics I

A.K. Kembhavi
Introduction to Astronomy and Astrophysics II.

R. Misra
Electrodynamics and Radiative processes II

T. Padmanabhan
Methods of Mathematical Physics II

A.N. Ramaprakash
Astronomical Techniques I

Tarun Souradeep
Extragalactic Astronomy I

R. Srianand
Interstellar Medium

K. Subramanian
Galaxies : Structure, Dynamics and Evolution

(b) University of Pune

(i) M.Sc. (Physics)

Sanjeev Dhurandhar
Mathematical Methods of Physics I (21 lectures)

Ranjan Gupta
Astronomy and Astrophysics I (Theory) and Laboratory for I and II courses

H. K. Jassal
General Relativity (Part of Astronomy and Astrophysics II)

J.V. Narlikar
Cosmology (Part of Astronomy and Astrophysics II)

Varun Sahni
Astronomy and Astrophysics II (Remaining part)

(ii) M.Sc. (Space Science)

Joydeep Bagchi
Radio Astronomy (Part course, 18 theory lectures + 8 laboratory sessions)

Ranjan Gupta
Advanced Observational Astronomy (Part course, 15 lectures)

A. N. Ramaprakash
High Energy Astrophysics (part course)

(c) Supervision of Projects

Joydeep Bagchi
Surajit Paul and Suklima Guha-Niyogi, (University of Pune)
Setting up a 1.4 GHz (21-cm) hydrogenline radio telescope and spectrometer for IUCAA radiophysics laboratory.

T. Vaishnavi (Madura College, Madurai Kamaraj University) and Binata Panda (Utkal University)
Searching for a supercluster of galaxies at $z = 0.3$ in the Sloan Digital Sky Survey data.

Vaibhav N. Prakash (University of Pune) (M.Sc. project)
Relativistic effects in CGCG049-033: a giant, one-sided jet-like radio source.

T. Vaishnavi (Madura College, Madurai Kamaraj University) (M.Sc. project)
Study of ZWCl 2341.1+0000: a supercluster scale forming structure of galaxies.

Ranjan Gupta
Daniel Sarat, and Abhra Ray MSc, (Pune University)
Observation of variable stars.

A.K. Kembhavi
C.D. Ravikumar
Fundamental and photometirc planes of galaxies (Cochin University of Science and Technology, Kochi).

Ashwini Doshi, VJTI, Mumbai
Shivani Patil, VJTI, Mumbai
Mithila Patwardhan, VJTI, Mumbai
Preeti Viswanathan, VJTI, Mumbai

Data mining for astronomical catalogues.

R. Misra
Anish Mokashi (IIT, Mumbai)
Bending of large scale AGN jets.

G. Krishanan, V. Lakshmi (M.G. University, Kottayam)
Gamma-ray bursts.

J.V. Narlikar
Deepak Agarwal, Rasika Kulkarni, Monica Joshi, Dhwani Shah, Milind Bhangre, Vaishali Rugge, Sonali Katkar, Ajinkya Sirsat, Snehal Patil, Uma Bapat, Swapnali Sathe, Om Bhutkar, Aditya Ghormade, Apoorva Nivargi, Pooja

Deshpande, Paroma Wagle, Mukta Paranjape, Tushar Kadam, Tejas Gaikwad, Pinak Kodgule, Amit Phadke, Abhishek Dange, Aniruddha Dhamne, and Shantanu Kulkarni.
School Students Summer Programme
Foucault Pendulum.

A.N. Ramaprakash

T. Fernandez (Mahatma Gandhi University, Kottayam)
Restoration of Meade 16 inch telescope.

H. Kuppuswamy, R. Devale, S. Vahule (College of Engineering, Pune).
Remote control system for Meade 16 inch telescope.

A. D. Jayashankar, V. Sharma (GSM Engineering College, Pune)
Astronomical observation planning tool.

M. Lemhe, N. Krishnamurthy, V. Joshi (Vishwakarma Institute of Technology, Pune).
Imaging polarimtery software upgrade.

S. Subramanian (Department of Physics, Pune University)
Brown Dwarfs : Detection techniques and classification.

Varun Sahni

Arman Shafieloo, IUCAA graduate school project
An examination of quintessence models for an accelerating universe.

Tarun Souradeep

Jeremie Lasue
Reconstructing the inflaton potential of the early universe.

Yasin Memari (IASBS, Iran)
Recovering effective mass of the inflaton field fluctuations.

Amir Reza Aghamousa (M.Sc. project, University of Pune)
Rapid Computation of CMB correlations.

R. Srianand
Bhargavaram, (Fergusson College, Pune).
Spectroscopic observations of sun with iucaa telescope.

Binesh Vedu (Wadia College, Pune).
Measuring the baryonic content of the universe using DH.

K. Subramanian
Chandrima Mitra (University of Pune)
Blackhole formation scenarios.

Prasad Subramanian

Deepali Salunke (Wadia College, Pune)
Radio signatures of streamer blowout coronal mass ejections from the sun.

B. S. Pujari (University of Pune)
Annular momentum transport in quasi-Keplerian accretion disks.

Thesis examiner for
A Study on the Influence of the solar activity on the climatic conditions of Tamilnadu.
R. Samuel Selvaraj, Bharathidasan University, Tiruchirapalli.

(d) Supervision of Theses

S. V. Dhurandhar (Guide)
Archana Pai,
Data Analysis Strategies for Detection of Gravitational Waves with a Network of Detectors.

T. Padmanabhan (Guide)
S. Shankaranarayanan,
Field Theoretic Methods of Gravity.

Somak Raychaudhury and Varun Sahni (Guides)
Tarun Deep Saini
Cosmology with Supernovae and Gravitational Lensing.

S. Sridhar (Guide)
Niranjan Sambhus
Stellar Dynamics in Galactic Nuclei.

(VI) IUCAA COLLOQUIA, SEMINARS, ETC.

(a) Colloquia

Anatoly Klypin: *Probing Galaxy Masses with SDSS*, April 1.

N. Mukunda: *Pancharatnam,Bargmann and Berry Phases-A Historical Account*, August 8.

Sushanta Dattagupta: *Dissipation*, August 9.

Nitin Nitsure: *Mathematics and Sets*, October 23.

Albert Lazzarini: *LIGO : Status, Results of the First Science Run, and Future Plans*, December 8.

Samuel Lee Finn: *Gravitational Wave Observations of Inspiraling Binary Systems in the Local Universe*, January 29.

(b) Seminars

Sujan Sengupta: *Polarization from Brown Dwarfs: Theoretical Prediction and Observational Confirmation*, April 8.

Sanjeev Dhurandhar: *Algebraic Structures Underlying LISA Data Analysis*, April 24.

Axel Brandenburg: *Structured Outflow from a Dynamo Active Accretion Disc*, May 8.

Shivaji Sondhi: *Quantum Liquids and Topological Order*, May 15.

Vinod Krishan: *Structure Formation Through Turbulence*, May 29.

Sushan Konar: *Magnetic Fields in Compact Objects*, June 19.

Chandrima Mitra: *Evidences of Blackholes, June 23.*

Tulsi Dass: *Non-Commutative Geometry and Quantum Mechanics*, June 24.

T.K.Ramkumar: *The Earth's Ionospheric Dynamo under the Influences of Atmospheric Periodic Oscillations*, June 26.

Mohemmad Sami: *Brane-World*, June 27.

Sverre Aarseth: *N-Body Simulations*, July 4.

Sukanta Panda: *Signatures of Low Scale Gravity in Ultra High Energy Cosmic Rays*, July 17.

J. Maharana: *Duality and integrability of two dimensional string effective action*, July 28.

Kandaswamy Subramanian: *Primordial magnetic fields and CMB anisotropies*, August 7.

Ali Reza Rafiee: *Super massive blackholes and sersic's parameter*, August 11.

Abhishek Rawat: *Quasar host galaxies*, August 11.

S. Sridhar: *Turbulent mixing and pulsar scintillation*, August 11.

Amir Ahmad: *Helium-Rich subdwarf B stars-where do they come from?*, August 14.

Arman Shafieloo: *An examination of quintessence models for an accelerating universe*, August 27.

Gora Mohanty: *The violent universe : Gamma-ray astrophysics in the new millennium*, August 28.

Ani Thakar: *SDSS data release 1 and virtual observatory development*, September 8.

Ranjeev Misra: *The effect of non-thermal protons on the high energy spectra of blackhole binaries*, September 11.

S.N. Tandon: *Detectors for ultra violet imaging telescope in astrosat*, October 16.

Atul Deep: *Supernova 1a : Their role in cosmography*, October 28.

S. Rai Choudhury: *Flavour changing decays of the B-meson*, November 8.

E.P.J. van den Heuvel: *Gamma ray burst research, status and prospects*, November 8.

U.C. Joshi: *Deep survey of inner galaxy from SAAO and spectroscopic observations from HCT*, November 8.

Pushpa Khare: *Some aspects of QSO absorption lines studies*, November 8.

Rajaram Nityananda: *Overview of GTAC observations at the GMRT*, November 8.

T.P. Prabhu: *Indian Astronomical Observatory*, Hanle, November 8.

Subhabrata Majumdar: Prospects for future Sunyaev-*Zel'dovich surveys*, December 1.

Neal Katz: *Galaxy formation : some problems and some answers*, December 4.

T. Padmanabhan: *New perspective on classical and semiclassical gravity*, December 10 & 11.

Arun Thampan: *Differentially rotating magnetised neutron stars, December* 18.

Parampreet Singh: Some cosmological applications of loop quantum gravity, January 12.

Horton Newsom: I*mpact craters on the Earth and Mars, January 16.*

Ramesh Narayan: Type I X-ray bursts, January 16.

Manoj Kaplinghat: *The supernova relic neutrino background*, January 19.

Roy Kerr: *Discovering the Kerr solution*, January 20.

Jasjeet Singh Bagla: *Cluster computing at HRI*, January 22.

A. Klypin: *Dark matter in galaxies*, January 23.

Russell Cannon: *The Universe at Z = 0.5 : A new spectroscopic survey of luminous red galaxies*, February, 16.

Chenzhou Cui: Astronomy research environments in China and Chinese virtual observatory, March 9.

Dipankar Banerjee: Dynamical fine structures in the solar atmosphere as seen by SOHO, March 18.

Prasad Subramanian: Solar noise storm continua : Power estimates for electron acceleration, March 25.

Neem Seminars

Kim Griest: *Toward a possible solution to the cosmic coincidence problem*, February 10.

Tabish Qureshi: *Quantum cryptography*, March 23.

(c) IDG Talks

Parampreet Singh: *Some Cosmological Applications of Loop Quantum Gravity*, October 10.

Tarun Souradeep: *A Cosmic Infra-red Cut Off?*, November 7.

Pavan Chakraborty: *Knowing Wild 2, the Target of STARDUST*, December 5.

A.N. Ramaprakash: *Model of Image Degradation due to Wind Buffeting on an Extremely Large Telescope*, March 5.

Kandaswamy Subramanian: *The Formation of Supermassive Blackholes : A Review of Current Ideas*, March 19.

Joydeep Bagchi: A *star in a 15.2-year orbit around the supermassive blackhole at the centre of the Milk Way*, April 4.

(d) MAHFIL (Mid-Day Astronomy Hour for Interaction and Lunch)

G.P. Singh)
Farookh Rahaman) April 16
T.K. Ramkumar)

(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 for Gravitation and Cosmology (ICGC), CUSAT, Kochi, January.

Joydeep Bagchi

Clusters of Galaxies for VSP and Refresher Course in Astronomy and Astrophysics, IUCAA, Pune, May-June.

Radio Telescopes for VSP and Refresher Course in Astronomy and Astrophysics, IUCAA, Pune, May-June.

Naresh Dadhich

Universalization as a Guiding Principle in Physics (a PEP talk) delivered at IUCAA, Pune, August 13.

How Do We Do Science?, Mar Thoma College, Tiruvalla, Kerala, September 15.

Light Shows the Way to the Einstenian World, Physics Department, Pune University, September 26.

Brane World Gravity : A Classical View, Workshop on Brane Worlds and Quantum Cosmology IUCAA, Pune, January 14.

Indian Science Experiment Workshop on *Challenges In Higher Education Today* at Pune University, January 31.

Universalization as a Physical Guiding Principle, FTAG-IV meeting North Bengal University, Darjeeling, February 29.

Gravity and its Universality, A.K.Raychaudhuri Gravity Seminar , St. Xavier's College, Calcutta, March 8.

The Einstein World , Conference on Einstein's Vision : Its Impact on Science and Society, Hyderabad, March 14.

Light Bends the Universe, APOGEE 2004 Festival, the Birla Institute of Technology and Science, Pilani, March 25.

S.V. Dhurandhar

Data Analysis Techniques for Gravitational Wave Astronomy, Joint Discussion session on 'Non-electromagnetic Windows' at the XXVth General Assembly of the International Astronomical Union, Sydney, Australia. July 15.

Data Analysis Techniques for Gravitational Wave Observations, International Conference for Gravitation and Cosmology, CUSAT, Kochi, January 9.

Algebraic Structures Underlying LISA Data Analysis, IUCAA, Pune. April 24.

