IUCAA

Annual Report 2002-2003

Inter-University Centre for Astronomy and Astrophysics

(An Autonomous Institution of the University Grants Commission)

Cover Pages :

Some glimpses of the Honourable President Dr. A.P.J. Abdul Kalam's informal visit to IUCAA, and the founder Director Professor J. V. Narlikar on the eve of his retirement from IUCAA.

IUCAA

INTER-UNIVERSITY CENTRE FOR ASTRONOMY AND ASTROPHYSICS

(An Autonomous Institution of the University Grants Commission)

Annual Report

(April 1, 2002 - March 31, 2003)

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HIGHLIGHTS OF 2002- 2003

This annual report covers the activities of IUCAA during its fifteenth year, April 2002 -March 2003. The endeavours of IUCAA span different fronts, as outlined in the pages of this Report. Here is a quick summary and highlights.

IUCAA has an academic strength of 15 core faculty (academic) members, 10 post-doctoral fellows and 15 Ph.D. students (Research Scholars). The core research programmes by these academics span a variety of areas in astronomy and astrophysics. These topics include investigations in quantum and classical gravity, gravitational waves, cosmology and structure formation, cosmic microwave background radiation, extragalactic astronomy, quasar absorption systems, high energy astrophysics, galaxy and interstellar medium, stellar physics, solar physics and instrumentation. These research activities are summarised in pages 16 -48. The publications of the IUCAA members, numbering to about 125 in the current year are listed in pages 69-73. IUCAA members also take part in pedagogical activities like lectures, seminars, popularisation of science, etc., the details of which are given in pages 79-80 of this report.

The extended academic family of IUCAA consists of 88 Visiting Associates, who have been active in several different fields of research. Pages 49-68 of this report highlights their research contributions spanning gravitational theory, gravitational waves, cosmological models, quantum cosmology, braneworld and quintessence, theoretical physics, non-linear dynamics, galaxies and quasars, compact stellar remnants, interstellar matter and star formation, Sun and the solar system, magnetohydrodynamics and plasma physics, atmospheric and ionospheric physics, and instrumentation. The resulting publications, numbering to about 118 are listed in pages 74-78 of this report.

A total of about 1400 man-days were spent by Visiting Associates at IUCAA during this year. In addition, IUCAA was acting as host to about 570 other visitors through the year.

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 6 such events in IUCAA and 7 were held at other universities/colleges under IUCAA sponsorship.

Another main component of IUCAA's activities is its Public Outreach Programme. On the National Science Day this year, several special events were organised. There was a demonstration of the Maze Solving Robot, which was built by the students of engineering colleges in Pune and demonstration and talks on aeromodelling by Madhav Khare. The other events comprised of programmes for school students consisting of quiz, essay and drawing competitions, and the Open Day when more than 3000 people visited IUCAA.

These activities were ably supported by the scientific and technical, and administrative staff (18 and 35 in number), who should get the lion's share of the credit for successful running of the programmes of the centre. The scientific staff also looks after the major facilities like library, computer centre and instrumentation lab. A brief update on these facilities is given on pages 101- 102 of this report.

IUCAA has plans for a 2-metre new technology telescope for optical astronomy. The telescope, which was made under contract with the Particle Physics and Astronomy Research Council of the UK Government, has now arrived at the site and is being assembled.

CONTENTS

The Council and the Governing Board

The Council

President

Hari Gautam, (till April 2002)
Chairperson,
University Grants Commission, New Delhi.

A.S. Nigavekar, (from July 16, 2002)
Chairperson,
University Grants Commission, New Delhi.

Vice-President

A.S. Nigavekar, (till July 15, 2002)
Vice-Chairperson,
University Grants Commission, New Delhi.

Members

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

Arvind Bhatnagar, (till October 4, 2002)
Emeritus Scientist,
Udaipur Solar Observatory, Udaipur.

A. K. Bhatnagar, (from June 30,2002 till December 31,2002)
Vice-Chancellor,
University of Hyderabad,
Hyderabad.

M. Bhattacharyya, (till December 31, 2002)
Vice-Chancellor,
West Bengal University of Technology, Kolkata.

L. Chaturvedi,
Banaras Hindu University, Varanasi.

Arnab Rai Chaudhuri, (from January 1, 2003)
Indian Institute of Science,
Bangalore.

S.M. Chitre, (till Dcember 31, 2002)
Tata Institute of Fundamental Research,
Mumbai.

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

G.G. Dandapat, (till April 2002)
Officiating Secretary,
University Grants Commission, New Delhi.

S. Dattagupta, (from January 1, 2003)
Director,
Satyendra Nath Bose National
Centre for Basic Sciences,
Kolkata.

Deepak Dhar, (from January 1, 2003)
Tata Institute of Fundamental Research,
Mumbai.

B. Hanumaiah, (till December 31, 2002)
Vice-Chancellor,
Mangalore University, Mangalore.

A.W. Joshi, (till December 31, 2002)
University of Pune, Pune.

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

S.S. Katiyar, (till December 31, 2002)
Vice-Chancellor,
Chhatrapati Shahu Ji Maharaj University, Kanpur.

C.L. Khetrapal, (till December 31, 2002)
Sanjay Gandhi Post-Graduate Institute of
Medical Sciences, Lucknow.

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

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

Sipra Guha-Mukherjee,
Jawaharlal Nehru University, New Delhi.

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

T. Padmanabhan,
IUCAA, Pune.

R. R. Pandey, (from January 1, 2003)
Vice-Chancellor,
Deendayal Upadhyaya Gorakhpur University,
Gorakhpur.

K.N. Pathak, (from November 7, 2002)
Vice-Chancellor,
Panjab University, Chandigarh.

Ved Prakash, (from November 7, 2002)
Secretary,
University Grants Commission,
New Delhi.

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

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

P. Rama Rao, (till June 29, 2002)
Vice-Chancellor,
University of Hyderabad, Hyderabad.

A. Sankara Reddy, (till December 31, 2002)
Sri Venkateswara College,
New Delhi.

Nityananda Saha, (from January 1, 2003)
Vice-Chancellor,
University of Kalyani,
West Bengal.

C.P. Srivastava, (from April 2002)
Officiating Secretary, (till November 2002)
University Grants Commission,
New Delhi.

S. S. Suryawanshi, (from January 1, 2003)
Vice-Chancellor,
Swami Ramanand Teerth Marathwada University,
Nanded.

J.A.K. Tareen, (from January 1, 2003)
Vice-Chancellor,
Univesity of Kashmir,
Srinagar.

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

Member Secretary

J.V. Narlikar,
Director, IUCAA.

The Governing Board

Chairperson

R.P. Bambah

Members

Arvind Bhatnagar (till October 4, 2002)
L. Chaturvedi
Ramanath Cowsik
G.G. Dandapat (till April 2002)
Sipra Guha - Mukherjee
A.S. Kolaskar
Rajaram Nityananda
T. Padmanabhan
K.N. Pathak (from November 7, 2002)
Ved Prakash (from November 7, 2002)
C.P. Srivastava (from April 2002 till November 2002)
M. S. Thimmappa

Member Secretary

J.V. Narlikar,
Director, IUCAA.

Honorary Fellows

Geoffrey Burbidge,
University of California,
CASS, USA.

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

A. Hewish,
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.

Statutory Committees

The Scientific Advisory Committee

S.R. Choudhury,
University of Delhi, Delhi.

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

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

Pushpa Khare,
Utkal University, Bhubaneswar.

N. Mukunda,
Indian Institute of Science, Bangalore.

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

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

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

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

J.V. Narlikar, (Convener)
IUCAA, Pune.

Users' Committee

J. V. Narlikar, (Chairperson)
IUCAA, Pune

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

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

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

N.K. Dadhich,
IUCAA, Pune.

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

Bharat Oza,
Vice-Chancellor,
Bhavnagar University, Bhavnagar.

R. Ramakrishna Reddy,
Sri Krishnadevaraya University, Anantapur.

The Academic Programmes Committee

J. V. Narlikar (Chairperson)
T. Padmanabhan (Convener)
N. K. Dadhich
S. V. Dhurandhar
Ranjan Gupta
A. K. Kembhavi
Varun Sahni
R. Srianand
S. Sridhar (till August 9, 2002)
K. Subramanian
S. N. Tandon

The Standing Committee for Administration

J.V. Narlikar (Chairman)
T. Sahay (Member Secretary) (till October 7, 2002)
S. Shankar (Member Secretary) (from October 8, 2002)
A.K. Kembhavi
T. Padmanabhan

The Finance Committee

R.P. Bambah (Chairperson)
L. Chaturvedi
G. G. Dandapat (till April 2002)
J.V. Narlikar
O.P. Nigam (till July 2002)
R. Nityananda
Ved Prakash (from November 7, 2002)
T. Padmanabhan
T. Sahay (Member Secretary) (till October 7, 2002)
S. Shankar (Member Secretary) (from October 8, 2002)
C. P. Srivastava (from April 2002 to November 2002)

Members of IUCAA

Academic

J.V. Narlikar (Director)
T. Padmanabhan (Dean, Core Academic Programmes)
A.K. Kembhavi (Dean, Visitor Academic Programmes)
J. Bagchi
N.K. Dadhich
S.V. Dhurandhar
R. Gupta
R. Misra
A.N. Ramaprakash
V. Sahni
Tarun Souradeep
R. Srianand
S. Sridhar (till August 9, 2002)
K. Subramanian
S. N. Tandon

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

Administrative and Support

T. Sahay (Senior Administrative Officer) (till October 7, 2002)
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
K.C. Nair
R.D. Pardeshi
R.V. Parmar
B.R. Rao
M.A. Raskar (till October 4, 2002)
M.S. Sahasrabudhe
V.A. Samak
S.S. Samuel
B.V. Sawant
S. Shankar (Senior Administrative Officer, officiating from October 8, 2002)
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 (from August 2, 2002)
P. Chakraborty (from October 29, 2002)
Tapas K. Das (till August 30, 2002)
H. K. Jassal
S. Konar (till October 1, 2002)
B. Mukhopadhyay (from May 6, 2002)
R. Nayak
S. Sahay
P. Subramanian
R.G. Vishwakarma

Research Scholars

A.L. Ahuja
U. Alam
T. Roy Choudhury
A. Deep
Amir Hajian Forushani
S. Mitra
Ali Reza Rafiee (from July 29, 2002)
A. Rawat (from August 6, 2002)
N.B. Sambhus (till July 31, 2002)
A. A. Sengupta
Arman Shafiloo (from August 12, 2002)
S. Shankara Narayanan (till October 17, 2002)
J.V. Sheth
P. Singh
H. Chand Verma

Project and Contractual Appointments

A.P. Chordia
(Computer Centre)

K. James
(System Administrator, ERNET Project)

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

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

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

P. Kulkarni (Virtual Observatory of India - Project Officer) (from April 3, 2002)

V. Raskar (Assistant, Public Outreach Programme) (from December 24, 2002)

Part time Consultant

S. S. Bodas
(Medical Services)

Visiting Members of IUCAA

Visiting Associates

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

Z. Ahsan,
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Department of Mathematics,
K.G.K. (P.G.) College, Moradabad.

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North Bengal University, Darjeeling.

U. Narain,
Astrophysics Research Group,
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S.K. Pandey,
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Pt. Ravishankar Shukla University, Raipur.

P.N. Pandita,
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North Eastern Hill University, Shillong.

B. C. Paul,
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North Bengal University, Darjeeling.

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

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St. Stephen's College, Delhi.

Lalan Prasad,
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Zakir Husain College, New Delhi.

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Department of Physics,
Jamia Millia Islamia, New Delhi

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

G.P. Singh,
Department of Mathematics,
Visvesvaraya Regional College of Engineering,
Nagpur.

H.P. Singh,
Department of Physics & Electronics,
Sri Venkateswara College, New Delhi.

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

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

D.C. Srivastava,
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D.D.U. Gorakhpur University.

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

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

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.

...till June 30, 2002

M.N. Anandaram,
Department of Physics,
Bangalore University.

S. Chatterji,
Department of Physics,
New Alipore College.

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

B.A. Kagali,
Department of Physics,
Bangalore University.

Lalan Kumar Jha,
Department of Physics,
L.N.T. College, Muzaffarpur.

M.L. Kurtadikar,
Department of Physics,
J.E.S. College, Jalna.

S.K. Pathak,
Department of Physics,
Christ Church College, Kanpur.

Amitava Sil,
Department of Physics,
St. Joseph's College, Darjeeling.

L.P. Singh,
Department of Physics,
Utkal University, Bhubaneswar.

V.O. Thomas,
Department of Mathematics,
M.S. University of Baroda.

...from July 1, 2002

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

Satyabrata Biswas,
Department of Physics,
University of Kalyani.

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

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

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

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

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

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

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

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

Saibal Ray,
Department of Physics,
Barasat Government College.

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

Bhim Prasad Sarmah,
Department of Mathematical Sciences,
Tezpur University

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

Rajendra N. Shelke,
Space Research Centre,
College of Engineering, Badnera

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

The thirteenth batch of Visiting Associates who were selected for a tenure of three years, beginning July 1, 2002.


Rashmi Bharadwaj


Tanuka Chatterjee


Kalyan K. Mondal


Ninan Sajeeth Philip


Anirudh Pradhan


K. D. Patil


Saibal Ray


Bhim Prasad Sarmah


Rajendra N. Shelke


T.R. Seshadri


R.C. Verma


Sanjay K. Pandey

The photographs of the following Visiting Associates from the thirteenth batch are not available: Satyabrata Biswas, S.K. Popalghat, Rastogi Shantanu and Ravindra V. Saraykar.

Appointments of the following Visiting Associates from the tenth batch were extended for three years: Zafar Ahsan, Bindu A. Bambah, Asit Banerjee, S.P. Bhatnagar, Somenath Chakrabarty, D.K. Chakraborty, Deepak Chandra, Suresh Chandra, Arnab Rai Choudhuri, Mrinal Kanti Das, Jishnu Dey, Mira Dey, Anil D. Gangal, Prem P. Hallan, Syed N. Hasan, K. Indulekha, Pushpa Khare, Ashok C. Kumbharkhane, V. C. Kuriakose, Daksh Lohiya, Usha Malik, S. Mukherjee, S.K. Pandey, Lalan Prasad, P. Vivekananda Rao, Lal Mohan Saha and Ramesh Tikekar.

Organizational Structure of IUCAA's Academic Programmes

The Director
J.V. Narlikar

Dean, Core Academic Programmes
(T. Padmanabhan)

Head, Post-Doctoral Research
(S.V. Dhurandhar)

Head, Computer Centre
(A.K. Kembhavi)

Head, Library & Documentation
(T. Padmanabhan)

Head, Publications
(T. Padmanabhan)

Head, M.Sc. & Ph.D. Programmes
(S.V. Dhurandhar)

Head, Instrumentation Laboratory
(S.N. Tandon)

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

Head, Visitor Facilities
(A.K. Kembhavi)

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

Head, Recreation Centre
(R. Srianand)

Head, Guest Observer Programmes
(R. Srianand)

Head, Workshops & Schools
(N. K. Dadhich)

Head, Public Outreach Programmes
(J. V. Narlikar)

The Director's Report

This report presents the account of events and activities forming part of the manyfold ways that IUCAA functions. The Project Report written in 1988 while setting up IUCAA has all along set the goals for whatever the Centre does today, although improvisations needed as per the existing situation are always allowed for. Accordingly, a menu of research, pedagogy, instrumentation, guest observership, associateship programme as well as efforts in public outreach may be found here. I am indeed thankful to my academic colleagues for taking on these numerous activities cheerfully and contributing their own ideas and innovations that have made IUCAA known nationally and internationally. I have yet to find another institution that carries out such a wide range of academic programmes under one roof.

Thanks to the support of the foundation set up by Ms. Sheila Watumull in Hawaii, USA, IUCAA was able to host a workshop jointly with the Institute for Astronomy, Hawaii on topics related to extragalactic astronomy and cosmology. This workshop is seen as a precursor to the longer term collaborations between IUCAA (acting on behalf of Indian astronomers and astrophysicists from the university sector), and the astronomers of the IfA.

This year saw five scientific meetings sponsored by IUCAA in the campuses of Colleges: the Mar Thoma College, Tiruvalla (Kerala), NES College, Nanded (Maharashtra), Science College, Nagpur (Maharashtra), Fergusson College, Pune (Maharashtra) and Siliguri College, Darjeeling (West Bengal). The fact that all five meetings went off with great local enthusiasm, is an indication of research potential in Colleges outside the university campuses. Indeed a significant fraction (35%) of our associates today come from colleges. Besides the above there were two workshops held in the campuses of the Universities: University of Delhi, Delhi and Cochin University of Science and Technology, Kochi.

As the awards and recognitions section of the report shows, an increasing number of IUCAA academics are being so honoured. Side by side, IUCAA is consciously trying to improve the visibility of university and college academics in the national scientific profile by increasing their active participation in national and international conferences.

The IUCAA Telescope is now passing through the final stages of installation which will be followed by testing. Although, it is hazardous to make predictions for this delayed project, we hope that the telescope will be able to begin significant observations by the winter of 2003-2004. The delays, though unfortunate, were for reasons beyond IUCAA's control.

This year's National Science Day celebration saw active participation by enthusiastic school-students on the first day and an equally enthusiastic public response to the Open Day that followed. We had several innovations and I am grateful to all IUCAA members and others from outside who contributed to a very successful public outreach exercise.