Algebraic Methods in LISA Data Analysis, Observatoire de la Cote d'Azur, Nice, France, May 12.

Algebraic Structures Underlying LISA Data Analysis, Penn State, US, September 22.

Optimising the Directional Sensitivity of LISA, University of Rome, La Sapienza, Italy, October 10.

Optimising the Directional Sensitivity of LISA , INFN, Frascati, Italy, October 13.

Optimising the Directional Sensitivity of LISA and Inspiral Binary Search with Chebyschev Interpolation, Osaka City University, Osaka, Japan, March 5.

Coherent Search for Inspiraling Binaries, the National Astronomical Observatory Japan (NAOJ), Tokyo, Japan, March 11.

Ranjan Gupta

IUCAA Telescope and Other Research Activities, Physical Research Laboratory - Thaltej Campus, Ahmedabad, September 8.

Industrial Dust Modeling, Winter school on *Mathematical Modeling of Engineering Systems,* D.Y. Patil Institute of Engineering and Technology, Pimpri, Pune December 19.

Application of ANN to Very Large Data Base of Astronomical Spectra and Other Applications, Centre for Space Physics, Kolkata, February 7.

Modeling of Interstellar Dust and Extinction in Galaxies and Comets, Centre for Space Physics Kolkata, February 7.

Astrophysics with Small Telescopes, Centre for Space Physics, Kolkata, February 8.

Light Scattering Study with Models and Observations, S.N. Bose National Centre for Basic Sciences, Kolkata, February 12.

H.K. Jassal

Brick Walls for Brane World Blackholes, International Conference on Gravitation and Cosmology (ICGC), Cochin University of Science and Technology, Kochy, January 5.

Stabilisation of Branes and Cosmological Implications, International Conference on Gravitation and Cosmology (ICGC), Cochin University of Science and Technology, Kochy, January 6.

A.K. Kembhavi

The International Virtual Observatory Alliance, Invited Talk at Joint Discussion on Large Telescopes and Virtual Observatories at XXV General Assembly of the IAU, Sydney, Australia, July 18.

Blackholes, University of Pune, May 20-21 (2 lectures).

Image Processing Astronomy and other applications, Sinhagad College of Engineering, Pune, June 13.

Blackholes, Maharashtra Institute of Technology (MIT), Pune, August 30.

The E-Journals Programme, Signing of MOUs for E-Journal Subscription Project, INSA Auditorium, Delhi, September 6.

Virtual Observatory - India - Programmes and Prospects, Invited Talk at IVOA Small Projects Meeting 2003, Beijing, China, November 27.

Binary Stars, St. Thomas College, Kozhencherri, September 15.

The Physics of Binary Stars, Cochin University of Science and Technology (IRC), Cochin, September 18.

Blackholes - From Newton to Einstein, Shri Shiv Chhatrapati College, Junnar, January 3.

Binary Stars - From One to the Other, Saturday Lecture Demonstration Programme for School Students, IUCAA, January 10 (English).

Binary Stars - From One to the Other, Saturday Lecture Demonstration Programme for School Students, IUCAA, January 10 (Marathi).

Stellar Luminosity Function, Workshop on *Galaxies Structure and Dynamics*, Osmania University, Hyderabad, January 19.

Stellar Initial Mass Function, Workshop on Galaxies Structure and Dynamics, Osmania University, Hyderabad, January 19.

Interstellar Medium, Workshop on Galaxies Structure and Dynamics, Osmania University, Hyderabad, January 20.

Binary Stars, Workshop on Introductory Astrophysics, Utkal University, Bhubaneswar, January 28 (3 lectures).

Virtual Observatory, Workshop on front-end controls and data retrieval / archival, IUCAA, Pune January 30.

Astronomical Image detection with CCD, Kalyani Government Engineering College, Kalyani, February 4.

Image Processing, Kalyani Government Engineering College, Kalyani, February 4.

Virtual Observatories, Kalyani Government Engineering College, Kalyani, February 5.

The UGC-INFONET and E-Journals E-Subscription Scheme, University Grants Commission Meeting, Delhi, February 24.

Supermassive Blackholes in our Galaxy and Beyond, Einstein's Vision: Its impact on Science and Society, University of Hyderabad, March 15.

Virtual Observatory, Visitors Programme, University of Delhi, March 19.

R. Misra

Observational Evidence for blackholes, Utkal University, Bhubaneswar, Orissa, January 27.

J.V. Narlikar

Society and the Scientist : Need for a Two-way Interaction, in the session on Science and Social Responsibility at the second International Conference of Science Communicators, Mumbai, June 20.

T. Padmanabhan

The Darker Side of the Universe, Colloquium, TIFR, Mumbai, May 7.

The Weight of the Vacuum, BARC, Mumbai, June 20.

Mathematics for Physical Sciences, Department of Mathematics, CUSAT, Cochin, October 10.

Universe - It's Structure and Evolution, Maharaja's College, Cochin, October 17.

History of the Universe, Department of Physics, CUSAT, Cochin, October 21.

Acceleration and Accelerated Frames, IIT, Madras, October 23.

Understanding our Universe, Department of Physics, University of Calicut, Calicut, December 4.

A New Perspective on Gravity, IUCAA, January 15.

Overview: CMBR, Dark Energy and Inflation, Coorg, Meeting of the Indian Academy of Science, February 22-26.

Varun Sahni

Dark Matter and Dark Energy, Second Aegian School on the Early Universe, Ermoupoli, Syros Island, Greece, September 21-30.

Colloquium on Dark Energy, University of Kansas, Lawrence, Kansas, USA, October 10.

The Enigma of Dark Energy, Canadian Institute for Theoretical Astrophysics, Toronto, Canada, October 12.

M. Sami

Problems of Relic Gravity Waves in Models of Quintessential Inflation, ICGC-2004, January 5 to 10.

Unification of Inflation with Quintessence and Relic Gravity Waves, Workshop on Brane Worlds and Quantum Cosmology, IUCAA January.

Joining the Two Ends, FTAG, Sikkim, February.

Anand Sengupta

Progress of Extended Hierarchical Search DSO Development, LIGO Lab, Caltech, USA, March 30.

Time-decimated Hierarchical Search Pipeline Implementation on LIGO Data Analysis System (LDAS), CUSAT, Kochi, January 9.

J. Sheth

Sheets or Filaments? - A Quantitative Investigation of the Morphology of Cosmic Web using SURFGEN, Max Planck Institute for Astrophysics, Garching, Germany, January 9.

SURFGEN: A New Method to Quantify the Supercluster-Void Network, Raman Memorial Conference, 2004, Physics Department, Pune University, February 26.

P. Singh

Some Cosmological Applications of Loop Quantum Gravity, Imperial College, London, UK, January 28.

Some Cosmological Applications of Loop Quantum Gravity, Queen Mary, University of London, London, UK, January 26.

Some Cosmological Applications of Loop Quantum Gravity, CITA, Toronto, Canada, January22.

Some Cosmological Applications of Loop Quantum Gravity, Perimeter Institute, Waterloo, Canada, January 20.

Cosmological Dynamics of Phantom Field, International Conference on Gravitation and Cosmology, Kochi, January 5.

Matter-Antimatter Asymmetry Generated by Loop Quantum Gravity, International Conference on Gravitation and Cosmology, Kochi, January 8.

Action Based Approach to the Dynamics of Extended Bodies in General Relativity, Kochi, January.

The Role of Ricci Scalar on Brane in Warped Braneworlds: Some Observational Consequences, Institute of Cosmology and Gravitation, Portsmouth, UK, August 14.

Matter-Antimatter Asymmetry Generated by Loop Quantum Gravity, The Tenth Marcel Grossmann Meeting on General Relativity, Rio de Janeiro, Brazil, July 25.

FRW Brane-Worlds, The Tenth Marcel Grossmann Meeting on General Relativity, Rio de Janeiro, Brazil July 24.

Formulation for Motion of Extended Bodies in General Relativity, The Tenth Marcel Grossmann Meeting on General Relativity, Rio de Janeiro, Brazil July 24.

Souradeep Tarun

Cosmic Microwave Background Anisotropy Observations, Workshop on Cosmic Microwave background, Coorg, Indian Academy of Science, Bangalore, February 23.

Cosmology with CMB Anisotropy Measurements, on *Cosmology Astrophysics and Braneworld, Indian Association for Cultivation of Science*, Kolkata, February 7.

Dawn of Precision Cosmology, Astronomy in the new Millennium, National Academy of Science, Ahmedabad, October 10.

Statistical Isotropy of CMB Anisotropy, Physics Colloquium, Indian Institute of Science, Bangalore, April 23.

WMAP: Topping off a Decade of CMB Anisotropy Measurements, Neighbourhood Astronomy Meeting, Indian Institute of Astrophysics, Bangalore, April 24.

Correlation Patterns in CMB Anisotropy, Raman Research Institute, Bangalore, April 28.

First Decade of CMB Anisotropy Measurements, Acceptance talk for the N.S. Satyamurthy award, Indian Physics Association, Homi Bhaba Center, Mumbai, April 9.

VSP, Refresher course, IUCAA, Pune, *Cosmic Microwave Background Anisotropy*, May 30.

R. Srianand

Molecular Hydrogen in High Redshift Damped Lyman Systems, Invited review in IAU, Sydney, 2003.

Thermal History of the IGM and Cosmological Reionization, 2 lectures in IUCAA, 2003.

Physics of IGM, 2 lectures, Indian Academy of Science, Coorg, February 2004.

K. Subramanian

Primordial Magnetic Fields and the CMB, University of Newcastle, UK, September 2003.

Supermassive Blackholes, Advanced School on the Physics of Galaxy Formation, Harish-Chandra Research Institute, Allahabad, December 2003.

Conference Summary, Advanced School on the Physics of Galaxy Formation, Harish-Chandra Research Institute, Allahabad, December 2003.

CMBR Anisotropies: Theory (2 Talks), Indian Academy of Sciences, Coorg, February 2004.

P. Subramanian

Transient Phenomena in the Solar Corona, Ravenshaw College, Cuttack, February 3.

Transient Phenomena in the Solar Corona, Introductory School on Astronomy and Astrophysics, Utkal University, Bhubaneswar, January 27 – 29.

The Solar Corona, Fergusson College, Pune, January 12 and 14.

The Solar Corona, one-day workshop at Shiv Chhatrapati College, Junnar, January 3.

(b) Lecture Courses

Naresh Dadhich

Relativity and Gravitation, Physics Department, Fergusson College, Pune, January 19, 21, 23 and February 6 (4 lectures)

Ranjan Gupta

Observational Astronomy, Introductory School on Astronomy and Astrophysics, The American College, Madurai, September 22-26.

Observational Astronomy Fergusson College, Pune, December 1-22 (5 lectures).

Observational Astronomy, Kalyani Government Engineering College, Kalyani, February 4-5 (3 lectures).

A.K.Kembhavi

Stellar Structure and Evolution, VSP/VSRP/Refresher Course Lectures, IUCAA, May 26-29 (4 lectures).

Certificate Course in Astronomy and Astrophysics, Fergusson College, Pune, December 24- February 27 (7 lectures).

J.V. Narlikar

Elements of Modern Cosmology, Vacation Students Programme, IUCAA, Pune, May 28-29 and June 2 (3 lectures)

T. Padmanabhan

Cosmic Microwave Background Radiation, TIFR, Mumbai, May 5-8 (4 lectures).

Order of Magnitude Astrophysics, VSP/VSRP/Refresher Course, IUCAA, Pune, May 19-21.

Statistical Mechanics, Summer School in Physics for College Students, Kodaikanal, June 2 -7 (10 lectures).

Classical Mechanics, Refresher Course for College and University teachers, Cochin University, October 15 –22 (10 lectures).

Introduction to Standard Model of Cosmology, XIX Main SERC School for students, Jaipur University, February 9 – 25 (14 lectures).

A.N. Ramaprakash

Optical Astronomy Techniques : VSP/VSRP, IUCAA, Pune, June 9-11 (2 lectures).
Gamma-ray Bursts : Refresher Course on A&A, IUCAA, Pune, June 10.

Observatories, Observations and Detectors : Fergusson College, Pune, December 3-15, (5 lectures).

2D Astronomy : Imaging and Spectroscopy : Workshop on Galaxies : Structure and Dynamics, January 21-22, Osmania University, Hyderabad (2 lectures).

M. Sami

Introductory Cosmology, Introductory School in Astronomy and Astrophysics, Madurai, September 21-September 26.

Souradeep Tarun

Introductory Cosmology, Fergusson College, January-February 2004 (5 lectures).

Introductory Cosmology, Introductory Astronomy School, Kalyani, West Bengal, February 7-8 (3 lectures).

R. Srianand

Observational Cosmology, Refresher Course for college teachers, IUCAA, Pune, May 2003 (3 lectures).

Galaxies and QSOs, Introductory workshop on Astronomy and Astrophysics, The American College Madurai, September 22-26 (3 lectures).

QSOs and Absorption Lines, Introductory workshop on Astronomy and Astrophysics, Utkal University, Bhubaneswar, January 26, (1 lecture).

Galaxy Evolution, Fergusson College, Pune, (2004) (3 lectures).

Probing the galaxy formation using QSOs and absorption lines :Advanced school on Galaxy Formation, HRI, Allahabad, (2003) (5 lectures).

K. Subramanian

Radiative Processes, Refresher Course in Astronomy and Astrophysics for College and University Teachers and VSP, IUCAA, Pune, May 2003 (3 lectures).

Magnetic fields in Galaxies and Dynamo Theory, Advanced School on the Physics of Galaxy Formation, Harish-Chandra Research Institute, Allahabad, December 2003 (4 lectures).

(VIII) SCIENTIFIC MEETINGS AND OTHER EVENTS

The President Visits IUCAA

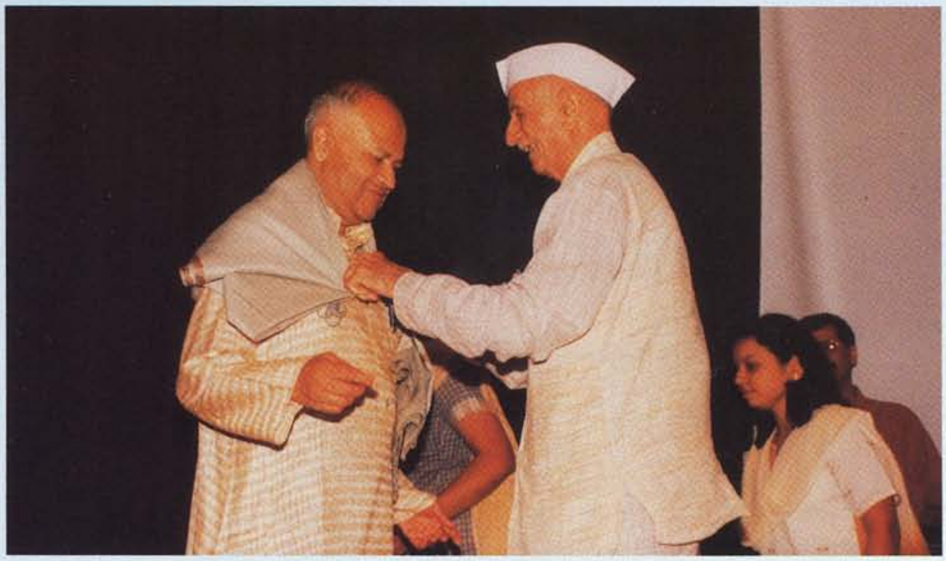
The President A.P.J. Abdul Kalam paid an informal visit to IUCAA on May 28. In the midst of several engagements in the City and its neighbourhood, he managed to spend one hour with us. He went round the Devayani Block, visiting the Foucault Pendulum, the Dome, the Library and the Instrumentation Laboratory and stopping to get photographed next to Aryabhata, on the first Lagrangian point on the Roche Lobes and with school students using our science popularization labs [see the adjoining photograph]. He expressed great pleasure being amongst scientists young and old. When we offered him tea, he was delighted to accept, saying that we were the first in Pune to give him tea!

The President A.P.J. Abdul Kalam with school students

The President A.P.J. Abdul Kalam observing through the Telescope

The Provocative Universe

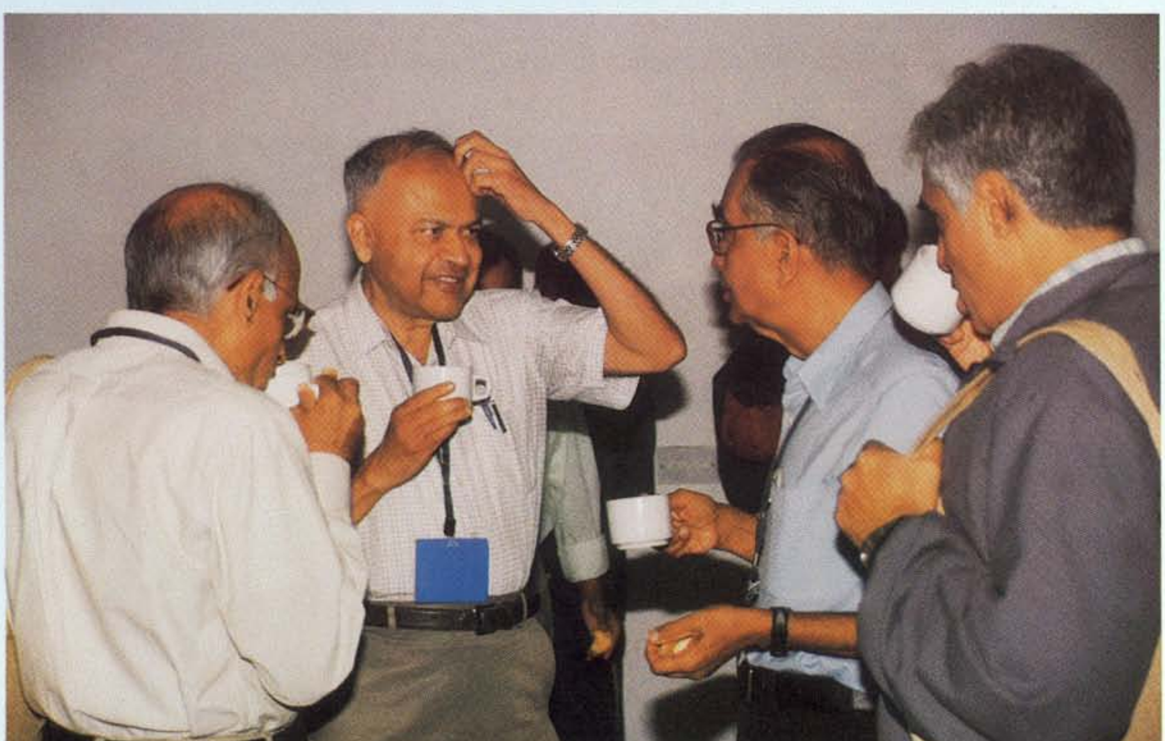
On the occasion of the retirement of Professor J. V. Narlikar, the Founder-Director of IUCAA, a meeting "The Provocative Universe" was organised in his honour. Held at IUCAA, during June 30 - July 2, 2003, the meeting did justice to the depth and spread of Narlikar's scientific interests and there were talks on different subjects, varying from micro-organisms in interstellar space to information loss problem in Blackholes, tackled by string theory. The speakers were Russell Cannon, G.C. Anupama, Roy Maartens, B.S. Sathyaprakash, Bernard Jones, Daksh Lohiya, A.D. Gangal, William Napier, Shiv Sethi, David Roscoe, Max Wallis, van den Heuvel, Jasjeet Bagla, Kameshwar Wali, D. Lynden-Bell, Mira Dey, Richard Ellis, Judith Perry, Brandon Carter, Narayan Banerjee, Suketu Bhavsar, Sverre Aarseth, Pankaj Joshi, Samir Mathur, Moncy John, and Jean-Claude Pecker. Even with a conscious decision by the Scientific Organising Committee to exclude scientists from IUCAA as speakers, we had a tight schedule for the three days. One afternoon was devoted to felicitation of Professor Narlikar and this session was marked by the affection, love and respect, the people in different walks of life had for him.



Professor Narlikar being felicitated by Professor P.C. Vaidya

The IUCAA Visiting Associate felicitated Professor Narlikar on the evening of June 30, 2003

Professor Narlikar being felicitated by Dr. Arun Nigavekar



Participants of The Provocative Universe

Participants and a few lecturers of the Refresher Course in Astronomy and Astrophysics

Nineteen highly motivated teachers from all over India attended the Refresher Course in Astronomy and Astrophysics for College and University Teachers at IUCAA during May 19 - June 20, 2003. Varun Sahni, and Prasad Subramanian coordinated the course, and were ably assisted by students, post-doctoral fellows, faculty members and members of the scientific and administrative staff at IUCAA. The course included core modules that covered the basics of modern astronomy and astrophysics. It also included shorter lecture modules addressing advanced topics. Invited speakers from the Indian Institute of Astrophysics, Bangalore, the ISRO Satellite Centre, Bangalore, and the Tata Institute of Fundamental Research, Mumbai, delivered special lectures on selected frontier research areas and emphasized the role of upcoming Indian observatories in each of these areas. Basic laboratory experiments and sky observing sessions comprised an important part of the course, providing valuable hands-on experience. Popular movies on topics in astronomy were occasionally screened, and the participants were given copies of CDs containing astronomy software and teaching aids. The participants of the refresher course, together with those of the Vacation Students' Programme visited the Giant Metrewave Radio Telescope at Narayangaon and the IUCAA telescope site at Giravali on June 16, 2003. Judging by the feedback received, the participants benefited from the course, and went back considerably enthused about research and teaching in astronomy and astrophysics

Vacation Students' Programme

The thirteenth Vacation Students' Programme (VSP) was held in IUCAA during May 19-June 27, 2003. Eight students in the penultimate year of their M.Sc. (Physics) and Engineering degree course were selected from over 200 applicants from various Indian universities, IITs and engineering institutes. Depending on their aptitude and interest, each student chose the research project to work during the programme from a selection offered by the IUCAA faculty members. The students displayed a lot of enthusiasm and made good use of the IUCAA facilities and resources and interacted with the IUCAA graduate students, post-docs, visitors and faculty members during their stay. The students also attended over 40 expository lectures given by members of NCRA and IUCAA on a broad range of topics in Astronomy and Astrophysics. The lectures were jointly organised with the Vacation Students' Research Programme (VSRP) of NCRA. During their stay, day trips were organised to the IUCAA's 2-meter telescope site and the Giant Metrewave Radio Telescope (GMRT) near Pune. S. V. Dhurandhar and R. Srianand were the faculty coordinators for this programme.

Introductory School on Astronomy and Astrophysics

Participants and Lecturers of the Introductory School on Astronomy and Astrophysics

An Introductory School on Astronomy and Astrophysics was held at The American College, Madurai, during September 22 - 26, 2003. The participants of the school were primarily from postgraduate students (about 80) and College/University teachers (about 20) in and around Madurai (mostly southern Tamilnadu).

Seven topics were covered during the school: Time and Co-ordinate System (B.A. Kagali, Bangalore University); Observational Astronomy (Ranjan Gupta, IUCAA, Pune); Radio Astronomy (Yashwant Gupta, NCRA, Pune): Solar Astronomy (S.S. Gupta, IIA, Kodaikanal Observatory); Introductory Cosmology (M. Sami, IUCAA, Pune); Extra Galactic Astronomy and Quasars (R. Srianand, IUCAA, Pune); Gravitation and Pulsars (A. Israel Stalin, The American College, Madurai). There were two evening popular talks on Radio Astronomy, and Cosmology by Y. Gupta, and M. Sami respectively.

The response from the participants was very good as this was the first time such a school was organized in this region and it was expected that this would help in introducing this subject at various teaching levels in the universities and colleges. Ranjan Gupta and A. Israel Stalin were the coordinators of the school.

Participants of the Workshop on Galaxies: Structure and Dynamics

Workshop on Galaxies: Structure and Dynamics, was organised at the Department of Astronomy, Osmania University, Hyderabad, during January 19 - 22, 2004. The coordinators were Ajit Kembhavi, S. K. Pandey, and S. N. Hasan. Topics included, surface photometry in the optical bands, galaxy morphology, stellar and galaxy luminosity functions, interstellar medium, dynamics of galaxy interactions, collisions and mergers, N-body simulations, and unification schemes based on radio observations. The speakers included Jayaram Chengalur (NCRA), Ajit Kembhavi and A. N. Ramaprakash (IUCAA), S. K. Pandey and D.K. Chakraborthy (Pt. Ravi Shankar Shukla University, Raipur), Somnath Bharadwaj (IIT, Kharagpur), P. M. S. Namboodiri (IIA), B. B. Sanwal (USO), Ashok Singal (PRL), K. S. Sastry, S. M. Alladin, G. M. Ballabh and S. N. Hasan (Osmania University). Evening sessions with practical demonstrations of techniques of surface photometry were also organised. The participants included 23 outstation researchers, as well as, about 40 M.Sc. students of the department studying Astronomy and Astrophysics.

Workshop on Introductory Astrophysics

Participants of the Workshop on Introductory Astrophysics

A workshop on Introductory Astrophysics was held at the Physics Department, Utkal University, Bhubaneswar during January 26-29, 2004. It was the first workshop sponsored by IUCAA in the state of Orissa. The speakers and the topics of their talks were as follows:

R. Nityananda (NCRA) on (i) *Cosmic Radio Telescopes* and *Binary Stars* (3 lectures); B.Paul (TIFR) on (i) *X-ray Universe* and (ii) *High Energy Astrophysics with Astrosat*; R. Srianand (IUCAA) on *Quasars*; R. Misra (IUCAA) on *Observational Evidence for Blackholes*; P. Subramanian (IUCAA) on *Solar Corona/flares and Solar Coronal Mass Ejections*; S. Bharadwaj (IIT/KGP) on *The Expanding Universe*; Sushan Konar (IIT/KGP) on *Astrophysical Compact Objects - A Physicists' Understanding*.