This is the last Director's Report that I will write, as I retire from my present position on reaching the age of 65 in July 2003. The President of the Council has already appointed Naresh Dadhich as my successor, who will take charge as Director on July 18, 2003. Naresh had the distinction of being the first appointee of IUCAA, when he assumed charge as the Project Coordinator of the IUCAA Project with effect from February 10, 1988. He set up an one-room office in the Golay Bungalow in the Pune University Campus, where I had joined him on June 1, 1989. The accompanying photograph shows both of us standing on the IUCAA land *before anything was built.*

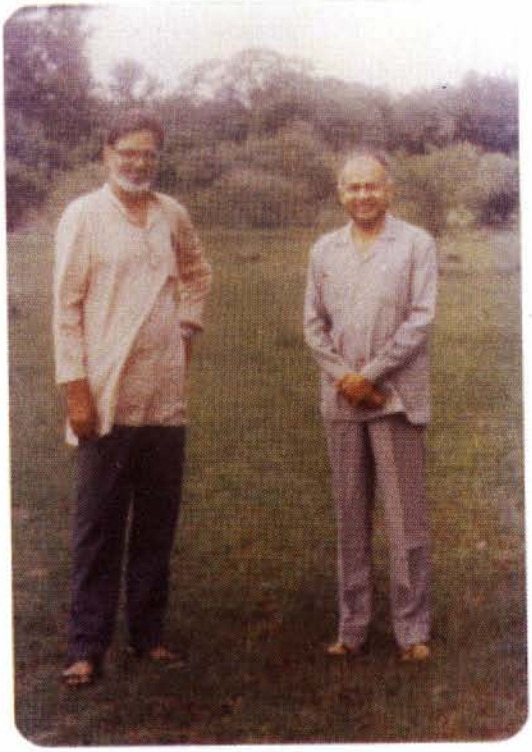
All that looks in the distant past, if one may allow IUCAA the luxury of calling its present age of 14 years, as something exceptionally large. If I may be permitted a brief introspection triggered by those early days, I begin by recording my satisfaction on the counts of academic excellence achieved by IUCAA and its associates, the spread of astronomy and astrophysics in the university sector, the unique stature of IUCAA's public outreach programme, the excellent support and rapport I have enjoyed from all staff members at IUCAA, and last but not the least, the positive encouragement I have received from the UGC. When Professor Yash Pal, the then Chairman, UGC asked me back in 1988, to leave Bombay and sever all ties with the Tata Institute of Fundamental Research where I was then working, to come to Pune and set up IUCAA, I was optimist but not sure as to what this effort would develop into. After fifteen years, let me say a belated "Thank You" to Yash Pal for entrusting me with this responsibility.

Of course, I am aware that I have not been 100% successful. The fate of the pension scheme promised in the Bye-Laws still hangs in balance. The highly dedicated administrative and support staff deserve a better promotion policy. The usage of facilities at IUCAA could be greater if we could persuade the university authorities to take a more liberal attitude towards granting permissions to their faculty-members to be away from their headquarters for pursuing their research interests with the help of facilities offered at IUCAA. Being the optimist that I am, let me hope that my successor, with the backing of UGC will be able to bring about improvements. He has my best wishes and all support that I can give as an individual.

I cannot sign off without recording my debt to Professor R.P. Bambah who, as the Chairman of the Governing Board was like a solid rock to lean on when the need arose. His wise counsel on several occasions helped me and my colleagues to take the right decisions and react rationally to crisis situations. He will relinquish office on June 18, 2003 and will be succeeded by another long-time friend and well-wisher of IUCAA, Professor N. Mukunda. On behalf of IUCAA, I convey to Professor Bambah our best wishes for a long happy and intellectually satisfying life ahead, and request him to keep in touch with IUCAA in the future. IUCAA also extends a warm welcome to Professor Mukunda, as the new Chairman of the Governing Board and looks forward to closer interaction with him in future.

Finally, it is a pleasure to welcome Professor A. S. Nigavekar, who assumed charge as Chairman, University Grants Commission during this year (2002-2003) and in that capacity is the President of the Council of IUCAA. He has been a source of strength and new ideas, and it is a pleasure to have him at the helm of not only IUCAA but all the IUCs.

J. V. Narlikar
Director



Awards and Distinctions

Naresh Dadhich

Honourable Mention in the Gravity Essay Contest (awarded by Gravity Research Foundation, USA), 2002.

Honorary Research Professor in the School of Mathematics and Statistics, University of Natal, Durban for 2003-2006.

J. V. Narlikar

Rajbhasha Award from the Indian Farmers Fertiliser Cooperative Limited (IFFCO), Delhi for work in Hindi literature.

Honorary Visiting Professor, Andhra University, Visakhapatnam.

Doctor of Science and Doctor of Literature (Honoris Causa) from the University of Kalyani, Kalyani.

Kamal Kumari National Award for Science & Technology (2000) from the Kamal Kumari Foundation, Assam.

Yashwantrao Chavan National Award (2002) from the Yashwantrao Chavan Pratisthan, Mumbai.

T. Padmanabhan

Second Prize in Gravity Essay Contest (awarded by Gravity Research Foundation, USA), 2002.

Homi Bhabha Fellowship, 2003-.

Varun Sahni

Elected fellow of the Indian Academy of Sciences, Bangalore.

Honourable Mention in the Gravity Essay Contest (awarded by Gavity Research Foundation, USA), 2002.

Tarun Souradeep

N.S. Satyamurthy award - 2001, Indian Physics Association (awarded in April 2003).

S. N. Tandon

Appointed "Adjunct Distinguished Professor" in Indian Institute of Astrophysics, Bangalore.

Designated "Programme Manager, UVIT Payload" in Astrosat Project of Indian Space Research Organisation.

R. G. Vishwakarma

Honourable Mention in the Gravity Essay Contest (awarded by Gravity Research Foundation, USA), 2002.

Awarded a 'Regular Associateship' of the Abdus Salam International Centre for Theoretical Physics (ICTP) from January 1, 2003 till December 31, 2008.

Calendar of Events

2002

April 8-May 17	**School Students' Summer Programme** at IUCAA
May 10	**IUCAA-NCRA Graduate School** Second semester ends
May 20-June 21	**Refresher Course in Astronomy and Astrophysics for College and University Teachers** at IUCAA
May 20 -July 5	**Vacation Students' Programme** at IUCAA
Augus 12	**IUCAA-NCRA Graduate School** First semester begins
October 7 -9	**Workshop on Gravity and Astrophysics** at Mar Thoma College, Tiruvalla
October 27 -30	**Workshop on Gravitation and Astrophysics** at Science College, Nagpur
October 28 - November 17	**Workshop on Telescope Making at M and N English High School, Margao.**
November 16 - 20	**Introductory School on Astronomy and Astrophysics** at Siliguri College, Darjeeling
November 16 - 20	**Workshop on Early Universe, Large Scale Structure and the CMBR** at Delhi University
November 26 - 28	**Introductory School on Astronomy and Astrophysics for College Students** at Fergusson College, Pune
December 11 - 14	**XXII Meeting of the Indian Association for General Relativity and Gravitation** at IUCAA
December 13	**IUCAA-NCRA Graduate School** First semester ends
December 18 -21	**Introductory School on Astronomy and Astrophysics** at N.E.S. Science College, Nanded
December 29	**Foundation Day**

2003

January 6	**IUCAA-NCRA Graduate School** Second semester begins
January 6 - 10	**Workshop on Astronomy with Small Telescopes** at IUCAA
January 23 - 29	**Workshop on Field Theoretic Aspects of Gravity - (FTAG - III)** at Cochin University of Science & Technology, Kochi
February 8-11	**Workshop on Cosmology and the High Redshift Universe, at IUCAA** (In collaboration with Institute for Astronomy and co-sponsored by Watumull Foundation, Hawaii).
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

Semi-classical quantisation of gravity

Several investigations in the field of quantum gravity has suggested the importance of two-dimensional surfaces as the key ingredients of spacetime. In the loop quantum gravity approach, there is a suggestion that areas are quantised in units of square of Planck length. In string theory, on the other hand, two-dimensional surfaces play a key role.

Recently, *T. Padmanabhan* and Apoorva Patel have come up with a direct and powerful approach for studying the semiclassical limit of quantum gravity and the role of area quantisation in this limit. After a careful analysis of general covariance, they argue that any theory of quantum gravity must lend itself into consistent formulation for any observer, including those who have only access to limited regions of spacetime.

This aspect, viz., that different observers may have access to different regions of spacetime and hence, differing amount of information, introduces an unusual feature in the theory. There is a strong motivation to postulate that physical theories in a given coordinate system must be formulated entirely in terms of the variables that an observer using that coordinate system can access. *Padmanabhan* and Patel call this postulate the "principle of effective theory".

This postulate is a new addition to the traditional principles of general relativity, although, it is a familiar principle in high energy physics. In the simplest context of field theories, a principle of the above kind "protects" the low energy theories from the unknown complications of the high energy sector. For example, one can use QED to predict results at, say, 10 GeV without worrying about the structure of the theory at 10^{19} GeV, as long as one uses coupling constants and variables defined around 10 GeV and determined observationally.

This principle is powerful enough to obtain the following results: (a) The action principle of gravity must be of such a structure that, in the semiclassical limit, the action of the unobserved degrees of freedom reduces to a boundary contribution, $A_{\rm boundary}$ obtained by integrating a four divergence. (b) When the boundary is a horizon, $A_{\rm boundary}$ essentially reduces to a single, well-defined, term. (c) This boundary term must have a quantised spectrum with uniform spacing, $\Delta A_{boundary} = 2\pi\hbar$, in the semiclassical limit. Using this principle in conjunction with the usual action principle in gravity, they show that: (i) The area of any one-way membrane is quantised. (ii) The information hidden by a one-way membrane leads to an entropy, which is always one-fourth of the area of the membrane, in the leading order. (iii) In static spacetimes, the action for gravity can be given a purely thermodynamic interpretation and the Einstein equations have a formal similarity to the laws of thermodynamics.