The workshop was attended by 60 postgraduate students, 6 research scholars and faculty members of the department and 30 other participants (8 teachers and 22 postgraduate students) from other colleges and universities of Orissa. The talks generated a lot of interest among the participants, who actively and enthusiastically took part in the discussions.

The workshop was a great success considering the participants response and fulfilled IUCAA's aim of spreading Astronomy and Astrophysics among the university community. In addition A. K. Kembhavi also gave an evening popular talk on "*Blackholes: From Newton to Einstein*" in the auditorium of the Institute of Physics, which was attended by about 300 persons, including school/college students. The coordinators were Ranjeev Misra from IUCAA, and Pushpa Khare from Utkal University.

AKR Gravity Seminar II

The AKR Gravity Seminar series was started last year in honour of Professor A.K. Raychaudhuri for exposing the undergraduate students of the Kolkata colleges to the exciting frontiers of physics and astrophysics. The first seminar was held in the Presidency College, where Professor Raychaudhuri had taught and inspired several students who grew up to become leaders in their fields. The second seminar was held at St. Xavier's College, Kolkata on March 8, 2004 in which J. Maharana, Romesh Kaul, Bhanu Das, and Naresh Dadhich gave lectures and it was attended by over 200 enthusiastic undergraduate students.

Workshop on Front-end Controls and Data Retrieval Archival for Indian Telescopes

Participants of the Workshop on Front-end Controls and Data Retrieval Archival for Indian Telescopes

A two-day workshop on Front-end Controls and Data Retrieval archival for Indian Telescopes was held at IUCAA during January 29-30, 2004 with the purpose to bring together representatives of Indian optical and radio observatories for discussion on their currently used facilities, control systems, software/hardware issues, etc. Presentations were made by S.N. Tandon, A.K. Kembhavi, Ranjan Gupta, Sunu Engineer, and Mahesh Burse from IUCAA on topics covering overview of the subject, virtual observatory, IUCAA telescope and its controls and data archival, etc. The other national observatories represented were: IIA Vainu Bappu Observatory by P. Anbazhagan; UPSO Telescope by B.B. Sanwal and P. Pant; PRL Telescope at GIRT by N.S. Jog; Osmania Observatory by P. Vivekananda Rao; RRI Radio Telescope at Mauritius by V.N. Pandey and GMRT by A. Adoni. The workshop concluded with a session on the action plans to be taken for bringing all the above observatories to a common platform, which can be easily upgraded in the future.

Mini-School on Introductory Astronomy and Astrophysics

IUCAA, and Department of Physics of IIPC, Kalyani Government Engineering College (KGEC) organized a Mini-School on Introductory Astronomy and Astrophysics during February 4-8, 2004. The lectures covered a wide view of the theoretical astronomy, cosmology, modern observational techniques and recent development in astrophysical processes. The details of the various topics covered by the lecturers and their names are as given below:

Ajit Kembhavi (IUCAA) on CCD Detectors and Image Processing in Astronomy; Ranjan Gupta (IUCAA) on Observational Astronomy; Sailoja Mukherjee (North Bengal University) on Cosmology I: Symmetries and Astroparticle Physics; Tarun Souradeep (IUCAA) on Cosmology II: Large Scale Structure of the Universe; Debi Prasod Duari (M.P. Birla Planetarium, Calcutta) on Evolution of Stars, Multi-wavelength Astronomy and Astrobiology; Amalendu Bandopadhyay, (Ex-Director of Positional Astronomy Centre, Calcutta) on Planetary Motion; Subhendu Joarder (GMRT, TIFR, Pune) on Techniques in Radio Astronomy and Experimentation; Somenath Chakraborty (Kalyani University) on An Overview of Neutron Star Properties.

The lectures were supplemented by Radio Astronomy Experiments conducted by S. Joardar, Sourav Chakraborty, Anup De, and Sisir K. Bose. The team has successfully recorded eight Jovian Bursts in the DAM range by using Dipole Antenna and 3 GHz Spectrum Analyzer. There was also a team of experts comprising of Nikhilesh Pal of Rohini Telescope; B.K. Mondal and B. Dasgupta of Positional Astronomy Centre, Calcutta; Indrajit Mukherjee and Sourav Chakraborty of KGEC, assisting in night sky observation with optical telescopes. Participants observed Jupiter with its satellites, Saturn and its rings, Orion Nebulae and the new born stars at the Nebulae and taking video photographs of Saturn and Moon.

The school was attended by a large cross-section of students from different colleges and universities of West Bengal, belonging to different disciplines. The participants also included college teachers, research scholars, and scientists from different institutes.

In parallel with the school was organised an exhibition under the title '*Cosmic Voyage*'. The exhibition was on the history of astronomy from its very inception at the stone age to the modern observational astronomy, the development of telescopes from Galilean to modern telescopes using adaptive optics, observation in other wavelength regions like UV, X-ray, γ-ray, radio and microwave regions, cosmology and relativity theory, astrophysics, theory of big-bang, star birth, etc. Indian astronomical studies from 18th century, the age of '*Jantar Mantar*' to the present 21st century, the development of large array of radio telescopes at GMRT were also depicted at the exhibition. The coordinator of the course was S. Mukherjee of North Bengal University.

Workshop on Brane Worlds and Quantum Cosmology

Following the ICGC meeting at Kochi during January 5-10, 2004, a cosy and compact meeting was organised at IUCAA, essentially to bring together active workers in brane worlds and quantum cosmology for a relaxed interaction. Apart from a general discussion on motivation for brane world gravity from classical standpoint as well as gravity's strong linkage with thermodynamics, the discussion on the brane side concerned various models of dark energy and inclusion of Gauss-Bonnet and induced gravity terms. Recently, there have been some interesting developments in loop quantum cosmology, where the loop quantum effects radically alter the behaviour of energy density as the Planck scale is approached. It results in the avoidance of the big-bang singularity. This question is now being studied for the homogeneous Bianchi cosmology. The speakers were G. Amery, M. Bojowald, N. Dadhich, G. Date, G.M. Hossain, T. Padmanabhan, E. Papantonopoulos, M. Sami, Y. Shtanov, A. Toporensky, and S. Tsujikawa. There was enough free time for informal interaction, which lent further a flavour of understanding and congeniality.

IIT Kharagpur IUCAA Workshop on High-Energy Astrophysics

Participants of the IUCAA-IIT Kharagpur Workshop and two shots of the presentation by Ph.D. students

Harsha Raichur

Raka Dona Roy Mandal

As a part of the activity proposed under the MOU signed between IIT, Kharagpur and IUCAA, a Workshop on High- Energy Astrophysics was organized during February 23- 25, 2004 at IIT, Kharagpur.

The aim of the workshop was to bring the experts in contact with the students (undergraduate and graduate), and the young researchers so that they could review the basic understandings and discuss the recent developments in this rapidly developing field of High-Energy Astrophysics. This aim has been amply fulfilled. The topics covered in this workshop included – a) compact objects, b) gamma-ray bursts, c) quasars/AGNs, and d) cosmology.

A total of 58 participants attended this workshop of which 36 were from outside Kharagpur, coming from all parts of the country. This included a number of IUCAA visiting associates too. There were ten invited speakers who reviewed several key areas and many contributed short talks, mainly by Ph.D. students and young post-doctoral fellows.

On the evening of February 24, Dipankar Bhattacharya, Dipanjan Mitra, and Biswajit Paul had an informal discussion session with the students, telling them about possible research opportunities in astrophysics.

A panel discussion on Astronomy and Astrophysics research was scheduled as the concluding session of the workshop. Ramana Athreya, Somnath Bharadwaj, Pijush Bhattacharjee, and Dipankar Bhattacharya acted as panelists. The issue that seemed to concern everyone is the still persisting lack of contact between the universities and the elite institutes.

Two other suggestions arose out of this panel discussion. The first one was to create a server of national workshops/schools/conferences on astronomy and astrophysics in the line of C-DAC. The second was to create a database of possible short-term projects (outside the standard summer projects) for undergraduate students. Scientists in the research institutes can advertise their projects in the web and the teachers in the respective universities can coordinate and recommend the names of suitable students. Several teachers (from colleges and universities) have shown interest in helping to create and maintain such a database.

Other details regarding the workshop is still available at the workshop webpage at http://www.cts.iitkgp.ernet.in/~heap04.

Public Outreach Programmes

Programmes for School Students

In order to inculcate scientific temperament in young generation, IUCAA has been arranging lectures and summer programmes for school students to 'catch them young'.

Saturday Lecture and Demonstration Programmes

IUCAA invited schools from Pune to attend Lecture and Demonstration Programmes, held every second Saturday of the month, when the schools were in session during the academic year June 2003 - February 2004. The programme was attended by students from class IX and X. Lecture and Demonstration programmes in Marathi/ Hindi were arranged in the first half followed by the same in English in the other half of each session. Lectures for Junior College students were also arranged every fourth Saturday in a similar manner. The lectures for Junior Colleges were arranged in English only. Following were the lectures arranged during the year of this report:

Naresh Dadhich Science : How we Do it? July 12, 2003.

Arvind Paranjpye : A Tour through Milky Way Galaxy, August 9, 2003.

Atul Deep : The World of Telescopes, September 13, 2003.

Ajit Kembhavi : Binary Stars - From One to the Other, January 10, 2004.

S. N. Tandon : How Many Drops in a CC of Water?, February 14, 2004.

Prasad Subramanian: The Sun and its Outer Atmosphere, July 26, 2003.

Ranjan Gupta: Earth's atmosphere and How it Affects Astronomical Observations, September 2.

Sunu Engineer : Computation in Astrophysics, November 22.

Amrit Lal Ahuja: Introduction to the Fundamentals of Astronomy and Astrophysics, December 2.

Arvind Paranjpye : Transit of Planets , January 24.

School Students' Summer Programme

This year's School Students' Summer Programme was held from April 4 to May 3, 2003. IUCAA has been conducting this programme for the Pune students of VIII and IX standards since 1993, to give them a brief insight of doing scientific research. 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 guides work out their own schedule for the week. The students were given access to the IUCAA library.

Students carried out various projects under the supervision of Amrit L. Ahuja, V. Chellathurai, N. K. Dadhich, Atul Deep, Sanjeev Dhurandhar, Ranjan Gupta, Harvinder Kaur Jassal, Vinaya Kulkarni, Jayant Narlikar, Rajesh Nayak, Shamin Padalkar, T. Padmanabhan, Arvind Paranjpye, A. N. Ramaprakash, Jatush V. Sheth and Tarun Souradeep.

On their very first day at IUCAA, the students were briefed about the programme and soon after that, they would go with their teacher to work on different projects. During the week, they also participated in various common activities. Vinaya Kulkarni conducted them guided tour of the Science Park. Arvind Paranjpye coordinated the programme and carried out a general question answer session. On the last day of the programme, that is on Friday, every student was asked to submit a report on the work carried out during the week. The programme ended with an oral presentation (by at least one student from every group) followed by Jayant Narlikar's three 'mathematical teasers'.

This year, the students of the last batch had an opportunity to interact with the Honourable President during his visit to IUCAA.

Public Lectures

IUCAA has arranged public lectures in the view of various forthcoming astronomical events/occasions, to create an opportunity for members of public to know more about the field of Astronomy and to give a forum for young amateurs and to know Astronomy and Astrophysics, and to get their doubts cleared. Following were the Public Lectures :

Arvind Paranjpye : Transit of Mercury - on the Solar Disk, May 02.

Naresh Dadhich : World View: Copernicus to Einstein and Beyond, October 1.

Jeremiah P. Ostriker : Heart of Darkness, January 12.

Horton Newsom : Impact Cratering in the Solar System, January 16.

Telescope Making Activity

During April- May 2003, the students of Science Club of IIT, Powai, Mumbai have made a 10" mirror for their proposed Newtonian Reflector. The grinding, polishing, testing, and figuring of the mirror was done in the Public Outreach Laboratory of IUCAA. Also, a student of B.Sc. Physics course of Pune University took qualitative measurements of the surface change with changing temperature as part of her project work.

National Science Day at IUCAA

The National Science Day was celebrated at IUCAA during February 28-29, 2004. On Saturday, February 28, various competitions were held for the high school students. In the evening, night sky viewing through telescopes was arranged for the general public. On Sunday, February 29, the Centre was open to the general public with special displays, experiments and demonstrations, set up by the members of IUCAA.

Inter-School Competitions

The National Science Day 2004 celebrations started with essay, drawing and quiz competitions for the high school students. Schools were invited to send a team of five students to participate in the competitions. Eighty five schools participated in the competitions. One student from each school was asked to write an essay on one of the topics specified by a panel. The drawing competition was held in a similar manner. Like every year, the quiz contest was the key attraction on the Science Day. A team of three students from each school participated in the qualifying round of the quiz competition. The first five qualifying teams were invited on the stage for the final quiz contest. The quiz had questions from different science fields with more emphasis on Physics and Astronomy.