Field theory in curved spacetime

Propagation of fermions in curved spacetime generates gravitational interaction due to coupling of its spin with spacetime curvature. This gravitational interaction, which is an axial-four-vector multiplied by gravitational four vector potential, appears as CPT violating term in the Lagrangian and that generates an asymmetry between the left-handed particle and corresponding right-handed anti-particle under CPT transformation. This spacetime interaction can generate neutrino asymmetry in the Universe. If the background metric is of a rotating Kerr blackhole, this interaction is nonzero for neutrino. Therefore, the dispersion relation for neutrino and anti-neutrino are different, which gives rise to the difference in their number densities and, thus to neutrino asymmetry in the Universe. This asymmetry can become significant for a high temperature Hawking bath around rotating blackholes, in accretion disks and for mini blackholes at the Large Hadron Collider. In fact, this asymmetry can be generated in any spacetime which is axially symmetric. For example, this asymmetry can be achieved in case of Bianchi model (say type II). *B. Mukhopadhyay* and *P. Singh* who have carried out these investigations, find that the main criteria to generate neutrino asymmetry in this mechanism are: (i) The spacetime should be axially symmetric, (ii) the interaction Dirac-Lagrangian must have a CPT violating term which may be an axial-four vector (or pseudo-four vector) multiplied by a curvature coupling vector potential, (iii) the temperature scale of the system should be large with respect to the energy scale of the spacetime curvature.

Classical Gravity

Structure of Einstein - Hilbert action

The action functional plays a crucial role in semi-classical and quantum limits of theories. In the semi-classical limit, the knowledge of action functional allows one to re-construct WKB limit of the wave function and in quantum theory action functional plays vital role in the path integral formulation.

T. Padmanabhan has been investigating several peculiar features of the standard action functional for gravity. He finds that several results which are conventionally thought of as having to do with quantum gravity are already ingrained in the classical action for gravity. For example, Einstein's theory is unique in that it requires second derivatives of the basic variables in its action. When these derivative terms are converted into surface integrals, an interesting relation emerges between the area of horizons and the entropy. This relation, of course, is well-known in the physics of blackholes.

Padmanabhan has been able to show that this result can be turned around on its head. It is possible to start from a postulate that any horizon which blocks information should contribute an entropy, which is proportional to its area and obtain the full dynamics of gravity from this postulate. This is a radical departure from the conventional approaches, where gravitational dynamics is postulated and the properties of horizons, etc., are treated as derived quantities.

This approach gains importance in the light of interpreting gravity as a low energy phenomenon somewhat like elasticity of matter being a low energy phenomenon compared to atomic physics. This work ties up nicely with the results reported in the previous Annual Report in which *Padmanabhan* showed that Einstein's equations can be interpreted as thermodynamic identity.

Perturbing the Kerr-NUT

The most general blackhole metric containing gravitational, electric and magnetic charge as well as rotation of the blackhole is of Kerr-NUT spacetime. It is invariant under the duality transformation involving the exchange of mass and NUT parameters, on the one hand, are radial, and angular coordinates on the other. *B.,Mukhopadhyay* and *N.,Dadhich* have studied the scalar and spinor perturbation to the generalised rotating, charged, magnetised blackhole spacetime. That is, they study Klein-Gordan and Dirac equations, in Kerr-NUT spacetime. They show that the original invariance is also shared by the scalar and spinor perturbation equations. Further, by the duality transformation, one can go from Kerr solution to the dual solution, and vice versa, and the same applies to the perturbation equations.

Although, Klein-Gordon and Dirac equations could be transformed under the duality transformation from Kerr to the dual Kerr case, it is not easy to show that their solutions also transform in a simple manner. This is because, in obtaining the solutions in a known form, they have defined new independent variables in a complicated manner which does not let duality transformation work at the level of the solutions. It would be interesting to find some duality between the solutions.

In Kerr geometry, angular part of the equation is free of mass and only involves the kinematic aspects arising from rotation. With NUT parameter, angular part attains active dynamical meaning by its presence. Radial part, however, involves both mass and NUT parameters. The behaviour of potential in different cases is also studied and is found to be similar to Kerr case. Potential barriers are higher for the dual Kerr spacetime. This is because of absence of mass, which produces the usual $1/r$ attractive potential, while NUT parameter contributes $1/r^2$ term asymptotically.

What makes singularity naked?

The ultimate end product of gravitational collapse is a spacetime singularity, where curvature diverges. The important question is, whether it is visible to the outside observer (naked) or is always covered by an event horizon of a blackhole. Cosmic Censorship Conjecture says that latter is the case.

The first study of gravitational collapse was the Oppenheimer-Snyder spherical collapse model of homogeneous dust, which ends in a blackhole with singularity being covered. However, it has been shown that collapse of inhomogeneous dust, for appropriate initial data, can uncover the singularity and make it naked. What is the physical process which is responsible for uncovering the singularity? This question was addressed by Pankaj Joshi, Roy Maartens and *Naresh Dadhich*. They begin by considering the forces that can act on fluid undergoing collapse, viz. acceleration produced by pressure gradient, centrifugal repulsion due to rotation and shearing deformation produced by inhomogeneity and anisotropy. The first two oppose the collapse, while the third makes collapse incoherent. For the question of covering the singularity, it is the shear which is most relevant. The crucial question is what forms first: singularity or event horizon? The shearing force deforms the fluid lines and thereby, can work against the formation of event horizon. It has been shown that there exists a critical threshold value for shear to expose the singularity. Shear which causes deformation in the fluid congruence is shown to be responsible for baring the singularity in spherical collapse.

Ending in a whimper

An interesting case of spherical collapse with heat flux has been studied by A. Banerjee, S. Chatterjee and *N. Dadhich*. As the collapse proceeds, gravitational energy increases and it diverges as singularity is approached. Could it happen that the energy so gained could be radiated out as heat flux? This is what has been demonstrated by an explicit example of spherical collapse in which energy gained by collapse is entirely radiated out as heat flux so that horizon is never formed. Here, the singularity is naked but it is weak because curvature diverges as $1/r^2$, while the mass would tend to zero as the singularity is reached. For strong singularity, curvature should diverge sharper than $1/r^3$. This is a novel example of gravitational collapse.

Collapse of strange quark matter

The precise nature of matter in its densest form is not known and hence, there is room for studying different possibilities. One such case, of the Vaidya null radiation plus strange quark matter, has been studied by S. G. Ghosh and *N. Dadhich*. The Vaidya null fluid collapse has been investigated extensively in the literature. The present work studies the effect of introduction of strange quark matter as well as higher dimensions. It turns out that both these factors tend to favour the formation of blackhole rather than naked singularity by narrowing down the window for naked singularity in the initial data set. However, the window can never be fully closed.

Gravitational Waves

The existence of gravitational waves (GW) was predicted by Einstein as early as 1916. Pulsar timing experiments by Hulse and Taylor led to accurate measurement of periastron time shifts in the PSR1913+16 binary pulsar system. These observations matched with the predictions of the theory of general relativity to better than 0.5%. This was the first strong indirect evidence for the existence of GW. However, detecting such waves with man-made 'antennas' has not been possible so far. Nevertheless, this problem has received a lot of attention during the last few decades, especially, due to the arrival of laser-interferometric detectors, which are expected to have sensitivities close to that required for detecting such waves.

The most well studied sources of GW important to detection are compact astrophysical objects moving at relativistic speeds, like merging black-holes, spinning neutron star systems, inspiraling neutron star binaries, etc. A gravitational wave burst with a typical GW strain of $h \sim 10^{-21}$ is expected to carry about 80×10^{-6} watts/meter^2 past the modern detectors over a duration of ~ 10 millisec. However, GW interact so weakly with matter that even this huge flux of energy (by electromagnetic standards) will produce only a tiny measurable signal in the arms of the detectors. Detection of such weak signals requires special signal processing methods for extracting signals buried in the noisy output of the detectors.

Over the last decade or so, a host of laser interferometric detectors like the two LIGO detectors in USA, GEO600 in Germany, the TAMA 300 in Japan and VIRGO in Italy-France are being built to *catch* these waves *in flesh* and unravel the physics encoded in them. As of present, several of these interferometers are in advanced stages of completion and vigorous R & D efforts are in progress for improving the sensitivity of the detectors. The TAMA 300 has achieved significant observation time with more than 1000 hours of observation, whereas the LIGO has had two successful scientific runs one in August 2002 and the second from February to April 2003. The group at IUCAA led by *S. V. Dhurandhar* has taken active part in the second science run. *A. Sengupta* was at the Louisiana detector site for ten days and manned the shifts. Among the detectors most sensitive are the LIGO detectors (which is not a surprise as their armlengths are an order of magnitude larger than GEO or TAMA), which crossed well below the mark of $h \sim 10^{-21}$. The most sensitive data taken so far can explore a neutron star - neutron star binary coalescence upto 1.2 Mpc which essentially covers our local group of galaxies. Thus, data from these detectors promise much interesting and new astronomical research over the next several years.