Programmes for the General Public

The Open House for Public : In the afternoon of February 29, 2004, the enthusiasts and amateurs crowded in the Bhaskara lobby of IUCAA to view the poster display by the academic members of IUCAA. The posters elaborated on the research work at IUCAA and topics in the field of astronomy such as, cosmology, evolution of stars, etc. The students were happy to get their doubts and ideas regarding career prospects cleared at the career guidance cell. Students keenly interested in getting into the field of Astronomy as a career, attended the lectures and question-answer session by Ajit Kembhavi on this topic. In addition, there were lectures by A. N. Ramaprakash (Large Astronomical Telescopes), Tarun Souradeep (Music of the Cosmic Drum), and T. Padmanabhan (Nobel Prize in Physics 2003).

The library staff made a poster on the statues in the kund area and also on the work done by those eminent physicists-mathematicians. Dilip Sathe from Dadawala Jr. College, Pune, explained the Foucault's pendulum to the public. The demonstration of working of radio telescope, the spectrum of light and the Schlieren effect in optics, posters on virtual observatory, viewing of scientific video films, and demonstration of do-it-yourself toys added flavour to the celebrations.

Visit to the Science Park : Visitors enjoyed the interactive outdoor exhibits in the IUCAA Science Park. Volunteering by students from Jnana Prabodhini Prashala to explain the exhibits, enabled the visitors to understand the scientific principle behind the exhibits.

Night Sky Show : Like every year, the night sky viewing session on February 28, 2004 seemed to be popular among the public. Around twelve hundred people enjoyed viewing through the telescope. People viewed Jupiter, Moon, and Orion Nebula through the six inch Newtonian reflectors made by amateurs in the Public Outreach Programme Laboratory of IUCAA. Viewing of Saturn through IUCAA's 14 inch telescope was also arranged. The members of SWAP and Akashmitra, the amateur astronomers' associations in Pune, volunteered to arrange the sky show.

A great deal of planning and administration was necessary for the smooth execution of the celebrations of the National Science Day. The successful organization of these events was possible because of the active participation by all the members of IUCAA.

Kshitija Deshpande, First Year B.Tech. student from the Pune Institute of Engineering and Technology won the Kishor Vaidnyanik Protrsahan Yojana(KVPY) Fellowship, for her Project 'Stereo Imaging Using a Web CCD Device'. KVPY is a highly prestigious scholarship provided by the Government of India to encourage students of basic sciences, engineering and medicine to take up research career in that area.

Shreelekha, Final Year B.Sc. student's project of making an astronomical telescope won first prize in her college and 2nd prize at Inter-collegiate project competition by Indian Physics Association (Pune Region).

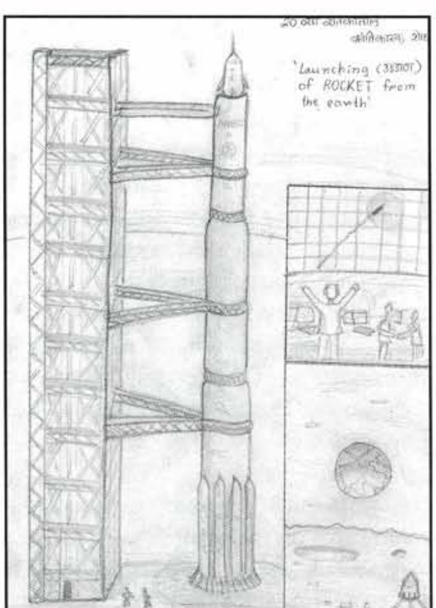
Arvind Paranjpye was the guide of both the students

IUCAA Science Activities Workshop (January - March 2004)

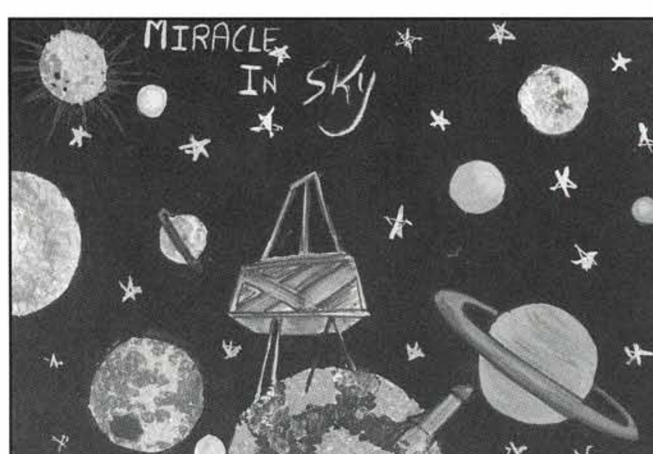
During one of the Saturday Lecture and Demonstration Programmes, teachers were informed to send children of class 7th and 8th for science activity workshops in IUCAA. The response was quite heartening. Twenty-eight schools sent 40 to 60 children each to participate in these workshops.

The workshops started with a 45 minutes lecture-demonstration showing the possibilities of making science models and toys using simple, day-to-day materials. The rest of the time was spent on making the models and toys. During the making session, children made half a dozen different caps with newspapers, a few dynamic paper toys like the hexaflexagon, 14-page unending book, the flapping bird and a spinner made from a broomstick and a piece of rubber slipper.

The children seemed to like making things. We hope that the children, in turn would share it with others in the school and the culture of making things and doing things would spread.



Sourabh Laghate



Amruta Garud

The various themes for the drawing competition were : i) The most remarkable scientific invention or discovery of the 20th century; ii) Suppose mankind had evolved and lived in water; iii) Closer view of the night sky. Above are the second prize (shared) winning drawings. (No first prize was awarded).

Results of Inter-School Competitions

Essay competition

English Medium

First Prize : Ameya Ambardekar (Abhinav Vidyalaya English Medium)

Second Prize : Yash Deshpande (Vikhe Patil Memorial School)

Honorable Mention : Srishti Mukherji (K.V., Southern Command)

Marathi medium

First Prize : Janavi Jagadale (H.H.C.P. Hujurpaga High school)

Second Prize : Shruti Hajirnis (Ahilyadevi High School for Girls)

Honorable Mention: Ashish Kamalapurkar (Jnana Prabodhini, Navnagar, Nigdi)

Drawing Competition

Second Prize : (shared by) Sourabh Laghate (Sou. Vimalabai Garaware High School) and
Amruta Garud (Abhinav Vidyalaya High School, Marathi Medium)

Third Prize : (shared by) Gayatri Sunandan Laghate (H.H.C.P. Hujurpaga High School)
Ashish Dilip Nade (Vidya Bhavan High School)
Sucheta Patil (The Army Public School)

Quiz Competition

First Prize : Jnana Prabodhini Navanagar, Nigdi (Abhishek Dang, Aniket Inamdar, Kedar Sanjay Jumde)

Second Prize: D.E.S. School (Sarang Kulkarni, Pushkar Pandit, Akshay Navgire)

Third Prize: Vikhe Patil Memorial School (Hamsa Padmanabhan, Chaitanya Joshi, Nikhil Yelamanchili)

The late N.C. Rana Memorial Trophy for the best all rounder performance in the Inter - School Competitions went to Jnana Prabodhini, Navnagar, Nigdi

Popular Talks and Articles by the IUCAA Faculty

(a) Popular Lectures

Naresh Dadhich

Vidnyan : Kaise Karte Hai Hum? (In Hindi) Science : How do we do it?, Saturday Lecture Demonstration Programme for School Students, IUCAA, Pune, July 12.

Science : Method and Vision, Crompton Greaves Management Development Centre, Mulshi, August 2.

From Newton to Einstein, Inauguration of Science Association 2003-2004 in Modern College of Arts, Science and Commerce, Pune, August 14.

Relativity for Everybody, Science Association, S.P. College, Pune, August 19.

How Do We Do Science? Palakniti's School Science Programme, Persistent Systems Sabhagriha, Pune, August 30.

How Do We Do Science?, Brihan Maharashtra College of Commerce, Pune, September 30.

World View : Copernicus to Einstein and Beyond (a Public lecture delivered at IUCAA, Pune, October 1.

Science, Method and Vision , B.J. Medical College, Pune, October 9.

Relativity for Everyone Pune Vidyarthi Graha College of Engineering and Technology, Pune, October 11.

From Copernicus to Einstein, Shri Shiv Chhatrapati College, Junnar, January 3.

Challenges in Science, Sangamner College, Sangamner, January 27.

Light bends the Universe, National Institute of Ophthalmology, Pune, February 7.

Relativity for Everyone , Department of Physics, Karnatak University, Dharwad, February 21.

The Modern World View : From Copernicus to Einstein and Beyond, Senate Hall, Shivaji University, Kolhapur, February 23.

Our Universe : From Copernicus to Einstein, Research and Development Establishment (Engineers), Dighi February 28.

S. V. Dhurandhar

Gravitational Wave Astronomy, Indian Science Communicators meet, BARC, Mumbai, June 20.

Ranjan Gupta

Earth's Atmosphere and How it Affects Astronomical Observations, Saturday Lecture for Junior College Students, IUCAA, Pune, September 27.

Telescopes as Tomorrow, Conference of Amateur Astronomers of India, National Institute of Opthalmology, Pune, November 28.

Dust, Pollution and Modeling, Birla Planetarium, Kolkata, February 12.

H.K. Jassal

Dhoomketu, Hindi, Saturday Lecture Series for school children, IUCAA, Pune, December 13.

Comets, Saturday Lecture Series for school children, IUCAA, Pune, December 13.

A.K. Kembhavi

Careers in Astronomy, Science Day, IUCAA, Pune, February 28.

Blackholes : from Newton to Einstein, Institute Of Physics, Bhubaneswar, January 29.

J. V. Narlikar

Search for Extra-terrestrial Life, Centre for Development of Advance Computing, Pune, April 17.
Search for Extra-terrestrial Life, Film and Television Institute of India, Pune, April 19.

How to capture the Thrill for Basic Sciences in Higher Education, the UGC Golden Jubilee Lecture Series under the auspices of the Maharashtra University of Health Sciences, Nashik, April 25.

Search for Life in the Universe, Workshop for the talented students at secondary level organized by Exploratory at Bharatiya Vidya Bhavan, Pune, May 2.

Vidnyankathanche vishwa (Universe of science fiction stories) (in Marathi) Fergusson College, Pune, organized by the Jyotirvidya Parisanstha, Pune, June 13.

Searches for Extraterrestrial Life, British Council, Mumbai, June 19.

T. Padmanabhan

Getting to Know the Universe, IUCAA Public lecture, November 27.

Nobel Prize in Physics - 2003, IUCAA Open House, February 29.

A.N. Ramaprakash

Large Optical Telescopes : (IUCAA Open House) February 29.

Souradeep Tarun

Music of the Cosmic Drum (Science day, IUCAA, Pune) February 28.

S.N. Tandon

How Many Drops in a CC of Water ? Lecture/demonstration for school students, IUCAA, February 14.

(b) Popular Articles:

Dadhich N. (2003) Threshold research support for university scientists, Current Science, 85, 11, 1511.

Narlikar, J.V. (2003) Science and Speculation : Behind the veil of cosmology, Times of India, May 2.

Narlikar, J.V. (2003) Asking for the moon : Back to basics in space, Times of India, May 30.

Narlikar, J.V. (2003) Ekeesavi sadi mein vidnyan (in Hindi) [Science in the twentyfirst century], Hindi Mein Vidnyan-Bhavana, 31.

Narlikar, J.V. (2003) Prithvibaheril jeevshristi (in Marathi)[Extraterrestrial life], Marathi Vidnyan Parishad Patrika, April, 4.

Narlikar, J.V. (2003) Ek aashavadi shastradnya (in Marathi) [One optimistic scientist], Gaurav Granth, 14.

Narlikar, J.V. (2003) Vaidnyanik drustikon (in Marathi) [Scientific outlook], Nirantar Shikshan, April, 8.

Narlikar, J.V. (2003) Chandrala gavasani (in Marathi)[Orbiting the Moon], Lokrang, June 15.

Narlikar, J.V. (2003) Tu mazi nirasha kelis (in Marathi) [You disappointed me], Gomantbharati, Text book of 11th Standard of Goa Board of Secondary and Higher Secondary Education, 81.

Narlikar, J.V. (2003) Vaidnyanik drustikon (in Marathi) [Scientific outlook], Vyaktimatav Vikas Deendarshika 2003-04.

c) Radio/TV Programmes

N.K. Dadhich

Vidnyan Bharati Magazine Programme - All India Radio, September 24.

Vidnyan Karyakram Me Mulakath - All India Radio, November 29.

J.V. Narlikar

Documentary Film on Professor J.V. Narlikar, DD-I, June 9 and 10.

Vidnyan Karyakram mein mulakhat, All India Radio, June 19.

Live Interview in Marathi at the Sydney Radio Station, Australia, July 7.

FACILITIES

(I) Computer Centre

The IUCAA Computer Centre continues to extend state-of-the-art computing facility to users from IUCAA, as well as visitors from the universities and institutions in India and abroad.

Research in a number of areas of Astronomy and Astrophysics (A&A) now rely on high performance computing (HPC) and capability to manage and process large volume of data. An attractive route to retaining competitive edge in HPC is based on clusters of modest computing units linked over a fast network. Several groups in IUCAA need high performance computing in their research. IUCAA also has a potentially large user base in the university sector, with very diverse research areas who will be able to tackle more computationally challenging problems. In such an user environment, it is important to provide a facility that would be readily harnessed for very diverse applications by users at varying levels of parallel computing expertise. In August 2003, a cluster called Hercules, which consists of four Hewlett-Packard Alpha server ES-45 nodes, each with four processors was set up for this purpose. Hercules was based on a trade-off between the increasing cost effectiveness of distributed computing and the diminishing user base with smaller nodes. The aim is to provide a gradual and easy path to encourage the migration of Astronomy and Astrophysics researchers into the high performance computing area.