GW distort spacetime, in that they change the distances between free test masses. A GW will cause a differential change in the lengths of the two arms, which is then detected as a phase difference between the optical paths of laser light in the two arms. However, the problem is that these changes in lengths are exceedingly small. For example, a neutron star binary at a distance of 100 Mpc will produce a differential length change of $\sim 10^{-17}$ cm., for test masses kept a few kilometres apart, which is the typical length of the arm of a large scale ground-based interferometric detector. These instruments are sensitive in the bandwidth from a few Hz (~ 10 Hz) to a few kHz having the best sensitivity around 500 Hz. In this window, the ground based interferometers will be able to observe inspiraling compact binaries in their last stages before merger, non-axisymmetric rotating neutron stars and supernovae.

However, the lower limit of a few Hz of the band-width of the ground-based detector is a serious limitation to observing GW events. The most predictable and most powerful sources of GW (such as supermassive blackholes) emit GW below 10 mHz. The basic difficulty in achieving sensitivity at low frequencies below 10 Hz lies in the impossibility of screening off Newtonian time-varying gradients of the gravitational field caused by seismic activity, atmospheric disturbances, etc. The solution then is to build a detector in space.

Laser Interferometric Space Antenna (LISA): Optimal signal extraction

The instrument for observing low frequency GW is the Laser Interferometer Space Antenna (LISA). The LISA is a NASA and ESA project and there is good chance of LISA launching as early as 2012. 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 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 $\Delta\nu/\nu_0 \simeq 3 \times 10^{-14}/\sqrt{Hz}$, 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 spacecrafts, 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 spacecraft, which can be conveniently expressed in terms of polynomials in the three 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*. This module has four generators, which can reproduce all the data combinations cancelling laser phase noise. Telemetering just the four generators to Earth is sufficient for obtaining all the information about the GW signal. Moreover, the telemetering can be done at a reduced band-width saving on the total cost. Finally, this approach is general in that it can be extended to space-missions with more than three spacecrafts.

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 in the sense of maximising signal-to-noise-ratio(SNR), detection probability, improving parameter estimates etc.

One application is the maximisation of SNR for a given GW source. This problem was addressed by *Nayak*, *Dhurandhar* and *A. Pai* and Vinet for an almost monochromatic source. The signal covariance matrix is computed for binaries whose frequency changes at most adiabatically (the strictly monochromatic case is included) and for which the signal is averaged over polarisations and directions. Here, adiabatic means that the signal response, the noise and hence, the SNR change imperceptibly even if the GW source changes frequency during the observation time. Thus, even though the results are presented at each fixed frequency, the sources need not be strictly monochromatic, and thus, the results apply to a wider class of sources. The signal covariance matrix has the same eigenvectors as those of the noise covariance matrix. Then, it is shown that the SNR for any data combination in the module, lies between an upper and a lower bound. The upper and lower bounds of the SNR are functions of frequency which are just the SNR curves of the eigenvectors. The extremisation - both maximisation and minimisation - of SNR is important for different purposes; maximisation is important for the detection and parameter estimation of a GW source, while minimisation is important for the purpose of distinguishing the GW confusion noise from the instrumental noise. The improvement of SNR of the upper-bound over the Michelson combination goes upto 70 % , but only at high frequencies $\gtrsim 5$ mHz. At low frequencies $\lesssim$ 5 mHz, both have the same sensitivity. Since the eigenvectors are orthogonal - orthogonality defined in terms of the scalar product given by the noise covariance matrix - they are statistically independent observables. Thus the sum of the squares of the eigenvectors produces a 'network' statistic whose SNR is improved by a factor between $\sqrt{2}$ and $\sqrt{3}$ over the maximum of SNRs of the individual eigenvectors. The improvement over the Michelson combination is about 40 % at low frequencies $\lesssim 3$ mHz and rises above 100 % at high frequencies.

The second application addressed by the same team consists in *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 cast in terms of the formalism developed. Here too one can combine outputs from independent data combinations to form a 'network' statistic which can yield higher SNR than any one single data combination.

The extended hierarchical search for inspiraling binaries

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. *A. Sengupta S. V. Dhurandhar*, A. Lazzarini and P. Shawhan have extended the hierarchy to a third parameter: the time-of-arrival. This work forms part of the Ligo Science Collaboration (LSC). Extending the earlier attempts, a template placement algorithm was designed which produces a valid bank of templates.

The extended search algorithm has been validated and a code has been written following LIGO specifications within the LAL and LDAS environments. The code has been tested on a stand alone machine and runs successfully in the LDAS environment. The next goal is to test the code on real data which is now available from the two science runs of LIGO. One problem with the initial detectors is that the noise is quasi-stationary and the template placement algorithm has to be implemented repeatedly in a short span of time. This demands that the template placement algorithm should be fast. A semi-analytic approach of modelling the ambiguity function is being explored, which is expected to dramatically increase the efficiency of the algorithm.

Continuous wave sources

Coherent extraction of the signal whose direction and frequency is unknown is impossibly expensive from computational poin of view. Besides the signal being frequency modulated, it is also amplitude modulated. Amplitude modulation arises due to the anisotropic response of the detector and splits the monochromatic signal of frequency f_o into five lines corresponding to frequencies $f_o \pm 2f_{rot}$, $f_o \pm f_{rot}$ and f_o where f_{rot} represents the rotational frequency of Earth. *S. Sahay* and D. C. Srivastava explicitly calculated the power associated with each of these lines. They also obtained an analytic expression for the Fourier transform of the frequency modulated signal and the complete response of the detector. From this analytical expression they were able to compute the number of templates required for an all sky and all frequency search. The estimates for the number of templates were $\sim 1.44 \times 10^{10}$, 3.5×10^{10} and 5.5×10^{10}, for analysing data of 30, 120 and 365 days respectively, assuming that the maximal mismatch was 3 % for GW sources whose frequencies were less than 50 Hz. The estimates of the number of templates were also studied for various upper limit frequencies. It was found that the numbers of templates required were approximately 1.22×10^{10}, 2.16×10^{10} and 5×10^{10} for respectively for signal frequencies less than 20, 50 and 100 Hz for analysing data of 120 days for 3 % drop in the SNR. At low frequencies, $\lesssim$ 20 Hz, there are approximate discrete symmetries in the response, within the mismatch of 3 %. These could be used to reduce the computational cost of the search by a factor of 4.

Cosmology and Structure Formation

Filaments or pancakes? - Morphological analysis of the large scale structure of the universe

Galaxies are the building blocks of the large scale structure of the universe and form a complex pattern in space. Although the formation of galaxies is an issue which is far from settled, there is a growing consensus that galaxy formation evolved according to a hierarchical scenario in which the smaller structures formed first, while the very largest objects – superclusters and voids – are going non-linear at the current epoch.

A great deal of understanding of the formation and evolution of large scale structure has been obtained using high resolution N−body simulations which clearly show the presence of superclusters and voids and thus provide an excellent means to test theoretical models against observations. Such a confrontation of theory against observations holds particular promise today since large redshift surveys (including the 2 degree Field Galaxy Redshift Survey (2dFGRS) and the Sloan Digital Sky Survey (SDSS)) will soon provide us with a large, statistically representative sample of the visible Universe, containing the 3-dimensional locations of as many as 250,000 to a million galaxies; the farthest of these being $\sim$ 1.8 Giga light-years away. Thus the statistics of superclusters and voids in large N-body simulations can finally be tested against similar objects in the real universe.

In order to compare predictions of gravitational clustering models with those of the real Universe, one must develop reliable and robust statistical methods which can quantify the multifarous properties of the supercluster-void network. The two-point correlation function and the power spectrum have been developed for this purpose and have yielded considerable success in quantifying gravitational clustering as well as in cosmological parameter estimation. However it is quite clear that in order to study clustering in the non-linear regime, the two-point correlation function must be complemented by other diagnostics which are sensitive to mode-coupling and hence to both global as well as local geometrical and topological aspects of the clustering process. An effective approach is to utilise the geometry and topology of the cosmic density field for this purpose. Statistics like the Minkowski functionals and the Shapefinders succeed in providing a very detailed picture of the clustering process and, as we shall see, of distinguishing between rival models of struture formation. They can,therefore, be used in tandem with correlation statistics to compare theory with observations.

The morphology of a given supercluster or void can be quantified in terms of (i) its volume V, (ii) its surface area S, (iii) its integrated mean curvature C, (which measures the total extrinsic curvature of the supercluster/void surface) and (iv) the genus G, (which quantifies the connectivity of the supercluster/void; see the annual report of last year). Collectively these four measures are called the Minkowski Functionals (MFs). MFs can be evaluated for individual structures at any given threshold of the cosmic density field. They thus provide information both about the morphology and topology of individual superclusters and voids and also give us a glimpse of the geometry and topology of the full non-linear cosmological density field. Ratios of MFs – the 3 Shapefinders – have dimensions of length, and define the thickness T ($=3V/S$), breadth B ($=S/C$) and length L ($=C/4\pi(G+1)$) of a given supercluster/void. T, B, L can be further combined to describe the filamentarity (F) or planarity (P) of an object.