Hercules marks a radical upgrade of the computational facility at IUCAA marking a major shift in emphasis towards computational problems. Each of the 16 processors of Hercules has more computing power than the previous fastest computer in IUCAA. The 16 Mb cache size per processor is an additional feature that aids the computing performance significantly. Each node of Hercules is an impressive four processor computing unit with 8 to 12 Gb RAM that would readily allow many initial users to run multi-threaded OpenMP applications on a 4-processor shared memory platform. As an user's computational need increases, the user can harness the computational power of entire cluster using distributed programming applications over all the nodes. In distributed computing, different applications face different levels of communication overhead. The Memory Channel Architecture on Hercules is one of the best inter-node communication hardware, that has very low latency with high bandwidth. This removes limitations that may be placed on users and their application from communication overhead.

In April 2003, a 16 node OpenMosix based distributed computing environment was set up with the help of MSc students (2001-2004 batch) from St. Thomas College in Kozhencherri under the guidance of Ninan Sajeeth Philip, who is a visiting associate of IUCAA from the same institution. The processors used are Intel PIV CPU @ 2.4 Ghz with 512 Mb DDR RAM. Of the 16 machines, one acts as a file server and the rest are etherbooted using the tftp protocol. To get Red Hat 9.0 compatibility on all the nodes, the exported file system was custom configured based on the concepts utilized by the Linux Terminal Server Project. The OpenMosix Linux patch for the Linux vanilla kernel 2.3.20 is used as the base system on all the 16 nodes and are networked by 100 Mbps fast Ethernet cards and a 24 port switch. The nodes are grouped into 4 units and are connected via a KVM switch for display, keyboard and mouse connectivity. These connections are not mandatory but are done for ease of testing and monitoring. LAM-MPI software is used for parallel computing.

A Qualstar 4200 robotic tape library having 22 slots for AIT3 tape has been added to the computing facility for backing up vast expanding user data area. DVD/CD writers and DVD/CD readers have been made available on windows and unix environment for data transfer.

The computing facility continues to offer technical support to visitors, project students and associates of IUCAA.

(II) Library and Publications

During the period under review, the IUCAA library added 227 books and 315 bound volumes to its existing collection, thereby, taking the total collection to 18,632. The library subscribes to 128 journals. The library has constantly endeavoured to provide efficient service to the inhouse academics, as well as the associates and official visitors to IUCAA. The table of contents and prompt article delivery service offered by the library have been possible due to the excellent rapport shared with other libraries in and outside Pune.

The IUCAA library was involved in the acquisition of books for two upcoming IUCAA Reference Centres, one at Gorakhpur and the other at Jadavpur. Additional resources required by the existing IRCs were also supported by the library.

The IUCAA library is an active member of FORSA (Forum for Resource Sharing in Astronomy), which comprises of seven institutes in which, Astronomy and Astrophysics is a major research area. Three institutes viz. Bose Institute (BI), Kolkata, Harish-Chandra Research Institute (HRI), Allahabad, and Saha Insitute of Nuclear Physics (SINP), Kolkata have joined FORSA in July 2003 taking the total FORSA members upto ten.

A meeting of the FORSA members was held during July 28-30, 2003 at TIFR, Mumbai, in which the members agreed to focus on the possibility of creating a union catalogue of each member library, which would be accessible on the internet, as well as maintain the current consortia agreements related to journal subscriptions and consider new proposals.

IUCAA has full-fledged publications department that uses the latest technology and DTP software for preparing the artwork and layout of its publications like the Annual Report, Quarterly bulletin "Khagol", Posters, Academic Calendar, Conference Proceedings, etc.

(III) Instrumentation Laboratory

The facilities at the laboratory are used for design, and development of instruments for optical astronomy; the facilities are also used by groups from the universities for developing their instruments.

During this year, a thermoelectrically cooled CCD camera was assembled by Umesh Dodia for use with the telescope at Bhavanagar University. A controller was developed for a CMOS imager to be used for readout in an image intensifier; as the image intensifier works in photon counting mode, the controller is designed to take upto 20 frames per second. An interface with standard high speed USB port has been designed for the CCD controller, which has been developed in the past, to substitute for the special purpose interface in use so far; this would soon be tested.

A set of test gadgets and procedures have been developed to test efficacy of baffles in a Cassegrain telescope at levels one part in ten million, and these will be used to estimate the attenuation factor provided by baffles of the ultra violet imaging telescope being made for Astrosat mission of ISRO.

(IV) The IUCAA Telescope

As reported in the past, IUCAA is setting up a 2 m telescope for optical and near infrared astronomy. The telescope is supplied by the Particle Physics and Astronomy Research Council of UK, and it has a large corrected field of 40 arcmin diameter for the optical band; the (uncorrected) field for the near infrared has a diameter of 20 arcmin.

As reported last year, the first phase of mechanical integration was done during the months of February and March 2003. The second phase of the mechanical integration was completed in May-June 2003. This was to be followed by electrical cabling on the telescope, but the manufacturer of the telescope, Telescope Technologies Limited, UK, decided that the electrical work needed a major diversion in metodology from what was originally anticipated by them, and this led to a long delay in starting the electrical work. It is expected that this work will start by June 2004, and the installation will be completed by early 2005.

(V) Virtual Observatory

Astronomers use vast quantities of data for their research. These data are obtained using many different kinds of telescopes and detectors situated on the ground and on satellites in space. Because of the rapid advance in telescope and detector technology, there has been a phenomenal increase in the quantity of data, both from observation of specific objects as well as from surveys which cover entire areas of the sky. The data volumes have already reached Terabytes and great growth is expected over the coming decade.

Because of the large volume of data, and the many different forms in which it is available, the storage and retrieval of data, as well as its management, visualization and mining have become extremely difficult tasks. It has also become very challenging for astronomers to use the vast store house of data to produce exciting new scientific discoveries. Large projects have been undertaken in the USA, UK, France, Germany, China, Japan, Russia and other countries to efficiently utilize the data through the establishment of a Virtual Observatory.

The ongoing Virtual Observatory - India (VO-I) project at IUCAA is a collaborative effort between IUCAA and Persistent Systems Pvt. Ltd. (PSPL), which is a major software company in Pune with expertise in data mining and related areas, and funded by the Ministry of Communications and Information Technology.

Projects undertaken under the VO-I involve, (1) research and development for data storage and retrieval; (2) software development for quick and efficient use of the data, analysis, visualization and data mining; and (3) scientific projects using the data.

The software projects which have been completed during the period of the report are (1) development of a fits browser, (2) development of a C++ parser for data in the VOTable format, including a streaming version, (3) development of a visualization engine VOPLot for the large database known as Vizier, with web based and stand alone versions, (4) streaming writers in the VOPLot format, (4) converters of data from one format to another, and (5) user interfaces for large data bases. These packages have been very well received by the international community and have being demonstrated in various international forums. VOPlot has been developed in collaboration with CDS, France, and is being adapted to various data bases. Pallavi Kulkarni (IUCAA) and Sonali Kale (PSPL), who work on the VO-I project, were invited to present their developmental work at the ADASS meeting in Strasbourg, France, in November 2003. Ajit Kembhavi, who is the principal investigator of the project, was invited to give a talk on the International Virtual Observatory Alliance at the International Astronomical Union meeting in Sydney, Australia in July 2004.

On the hardware side, a RAID disk array with several Terabytes of storage capacity has been set up, and important astronomical databases are being mirrored on it. A suite of software packages including SQL server have been donated to the project by Microsoft, and query engines using this facility are being developed. All the development is being carried out by a team of software engineers from PSPL and IUCAA, in collaboration with astronomers from IUCAA.

Archives of several large databases, including the Sloan Digital Sky Survey Data Release 1 catalogue, which is about a Terabytes in size have been constructed at VO-I.

VO-I has initiated a project to make archives for observations made from different observing facilities in India. The database incorporates details of the observations, the data in VO compatible as well as traditional formats, low resolution representations of the data, arrangements to protect the data from unauthorized access, and the ability to link to other observations and catalogues in a seamless fashion.

(VI) IUCAA Radio-Physics Educational and Training Facility

During 2003-2004, plans were finalised for setting up a 'Radio-Physics Educational and Training Facility' in IUCAA and developmental work was initiated by J. Bagchi. This long-term project is being carried out with technical collaboration and support of National Centre for Radio Astrophysics (NCRA). The main objectives of this project are to train motivated students nationwide in the use of Radio Telescopes and introduce them to the specialized concepts of radio astronomy research and to prepare them for advanced level research with the GMRT and other world class radio telescopes.

Intiating the developmental work, a number of essential radio astronomy hardware and instruments were obtained from M/s Radio Astronomy Supplies, Sunrise, Florida, USA. Instruments have been both calibrated in laboratory and actual astronomical data were obtained. These experiments were done with an active participation of M.Sc. students from the University of Pune, as part of their radio astronomy course curriculum. The 21-cm hydrogen line receiver and spectrometer were fully assembled and the controlling software was loaded on a dedicated PC. Astronomical test observations were done by employing a cylindrical horn antenna acting as a low-gain wide-field telescope, which was mounted piggy-back on top of an optical telescope for pointing accuracy. From IUCAA roof-top one 'looked' at various directions along the galactic plane to test the system performance.

The Doppler shifted 21-cm galactic hydrogen line was easily detected (in less than 1 second integration) towards the cold hydrogen clouds located in Orion arm, the galactic center (Sgr A) and towards several other points along the galactic plane. From such measurements, the students were able to determine the rotation curve of the Milky Way galaxy upto a distance of 12 kpc from the galactic centre.

IUCAA REFERENCE CENTRES (IRCs)

(1) Delhi University
(Report by T. R. Sheshadri - Coordinator)

The IUCAA Reference Center at Delhi has been fully functional for more than a year now. With the generous grant received from the University of Delhi, the IRC is now well equipped with two Pentium machines with 128 MB RAM. Both the machines are on the university wide network through which, there is a good access to internet. Besides this, a laser printer, one office jet printer cum fax machine and a CD writer for visitors to take a backup of the work they have done, are also available. In addition, there is an over head projector and other paraphernalia with which the small seminars are held in the IRC itself. Further, there are many books in astronomy and astrophysics, as well as in other areas for reference. (These include books loaned from IUCAA and books donated by people to the centre and a number of personal books of regular users which are available for consultation.) Ph.D and M.Sc students, as well as the visitors to the centre, use these books regularly. The major activities that were conducted at the Centre are as given below :

(i) A series of 5 lectures in St. Stephen's College were delivered by T. R. Seshadri on *Distance Measurements in the Universe*.

(ii) A one day discussion meeting on *Small Telescopes* was held at IRC on January 16. H. P. Singh was actively involved in arranging this meeting. Ranjan Gupta, S. K. Pandey, Sanat Kumar, and A. Paranjpye delivered talks and the meeting was attended by several college teachers, in addition to some research students and faculty members of the Department. Ranjan Gupta, S. K. Pandey, and A. Paranjpye were at the Centre for a few more days for discussions. A proposal for buying a new more Telescope was drawn up and the university has sanctioned funds for this purpose. It is proposed to start telescope related projects for students with this.

(iii) Following are the details of Talks delivered during the period under review H.P. Singh: Stellar Spectroscopy, September 10; Avadesh Prasad: Detection of Direction of Information Flow in Coupled Complex Systems, September 24; Ashok Goyal: Many Faces of Compact Stars , October 22; O. W. Greenberg: Quarks and Colour, December 26; Vinay Gupta: PN Junction Theory of Semiconductor Gas Sensors, March 17; Ranjan Gupta: M.Sc. Experiments with Small Telescopes, January 16; S. K. Pandey: Research Level Projects with Small Telescopes, January 16; Sanat Kumar: Astronomy Activities in Nehru Planetarium, New Delhi , January 16; A. Paranjpye: Observation of Transit Phenomena with Small Telescopes, January 16; Sitambhra Sinha: Does Complexity imply Fragility, February 27; H. K. Jassal: Dark Energy, January 17; and Namit Mahajan: An Introduction to Little Higg's Model, March 24. In addition to the talks listed above, the IRC in Delhi has become a place, where there is a lot of interaction especially among research students. Students regularly give informal talks. H.K. Jassal (IUCAA) (8 days), Sitambra Sinha (IMSc) (3 days), A. Paranjpye (IUCAA) (4 days), Ranjan Gupta (IUCAA) (4 days), S.K. Pandey (Pt. Ravishankar Shukla University) (4 days), Ratnashree (Nehru Planetarium) (1 day), Sanat Kumar (Nehru Planetarium) (1 day), Alan Cornell (Korean Institute of Advance Studies) (10 days), Greenberg (University of Maryland) (3 days), Anirudh Pradhan (Hindu Post-graduate College, Zamania) (10 days), Bhatt (10 days), Kedar Purohit (10 days), and Sanjeev Kumar (10 days) visited the Centre in connection with seminars, discussion meeting on Small Telescopes, Library consultation and for future collaborations.