Jatush Sheth and *Varun Sahni* have developed and refined this geometrical approach towards quantifying the large scale structure of the supercluster-void network. *Sheth* has developed a triangulation based surface modelling scheme (SURFGEN) which, in addition to triangulating a well defined isodensity surface, also computes the Minkowski functionals and the Shapefinders for the resulting supercluster or void. The code SURFGEN was tested against Gaussian random fields and the results, shown in Figure 1, show the excellent agreement between SURFGEN estimated MFs and their exact analytical values.

Sheth and *Sahni* (in collaboration with Sergei Shandarin and B.S.Sathyaprakash) analysed a suite of high resolution N−body simulations provided by the Virgo Consortium for three cosmological models with flat background geometry; (1) ΛCDM with $\Omega_m = 0.3$, Ω_Λ=0.7, (2) Standard CDM with Ω_m=1.0 and (3) τCDM with Ω_m=1.0, and the same power spectrum as that of ΛCDM. Their main aim was to determine the topology and geometry of the supercluster-void network in the three distinct cosmological models and to see whether SURFGEN could distinguish the three models from one another.

All model samples consist of z=0 distribution of 256^3 particles in a box of size 239.5 h^{-1}Mpc box. Density fields were generated by fitting a 128^3 grid on the box. Cloud-in-Cell smoothing was followed by an isotropic smoothing with a Gaussian kernel of length $2h^{-1}$Mpc.

Figure 2 studies global Minkowski functionals (which are summed contribution of MFs due to all

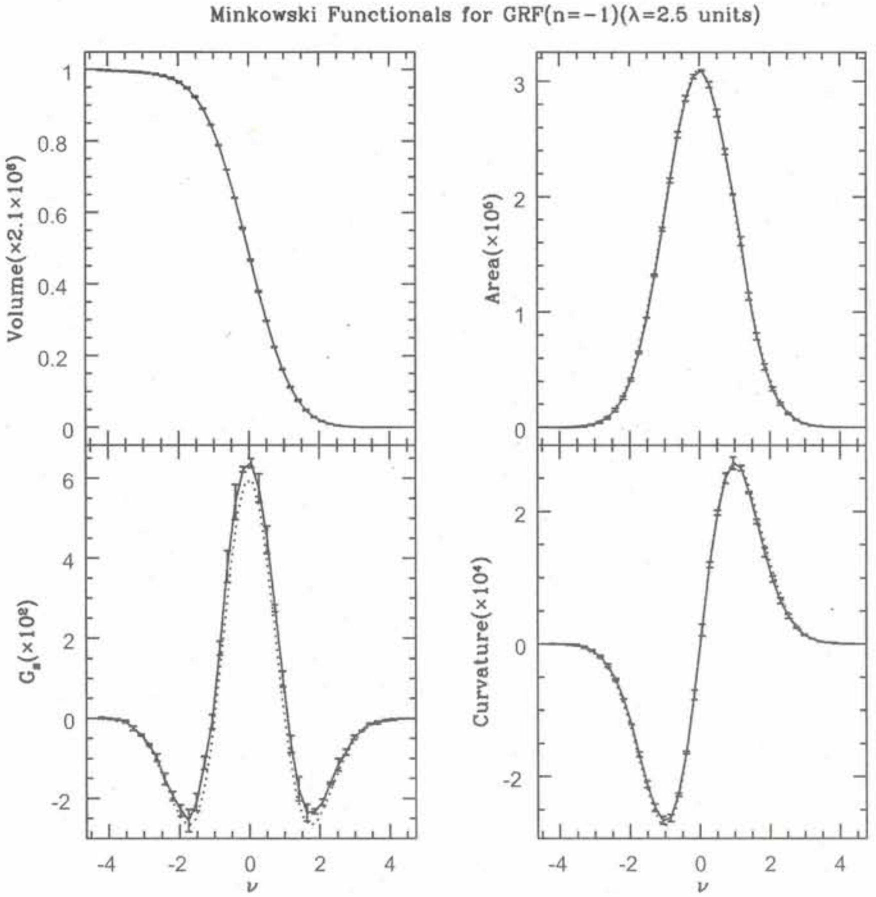


Figure 1: Four Minkowski Functionals for a Gaussian random field with power law power spectrum ($P(k) \sim k^{-1}$) defined on a 128^3 grid are studied at a set of density levels from the highest density value to the lowest. The field is smoothed with a Gaussian kernel of width 2.5 grid-units. Contribution from all the clusters is included. The solid lines denote the SURFGEN-estimated values, which are in excellent agreement with the exact analytical values (shown as dotted lines).

the clusters) at levels of density commencing with the highest and ending at the lowest. The overdense mass fraction is used to label these density levels. As shown in this figure, the global MFs show appreciably different trends for the three models and this demonstrates that this statistic could play a crucial role in distinguishing between rival theories of structure formation.

Important differences in the morphology of the superclusters of the three models were also noted. The percolating supercluster of the ΛCDM model was found to be the most filamentary, least planar and topologically the simplest [(F,P,G) = (0.81,0.13,6)], in marked contrast to the τCDM for which the percolating supercluster shows as many as 20 tunnels and is much less filamentary [(F,P,G) = (0.7,0.15,20)].

In addition to studying the geometrical properties of the full density field as they have done above, it is informative to quantify the morphology of individual objects (superclusters & voids) at the percolation threshold.

Figure 3 shows scatter plots of the Length (L), Breadth (B) and Thickness (T) for several dozen superclusters evaluated at the percolation threshold in the ΛCDM model. The left panel of the figure shows a strong correlation between the the thickness T and breadth B of the clusters regardless of their linear extension L. Surprisingly the thickness and breadth scales turn out to be very close to the correlation length. Indeed, the left panel of Figure 3 shows that clusters have a small planarity: $P=(B-T)/(B+T) \sim 0$. The right panel shows the mass-weighted scatter plot of the length L and breadth B of each supercluster. It is easy to see from this figure that a sizeable fraction of clusters shows filamentarity $F > 0.5$ and that the most massive clusters (larger circles) are very filamentary with $F = (L-B)/(L+B) \sim 0.8$ for the largest supercluster in the simulation. Thus, using the

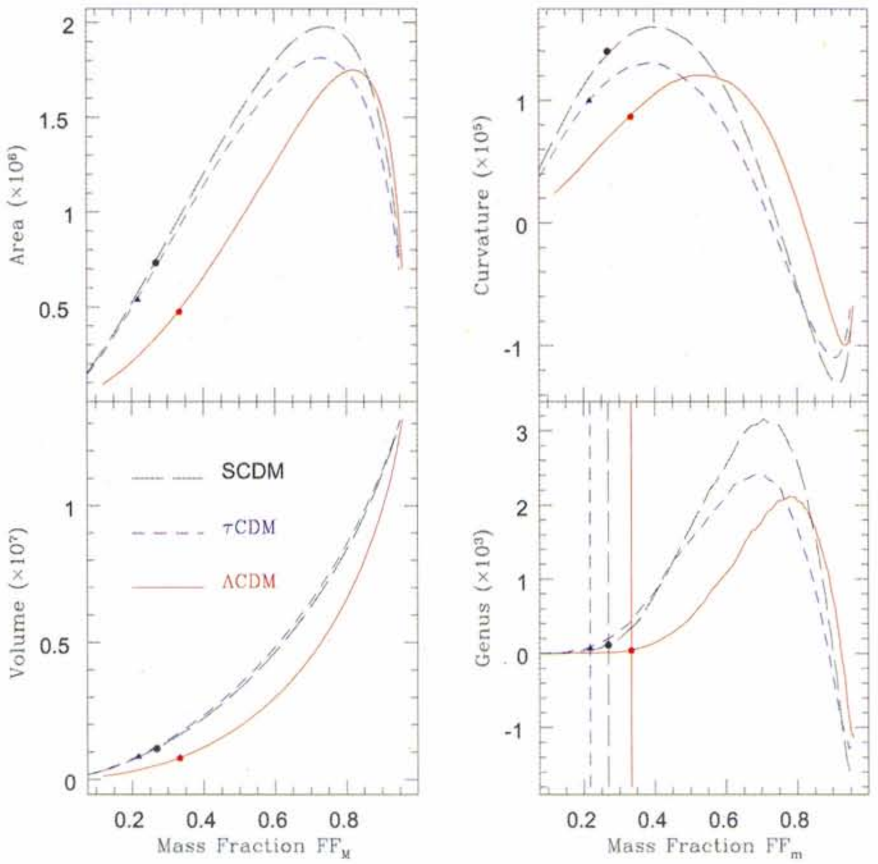


Figure 2: Global Minkowski functionals for the three models are shown as functions of the mass fraction defined as $FF_{\rm M} = M_{\rm total}^{-1} \int \rho\ (\geq \rho_{\rm TH})\ dV$. Parametrising the MFs w.r.t. the mass fraction brings out appreciable differences between the rival models. The markers on the curves show the mass fraction at the onset of percolation in each of the three cosmological models. (For the sake of greater clarity, vertical lines through the markers are shown in the lower right panel.) High value of genus marks the onset of sponge-like topology in the systems. The SCDM model shows considerably larger number of 'holes' (or tunnels) compared to the other models. The relatively larger surface area and mean curvature in this model may indicate that moderately overdense superclusters have many more 'twists and turns' in SCDM than either in LCDM or τCDM. We also note that at percolation, the topology of the fields is relatively simple.

Shapefinders one can objectively establish that superclusters in a gravitational instability driven system develop a pronounced filamentarity which is greater for more massive objects.

Figure 4 shows the 'shape-space' evolution of the largest supercluster in ΛCDM as the density threshold is progressively lowered from a high initial value. This supercluster is distinctly filamentary even at the highest density contrast (δ ~7). In addition there is a sudden spurt in the growth of filamentarity at the percolation threshold (denoted by a solid triangle). As the density threshold is lowered the percolating supercluster becomes topologically more complicated and massive and less filamentary. The degree of filamentarity of the largest supercluster peaks at the percolation threshold which is a useful threshold at which to compare theoretical structure formation models against observations.

What do the supernova observations actually tell us?

The cosmological observations of Supernova Type Ia strongly suggest that the Universe is accelerating at the present epoch, which in turn, implies the presence, a component of energy density ρ with its pressure given by $p = w_X \rho/3$, where $w_X \leq -(1/3)$. This component of energy, with negative pressure, is called the "dark energy". The most popular form of this dark energy is the cosmological constant with the equation of state $w_X = -1$. There are,

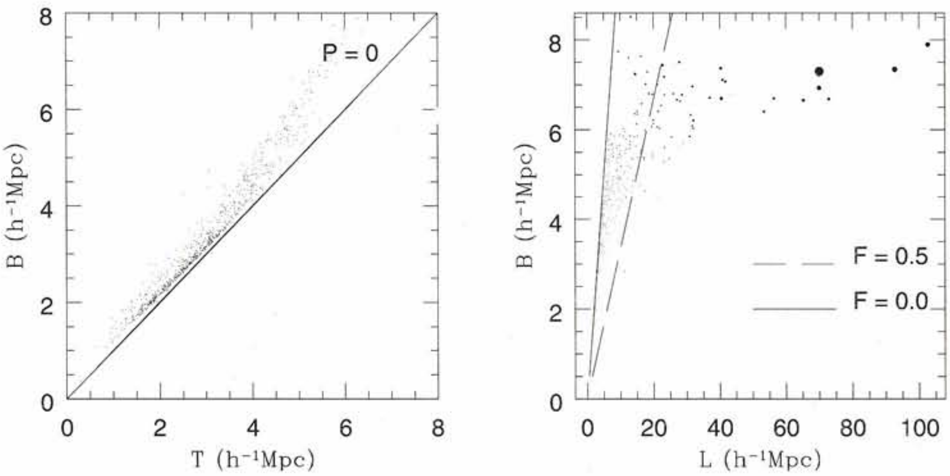


Figure 3: Scatter plot for the pair of Shapefinders T, B (left panel) and L, B (right panel) defining the morphology of clusters/superclusters in the ΛCDM model. The strong correlation between T and B in the left panel near the line P = 0 indicates that two of the three dimensions defining a cluster are equal and of the same order as the correlation length ($\simeq$ few Mpc.). Judging from the left panel one finds that clusters/superclusters in ΛCDM are either quasi-spherical or filamentary (since both satisfy $T \simeq B \Rightarrow \mathrm{P} \simeq 0$). The degeneracy between spheres and filaments is lifted by the right panel which is a mass-weighted scatter plot for the Shapefinders L, B. Each dot in this panel refers to a cluster and its area is proportional to the fraction of mass in that cluster. The concentration of points near the line F = 0 ($B = L$) reflects the fact that a large number of smaller clusters are quasi-spherical. The more massive structures, on the other hand, tend to be filamentary and the largest and most massive supercluster has $F = 0.81$. All objects are determined at the percolation threshold.

however, deep theoretical problems with the existence of a non-zero cosmological constant Λ with a magnitude of about $\Lambda(G\hbar/c^3) \approx 10^{-123}$. This has prompted a host of activity in which one looks for a dark energy component in the universe with $w_X < -(1/3)$ which is different from cosmological constant. *T. Padmanabhan* and *T. Roy Choudhury* have looked into the supernova data critically, and have discussed certain questions related to the determination of the nature of dark energy component from observations related to supernova.

The first point to note is that any observation based on the geometry of the Universe (like the supernova observations), however complex it may be, will not allow us to determine anything other than the Hubble parameter ($\dot{a}/a$) where, a is the scale factor as a function of the red shift. This degeneracy is inherent in the FRW metric which describes the large scale geometry of the Universe. Since, Friedmann equations relate $\dot{a}/a$ to the *total* energy density in the Universe (assuming that the curvature of the spatial part of the metric is known from independent observations or fixed by some theoretical prejudice), the best we can do from any geometrical observation is to determine the total energy density of the universe at any given redshift z. It is not possible to determine the energy densities of individual components from any geometrical observation.

The supernova observations directly measure the apparent magnitude m of a supernova and its redshift z. These measurements can be converted into the measurement of the luminosity distance to the supernova assuming that the absolute magnitudes of the supernovae do not evolve with time. However, the presence of an accelerating phase of the Universe is more evident if one plots the data points in the $\dot{a} - a$ plane rather than plotting the luminosity distance itself. Converting the measurements of the luminosity distance into those of $\dot{a}$ is a non-trivial task. *Padmanabhan* and *Choudhury* have plotted the data points in the $\dot{a} - a$ plane for flat models, which is shown in Figure 5. The data points, with error-bars, show a clear sign of an accelerating universe at late times. There is another crucial point to be noted from this figure. It is clear from Figure 5 that it is *not* possible to rule out any of the cosmological models using low redshift ($z \leq 0.25$) data because of large error-bars. On the other hand, high redshift data *alone* cannot be used to establish the existence of an accelerating phase. For example, one can use the freedom in the value of the absolute magnitude of the supernovae to shift the data points vertically, and make them consistent with a decelerating model ($\Omega_m = 1$, topmost curve). It is the interplay between both the high and low redshift supernova data which leads to a clear indication of an accelerating phase. This conclusion can be made more quantitative by studying at the confidence ellipses in the $\Omega_m - \mathcal{M}$ plane,

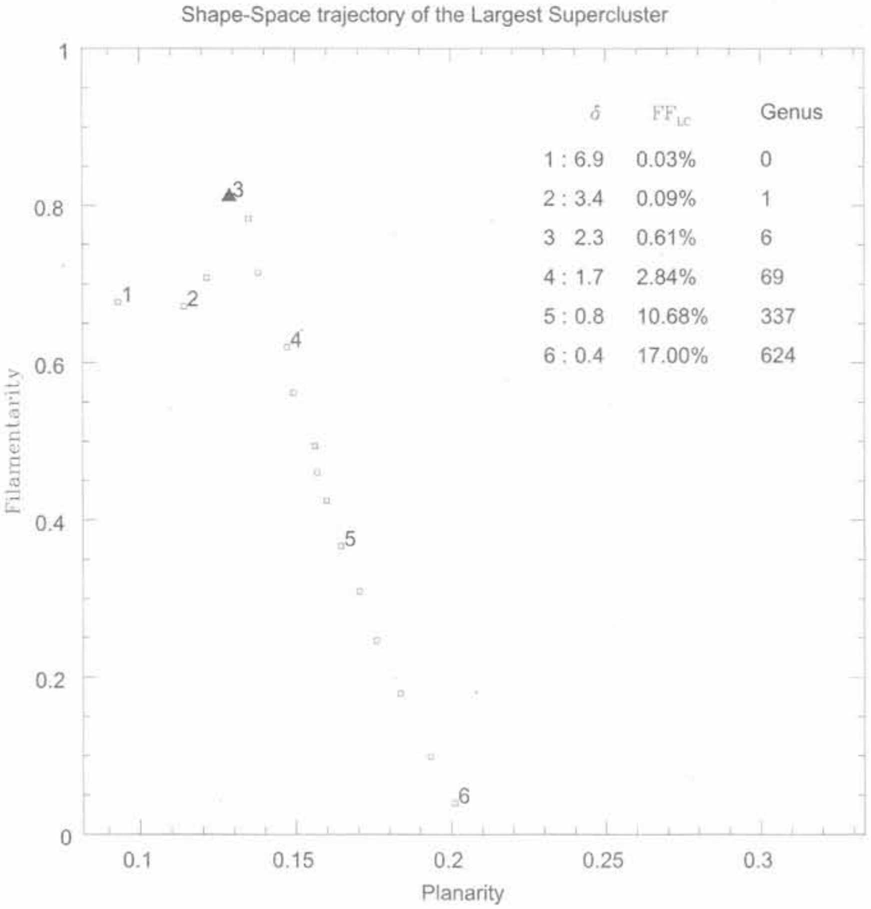


Figure 4: The morphological evolution of the largest supercluster in LCDM is shown as a series of open squares in shape-space $\{F, P\}$. Each square corresponds to a different value of the density threshold which is progressively lowered from a large initial value ($\delta \simeq 6.9$; left most square) until the mean density level ($\delta = 0$; lower most square). The legend lists the density contrast, the associated volume fraction and the genus of the largest supercluster at six monotonically decreasing values of the density contrast ($1 \to 6$). At the highest ($\delta \simeq 6.9$), the largest cluster appears to have a large filamentarity and a small planarity. The solid triangle (labelled 3) refers to the percolation threshold at which the largest cluster first spans across the simulation box. After percolation, the filamentarity rapidly decreases from a maximum value of 0.81 to 0.0 as the threshold is lowered from $\delta \simeq 2$ to $\delta \simeq 0$. The decline in filamentarity of the largest cluster is accompanied by growth in its complexity as revealed by its genus value, e.g., the fractional volume occupied by the largest cluster at the mean density is $\sim$26% and its genus exceeds a thousand.

shown in Figure 6. It is clear from the middle panel that, although the low redshift data can constrain $\mathcal{M}$ very well, it is unable to constrain Ω_m. On the other hand, the high redshift data (right panel) is able to constrain neither $\mathcal{M}$ nor Ω_m. In particular, the decelerating model ($\Omega_m = 1$) is quite consistent with both the low and high redshift data sets when they are treated separately. One needs to combine the low and high redshift data to constrain Ω_m.