(2) Pt. Ravishankar Shukla University, Raipur
(Report by S.K. Pandey - Coordinator)

Some of the important activities of the Centre during the period under review are listed below:

(i) ***Sky Gazing Programme*** : from time to time, sky gazing programmes were organised for general public, using the telescope facility in the physics department to have a nice view of Jupiter and its moons, Saturn and its beautiful rings, as well as surface features on the moon. M.Sc. students of the department also enjoyed having a view of sunspots using our 6" telescope fitted with solar filters. Likewise, a special and relatively rare event of transit of Mercury across the Solar disk (May 7, 2003) attracted a lot of crowd and enjoyed attention of local newspapers during May 2003.

(ii) ***Project Work in Astronomy*** : During the academic session 2002-2003, thirteen students from M.Sc. (final) of the department used IRC facilities (INTERNET and library) in carrying out their project work, as apart of their course work, in observational Astronomy using the observing facility in the department. During the current session (2003-2004), nine students have opted for carrying out project work in A&A as a part of their M.Sc. course. Three students opted for data analysis work while six students carried out project work in observational astronomy on various types of variable stars using the 6" Carl-Zeiss telescope and a stellar photometer SSP3 (This telescope was in use since 1978, but unfortunately, was stolen during the last week of

December 2003, which is a big blow to the Astronomy programme of the department)

(iii) *Students' Seminar* : As a part of student seminars organized every weekend in the department, several students delivered seminars on topics from Astronomy, which they prepared using facilities offered by the IRC.

(iv) *Research Project* : A research project entitled "*A study of stellar activity in chromospherically active stars*" submitted by S. K. Pandey to CSIR, New Delhi, got approval for financial support of approximately Rs. six lacs with the provision of one research fellow for a period of three years with effect from April 1, 2003. This will help in rejuvenating research activities using small optical telescopes in the department. Ph.D. degree was awarded to Mousami Das under the supervision of D. K. Chakraborty. The title of the thesis is "A Study of Photometric and Kinematical Physics of Elliptical Galaxies" (June 2003).

(v) *Talks at the IRC* : U. C. Joshi: Our Galaxy: The Milky Way; glimpse of the inner region., August 30.

***Visitors*:** Saibal Ray (5 days); M. K. Patil (23 days); Akalish Jadhav (6 days); D. K. Sahu (3 days); and K. N. Mishra (2 days), visited the Centre for discussions.

(3) North Bengal University, Siliguri
(Report by S. Mukherjee - Coordinator)

The following major activities were conducted at this Centre :

1. National Workshop on "Field Theoretic Aspects of Gravity- FTAG IV" was organized by IRC, NBU during the period March 2-6, 2004 in Hotel Newa Regency, Pelling, Sikkim. Twenty scientists from different research institutes and universities participated in the meeting and had detailed discussions on their recent research findings, as well as recent developments in the field of gravity. The meeting was sponsored by IUCAA, Pune; IMSc, Chennai; SINP, Kolkata, and IRC, NBU. N. K. Dadhich, IUCAA and S. Mukherjee were the Academic Directors for this workshop.

2. IRC, NBU helped Kalyani Government Engineering College to organize a Mini-School on Introductory Astronomy and Astrophysics, held at the college campus during February 4-8, 2004. About 100 college and university teachers and students of Xavier's College, Lady Brabourne College, Serampore College and Kalyani Government Engineering College participated in the workshop. Apart from lectures given by eminent scientists in these fields, laboratory training and night-sky watching formed parts of the programme. A.K. Kembhavi and S. Mukherjee were Academic Directors for this school.

3. IRC, NBU and Physics Department, NBU jointly organized a seminar on "Frontiers of Physics" during March 7-8, 2004 in the Physics Department of North Bengal University. Eminent scientists reviewed recent developments in the frontline areas of physics to the students and faculty, numbering about 80.

4. IRC, NBU and Physics Department jointly organized one day seminar on Compact Stars and Quark-Gluon Plasma on August 18, 2003. About 80 students and college/university teachers participated in this programme.

5. IRC, NBU, Paschim Banga Vigyan Mancha, and Siliguri College jointly organized a meeting on February 28, 2004 (National Science Day) in the auditorium of Siliguri College in which S. Mukherjee gave a popular talk on cosmology.

***Talks*:**

M. Dey: QCD-Motivated Equation of State for Strange Star, August 18; S. Mukherjee: Stars : Normal and Exotic, August 18; S. Bhowmik: Surface Vibrations of Strang Star, August 18; S. K. Ghosal: Myths in Relativity Theory : Yet Another!, August 18; M. Ghosh: Quark-Gluon Plasma in Particle Interactions, August 18 ; J. Dey: Compact Stars: Observational Problems or Peculiar Observation, August 18; A. Bhadra: High Energy Gamma Rays from Young Pulsars, August 18; B. C. Paul: Compact Stars in Higher Dimensions, August 18; S. Chakraborty (Visva Bharati): Supersymmetry, December 30; V. C. Kuriakose: Nonlinear Dynamics and Solitons, March 7; R. Kaul: Gravity as Gauge Theory, March 7; P. Majumdar: Universal Blackhole Entropy, March 7; J. V. Yakshmi: Superconductivity and Super Fluidity in Recent Focus : A Popular View, March 7; P. N. Ghosh: Bose Einstein Condensation : Physics and Nanokelvin Temperature, March 7; S. Dattagupta: Dissipation, March 8; S. Banerjee: Nonlinear Dynamics, Chaos and Fractal Geometry, March 8; S. Ravi: Ferromagnetism and Colossal Magneto-resistivity in Maganites, March 8.

***Visitors*:**

The following members visited this centre for various purposes like giving lectures, discussions, and collaborations and their stay extended for varying durations. Arun K. Jana (Darjeeling Government College) (5 days), Sukanta Daw (MMC College, Kolkata) (6 days), J. Dey (Maulana Azad College, Kolkata) (5 days), M. Dey (Presidency College, Kolkata) (5 days), S. Bhowmick (Barsat Government College) (5 days), S. Chakraborty (Visva Bharati) (3 days), V.C. Kuriakose (Cochin University of Science and Technology) (2 days), P. Majumdar (Saha Institute of Nuclear Physics, Kolkata) (2 days), P.N. Ghosh (Calcutta University) (1 day), Y. V. Yakshmi (BARC, Mumbai) (7 days), S. Dattagupta (S. N.

Bose National Centre for Basic Sciences) (1day), S. Banerjee (IIT, Kharagpur) (3 days), S. Ravi (IIT, Guwahati) (2 days), R.Kaul (Institute of Mathematical Science, Chennai) (2 days) R.Chhetri (Sikkim Government College), B. Kunwar (Sikkim Government College), and R.Sharma (St. Joseph College, Darjeeling). The last 3 have visited the centre frequently, mainly during weekends.

(4) Cochin University of Science and Technology, Kochi
(Report by V. C. Kuriakose - Coordinator)

Academic Activity :

1. IRC coordinator organized two meetings :

i. Workshop on Geometry and Topology Inspired by Physics during December 4-8, 2003, and

ii. International Conference on Gravitation and Cosmology during January 5-10, 2004.

2. The IRC Colloquia are being organized regularly for the benefit of postgraduate students, who are interested in theoretical physics. They are :

V.C. Kuriakose : Some recent developments in cosmology; Ramesh Babu T. : Multiphoton processing in atomic systems; Ninan Sajeeth Philip: Neural network in astrophysics; G.Ambika: Chaos in variable stars; K.P. Harikrishnan: Chaotic behaviour of a blackhole system; Ramesh Babu T.: Spontaneous symmetry breaking; M.Sabir : Chaos in solar system; K.P. Satheesh: Blackhole entropy

3. IRC has organized a series of lectures on topics like - tensor analysis, group theory, quantum field theory and nonlinear dynamics for the benefit of fresh Ph.D. students and post graduate students of this department.

Details of Seminars/Talks, etc.

Monthly Seminars: V.C.Kuriakose: Brane cosmology, July 30; C. Sudha Kartha: Holographic storage technology, August 29; K.B. Jinesh: Nano-materials: Basics and properties, September 2; V.C. Kuriakose: Superconductivity and Superfluidity, October 31; R.P. Kerr: Blackhole Physics, January 27; L. Godfrey: Mysterious red rains in Kerala, Extraordinary findings, February 26.

Seminar on Astrophysics on September 18. The speakers and the titles are, N.Dadhich: Subtleties of gravity; C.D. Ravikumar: Photonic and fundamental plane studies of galaxies; A.Kembhavi: The Roche potential, binaries and X-ray sources.

Seminar on General Relativity and Nonlinear dynamics held at Department of Physics, St.Thomas College, Kozhencherri during January 24-25, 2004. The speakers and the titles are, K.P.Satheesh: Introduction to general relativity; P.I. Kuriakose: Blackhole entropy; M.N.Vinoj: Introduction to optical solitons; P. Ajith: Gravitational waves; R.P. Kerr: Blackholes I; G.Ambika: Fractals; V.C. Kuriakose: Introduction to cosmology; R.P.Kerr: Black holes II; Ramesh Babu T: Scale invariants and renormalization group an introduction; Moncy V. John: Cosmographic evaluation of cosmological parameters using SNe IA data; Ninan Sajeeth Philip: On the possibility of building a super computer at affordable prices. (The last three talks were held on March 20.)

Visitors:

N. Dadhich (IUCAA) (3 days), A. Kembhavi (IUCAA) (3 days), R.P. Kerr (New Zealand) (4 days), Sumesh (Maharaja's College) (often visited for IRC work), and the others visited the Centre for delivering lectures and for collaborative work.

Papers published by associates and their collaboartors connected with the IRC are included in the list of publications by Visiting Associates.

The Fifteenth
IUCAA Foundation Day Lecture

DARKNESS OF THE CITY

Ashis Nandy

All explorations in the culture of the city oscillate between two poles. They have to do so to cope with the tension between the two tacit emphases in contemporary studies of the city: the ones that centre on the mind of the city and the ones that centre on the city of the mind. My work on the city has done so, too, and, in retrospect, it has gradually moved from the former to the latter. I think, I know why: mapping the city of the mind is a less formidable empirical venture than mapping the mind of the city. Identifying the unique personality of a city is always a tougher task than identifying a unique narrative on a city. It is true that sometimes the tension between these emphases dissolve, as for instance in Salman Rushdie's fictional Bombay in *Midnight's Children* or in Ziauddin Sardar's lively social and cultural history, *The Consumption of Kuala Lumpur*. But sometimes it may also sharpen, as in the fictional ethnography of Mangalore in Amitabh Ghose's *In an Antique Land*.

This tension takes different forms in different cities and, to grasp it, one must confront the diverse self-definitions of cities themselves. These self-definitions cluster around three nodes that seem to classify cities into three types: the ones that mainly define themselves in opposition to the village, the ones that mainly define themselves in opposition to other cities; and the ones that mainly define themselves in opposition to their own slums and ghettoes. As the types overlap, an empirically more faithful way of describing a city may be to conceptualise the nodes as dimensions and plot each city on a three-dimensional space. To add a touch of contemporaneity, one may even propose that each city can be simultaneously located in three intertwined narratives.

As I shall not have much to do with the first two kinds of city here, I shall say a few words on them first. The city that defines itself as a counterpoint of the village looms large in South Asian consciousness. Though cities like Varanasi and Cochin have represented a different kind of civic awareness for at least two millennia in this part of the world - by being coterminous with the village rather than being the successor of the village - the colonial city, particularly the three presidency towns - Calcutta, Madras and Bombay - were first of all negations of the Indian village. This negation was non-specific. That is, the presidency town did not have to have the qualities to be a counterpoint to the village but, because the colonial city had to be a denial of whatever the Indian village stood for, it had to acquire the qualities that would separate it simultaneously from a village and from 'compromised' premodern Indian cities. In this respect, 'moving' to a presidency town was different from going to a traditional city. The presidency town allowed a radical, this-worldly redefinition of self; a traditional city usually allowed only a more modest extension or expansion of self.

That redefinition of self in a colonial city could be emancipatory, as for instance when a dalit migrated to a city. But it had to come as part of a larger package. The colonial city proffered a brand-new Mephistophelian bargain, a sinister but highly attractive invitation to a sin-drenched anonymity and a seductive unencumbered individualism with new, strange principles of hierarchy built into it. These hierarchies negated many of the older hierarchies of the abandoned village and could pass themselves off as a legitimate, necessary, practical, this-worldly markers of progress. Both the anonymity and the individualism went beyond ordinary census-defined idea of urbanisation and ensured the presidency town's magnetism and ambivalent status. They also partly explained why the colonial political economy allowed a softer negation of the village through its administrative and revenue outposts in the form of small district towns. The primary purpose of these towns was pedagogic; while teaching the subjects civic virtues through moderate exposure to a moderately modern city, they taught the apprentices of the ruling classes, usually 'posted' in the town for short stretches of time, the art of management of the 'real' India. That was the bond between the district magistrate or the sub-divisional officer and his wards.

For both the rulers and the ruled, the smallness that the small town conveyed was not merely geographical; it was social. For the surrounding villages, the small town was not merely an outpost of the state; it was a relatively friendly neighbourhood town in touch with the village. The pathologies, the absurdities, even the everyday villainies of the small town bore the stamp of the rustic and the idyllic. The small town was different from the metropolis by virtue of the fact that it had to define itself with the help of the village, but never entirely in opposition to the village. That tradition survives, even if in an attenuated form.

Then, there are the cities that define themselves mainly in opposition to other cities. Such cities are rare in South Asia, though Singapore next door is a good example of such a city. Chandigarh and, to a lesser extent, Islamabad may be the only major cities in the region that meet the criterion. Chandigarh's earlier modest, pastoral self is now a recessive element in the myth of Chandigarh. The all-powerful mother goddess associated with its name is certainly a less weighty presence in the city's self-definition than its acquired presiding deity, architect Le Corbusier, whom Peter Hall calls an 'authoritarian centralist'. Yet, Chandigarh, all said, is the capital of Punjab and Haryana, two states known for their robust capacity to celebrate the idyllic. Architecturally, Chandigarh may be a flamboyant counterpoint of an Indian village, but its links with the rustic are all too obvious. However, that cannot be said about a number of First World cities; they have abrogated the village as their 'other.' Often located in countries where the village is increasingly an attenuated, partly fictive entity, cities like Houston and Los Angeles define themselves in opposition to other cities. These are cities where even the imagination of the village has died or become moribund. The civic cultures in these cities often do not presume a hinterland, a la Singapore, even though both the cities have such hinterlands just outside the borders of the United States. When a city sheds the village as a counterpoint, one does not have to seriously negotiate, negate or use as a utopian alternative the idea of the village. When someone does so, it is a highly individual act, almost a private whimsy. Probably, only in the last century we have produced modern cities that does not have to use the village as its antonym.

The third kind of city is related to the village primarily through its slums and ghettoes. The slums and the ghettoes epitomise village community life and the vernacular, as they struggle to survive in the city and as they adapt to the civic and the cosmopolitan. Like all epitomes, they are partly autonomous of what they epitomise. The village, which the slums and the ghettos seek to represent, changes colour according to needs of survival in the city. The oppressive village one has escaped to embrace the contractual, individualistic anonymity of the city does not stop the slum dweller from trying to recapture the village in the slum. Exactly as the village in the dreams of the uprooted does not oblige the dreamer to return to the village to actualise the dream. The city gives more space, Jane Jacobs argues, to relationships that are useful and enjoyable rather than intimate. The ghettos and the slums - especially slums that attract people from rural hinterlands - have to conform to this trend, but tend to create subcultures that idealise intimacies the city cannot sustain.

One could phrase this in a more prosaic way. One could claim that in a metropolis community, life and vernacular experience have to be, in the long run, pushed to the slums and the ghettoes to be sustainable parts of everyday life. This stylised relationship between the city and the village, though mediated in public, in full view of the citizens, does not constitute the metropolitan idea of negotiating with the village, because the slums and ghettoes do not passively seek space in the city. They defy and constantly try to subvert or distort the mainstream idea of the civic - the individualism, the anonymity and the emphasis on the contractual and the impersonal. It was as if they were exploring, against their grain, an alternative idea of civility. The slum is eventually an internal criticism and an internal defiance of the city. A society's living problems are epitomised in a slum in dramatic fashion, as if to make sure no one missed them or could claim that they had missed them. A ghetto is always partly a negation of the cosmopolis; it can give a city a touch of the exotic and the wild, as the China towns in some cities and black neighbourhoods in others do. However, the ghetto has an even more important role in the life of first-generation urbanites. What poet Daya Pawar says of Bombay, one can say of the city in general: it tears one into two the way king Jarasandha was torn into two in the *Mahabharata* by the second Pandava. In the ghetto, the two parts tend to come together, for the ghetto serves as the repository of the other self that is left behind when one surrenders to the city. The ghetto may be the anti-city, but it is the anti-city that completes the city. It connects, without anyone being wiser, the premodern city to its modern self. In some cities, it is the only accessible form of living tradition; the rest are in museum or on stage.

The criticism and the defiance that slums and ghettos venture do not come as a simple invocation of the pastoral or the 'uncivil'. They involve a new mix, where the urban and the civic - and the values and forms of awareness associated them - have to have a place, even if occasionally in a strange concoction. The slum and the ghetto represent the metropolis in a much more serious way than a district town, for instance, can ever do. The central problems of a modern city and the way individual subjectivity is caught in their hinges are both aggravated and dramatised in these anti-cities, serving as depositories of shared anti-memories. Hence, even when the slums and ghettos are doing well by the available criteria of civic performance, they can become the targets of eliminationist interventions. This targeting can take an ominous form in cities where slums are not dull, stagnant neighbourhoods, which the more energetic, the ambitious and the affluent flee, but are actually an escape for the energetic and the ambitious who are not affluent. Such slums are the *in situ* alternatives to the city, by being the underside of the city, the disowned, unintended, dark city. One strand in contemporary urban awareness seem to read such slums as shadows of the city. But it is possible to read many cities - Calcutta, Bombay, Mexico City, Rio de Janeiro, Sao Paulo - as shadows of their own slums and ghettoes. Their slums define them, while everyone believes that these cities define their slums.

The internal criticism and defiance of the dominant culture of the city become sharper when the slum and the ghetto overlap, when the slum is also a ghetto. When they do not, it becomes a different story. The individuality and anonymity that have to be underplayed in a ghetto face lesser challenges in a slum that is not a ghetto. The community that has to be built in a slum is presumed to exist readymade in the ghetto.

The slum mimics the village but its ambition is never to be a village. Its ambition is to conjoin the villager's concept of the city with the city's concept of the village. That is why, the village survives in the slum not by replicating itself, but by projecting another imagination of the city. The slum only technically opts out of the normal city; its project is to live in the city and live off it. The ghetto, similarly, is not the communitarian's ideal of a community in the city. It is partly the idea of a community of those who remain in their hearts immigrants to the city, desperately trying to recreate a community in an atmosphere hostile to communities. The ghetto is defined by its exclusions. It is simultaneously the city's revenge on those who have refused to melt in its melting point and the community's negation of the steam-rolling culture of a civic melting pot. The coagulants that refuse to melt - when skimmed, collected and relocated or reconfigured correctly - are projections of other kinds of civic subjectivities, the contents of which are shaped by a larger cultural politics of survival and resistance. The ghetto survives not only on primordiality but also on secular constructions of primordiality. Above all, the ghetto survives by giving its residents the illusion of protection when other illusions of protection have collapsed. As the illusion of the security that the modern nation-state promises frays at the edges, public consciousness increasingly gets used to the twentieth century's most public secret - that the modern state has an in-built tendency to refuse security to its ordinary citizens when the need for that security clashes with the need to ensure its own security. In fact, the security of a modern nation-state feeds on the insecurity of its citizens, particularly when the citizens flaunt self-definitions that are fully acceptable or transparent to the modern self.

The ghetto offers to resist the projects of the modern nation-state. It does so by relocating the much vaunted individual of the post-seventeenth century world in the matrix of a settlement trying to survive as a culturally distinct community, thus, conflating the two survivals, the individual's and the community's. That conflation, by conjuring up the imagery of another kind of individualism, declines the invitation of the modern state to its citizens to live in an abridged interpersonal world to qualify as a responsible citizen. This is an example of how the modern city promotes a particular brand of primordiality even when subverting the primordial. A ghetto when it explodes in ethnic or religious violence illustrates contemporary secular uses of primordiality and brings that primordiality closer to the normal city than its normal citizens like. It looks dangerously like a self that has caught fire. Hence, the frantic attempts to fit such violence in theoretical frames that will distance the violence, by seeing it a pathology of anachronistic primordiality that has somehow survived in a modern city.

The slums and the ghettoes constantly threaten the mould of respectability and normality. When they cannot break it, they seek to trespass or gatecrash into our conscience, often as a ploy and as a technique of survival. When they cannot even do so, their politics of recognition may take pathological forms. In the slum, that pathology should typically take the form of crime; in the ghetto, some form of fundamentalism or ethnic chauvinism. I say 'should' because mainstream global common sense, which takes over our lives the moment we lower our guards, feels let down if pathologies in the anti-city do not take these preformatted courses. The most feared form of riots, feared even by those who organise them, are the ones in which the slums explode. When that happens, we think we know that the ghetto has entered the slum. The most feared form of terrorism, the one that the terrorists themselves fear, is the one in which the individual terrorist self-destructs. When that happens, we think we know that the ghetto has crossed the threshold of desperation.

What Sardar contests is the idea of cosmopolitanism as a European concoction when, even historically, impressive versions of cosmopolitanism have existed over the millennia in Asia, Africa and in the Americas. However, even Sardar may admit that the metropolis, in its present sense, does not have a long past in Asia. Baghdad, Damascus, Varanasi, Beijing and Jerusalem were cities, so were Athens and Rome. None could be called a metropolis in the contemporary sense, because the term now indicates a city that has taken the first step towards being a megalopolis and, perhaps, eventually a necropolis, a dead city that is at the same time a city of the dead. One suspects that the term acquired a post-medieval meaning for the first time in the case of imperial London. This had much to do with London's new status as the hub of and modern industrial capitalism and colonialism. That particular touch of megalomania cities like New York, Los Angeles, Bangkok, Bombay, Shanghai and Mexico City now seem keen to acquire.

However, a city can partly obviate the need for alternatives by building into its culture a different kind of transience than the one in which Los Angeles specialises. Varanasi or Benaras is unique, not because of its traditional cultural core but because of the way the city plays with binary opposites it has set up *within* the myth of the city: the classical and the canonical versus the local and the noncanonical, the traditional versus its recreated or reworked versions, the sacred and the austere versus the secular and the hedonic, and above all, the time-transcending versus the transient. The uniqueness of the four-thousand year-old city lies in the way it plays with these oppositions - coexisting, contradictory pasts and 'histories'- without being overwhelmed.

Other cities have other ways of handling their multiple selves. A number of cities of Asia, for instance, became cities not because they grew from being fortifications against attacks, capitals of principalities, or commercial hubs, but because they were at crossroads. Actually, they were the crossroads. The cities on the old silk route, such as Samarkhand and Damascus, cities on the Indian Ocean's sea routes, such as Cochin and Mangalore, which connected East and West Asia, Africa and Europe - all began their journey as habitats, where different traditions of cosmopolitanism contested and conversed. They *were* commercial centres, but the culture of commerce, serving as the building block of civic consciousness, gradually acquired as its adjunct the culture of a crossroad, a place where one stopped on the way to other destinations. These destinations could be countries, regions or even other small, esoteric cities like Lhasa or Timbuktu. By negotiating such crossroads or even simply stopping at them, one could engage not merely with the past but also with 'strange' cosmopolitanisms. The shared, popular memories and the mythic early years in the biographies of many of these cities - the *janapada puranas* - handicap them as futuristic cities. As I have said, in the contemporary civic awareness, a futuristic city must learn to constantly erase its past or museumise or historicise it for the sake of experts and tourists. (Like all *puranas*, these mythic pasts also often have a touch of the demonic and the magical. I have already mentioned Maya, who participated in building Delhi that was Indraprastha. Lanka was the vision of a brahmarakshasa; Rome was made possible by a nurturing wolf. As if by recognising that touch of the creative and the life-giving in the demonic, one recognised the full meaning of the city and, in some cases, made peace with its seductive 'sinfulness'.)

The software of the dark city lies in slums and ghettoes, the hardware in sewers and by-lanes. Exactly as the darkness of the village lies not only in its sinister hierarchies and exclusions but also in its caves, forests and marshes. They hid the evils of the village, real or imaginary. But the relationship is not isomorphic. The caves, forests and marshes are never in the village but haunt the village from outside. The sewers and by-lanes that haunt the city are all inside; they are the abode of epidemics that have haunted the city for millennia and, during the last century, they have sometimes become a haven for political terror. They remain at the peripheries of our vision not always for the reasons the urban planner wants them at the periphery - for being eyesores and uncomfortable reminders of filth, pollution, waste and, sometimes, poverty, hunger and lowbrow diseases like cholera, typhoid and dysentery. They remain outside, also as a projection of our exiled selves and as a mythic middle-class concretisation of the avoidable, the fearsome, the volatile, the haunting and, above all, the necessary that need not be unnecessarily seen. The concretisation makes it psychologically more manageable. That is why, when the slums explode during a religious or ethnic riot, everyone is disturbed, including those who ferment the riot and those who believe that it is evil but inevitable. Such explosions come to symbolise a part of one's self that has given way. We begin to feel that both our targets of social engineering and myths of the incorruptibility of the poor and the powerless have collapsed. Hence, as sometimes happens in the case of individuals, the slums of a city become its externalised conscience. Hence, also the charisma of Mother Teresa and Akhtar Hamid Khan. To own up the slums is more difficult than to own up the high crime rates or pollution of a city. The slums are within the city and yet outside, exactly as the caves, forests and marshes are outside the village but actually in within. To own up the slums is to own up, painfully, the entirety of our cities and, perhaps, the entirety of our public selves.

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