This analysis indirectly stresses the importance of any evolutionary effects. Any possible evolution in the absolute magnitude of the supernovae, if detected, might allow the decelerating models to be consistent with the data.

Padmanabhan and *Choudhury* have also tried to see the possible constraints on the equation of state of the dark matter w_X. For this purpose, they have used a phenomenological model with $w_X(a) = w_0 - w_1(a-1)$, where w_0 measures the current value of the equation of state and $-w_1$ gives its rate of change at the present epoch. The constraints in the $w_0 - w_1$ plane is shown in Figure 7. The shape of the confidence contours clearly indicates that the data is not as sensitive to w_1 as compared to w_0. This means that while one can constrain the current value of w_X quite well, determining the evolution of w_X will be comparatively a difficult task. The situation is further worsened when one takes the uncertainties in Ω_m into account.

Finally, there is another — and from a theo-

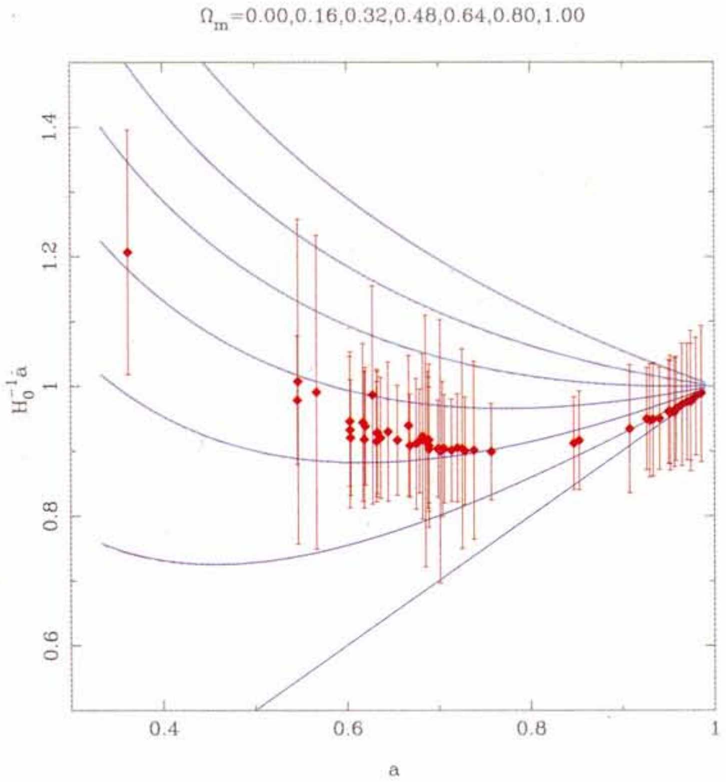


Figure 5: The observed supernova data points in the $a - \dot{a}$ plane (the phase portrait the universe) for flat models. The values of $\dot{a}$ increase at late times indicating the acceleration of the universe. The solid curves, from bottom to top, are for theoretical flat cosmological models with $\Omega_m = 0.00, 0.16, 0.32, 0.48, 0.64, 0.80, 1.00$ respectively.

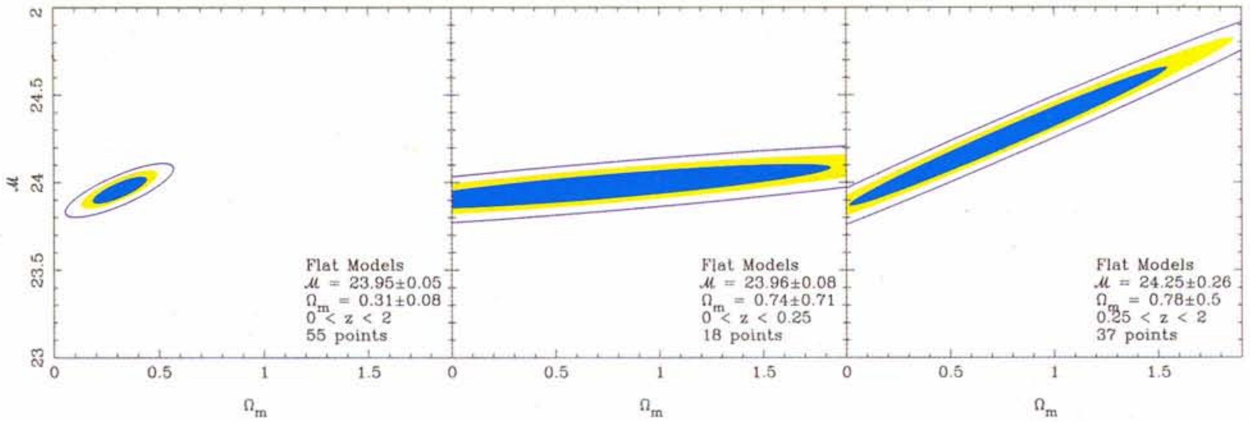


Figure 6: Confidence region ellipses in the $\Omega_m - \mathcal{M}$ plane for flat models with non-relativistic matter and a cosmological constant, where $\mathcal{M}$ essentially measures the absolute magnitude of the supernovae. The ellipses corresponding to the 68, 90 and 99 per cent confidence regions are shown. In the left panel, 55 data points in the redshift range $0 < z < 2$ are used. It is obvious that most of the probability is concentrated around the best-fit value. In the middle panel, only those data points with $z < 0.25$ are used, while in the right panel, one has used data points with $z > 0.25$.

retical point of view, more serious — degeneracy which seems to have been inadequately stressed in the literature. While the cosmologists may be happy with the equation of state of dark energy, the theoretical physicists are interested in the physical nature (say, the Lagrangian) for the dark energy. However, observations based on uniform background cosmology can, at best, give the the dark energy equation of state $w_X(a)$ which, it turns out, is grossly inadequate for determining the physical nature of dark energy. For example, even if one makes another gigantic leap of faith and assumes that the dark energy arises from a scalar field, it is possible to come up with scalar field Lagrangians of

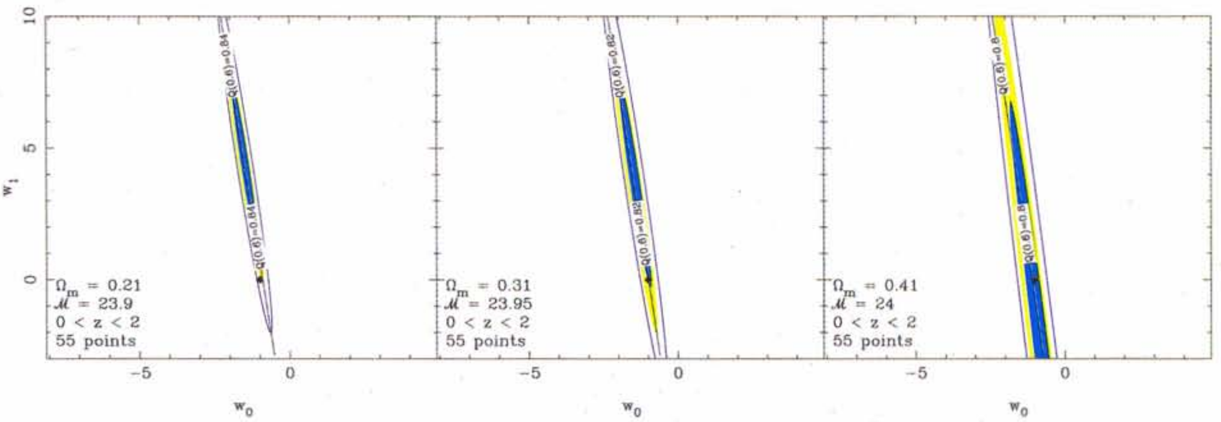


Figure 7: Confidence region ellipses in the $w_0 - w_1$ plane for flat models with $\Omega_m = 0.21, 0.31$ and 0.41 respectively, as indicated in the frames. The value of $\mathcal{M}$ is chosen to be the best-fit value, which is also indicated. The ellipses corresponding to the 68, 90 and 99 per cent confidence regions are shown. The square point denotes the equation of state for a universe with a non-evolving dark energy component (the cosmological constant). The unbroken slanted line corresponds to the contour of constant luminosity distance.

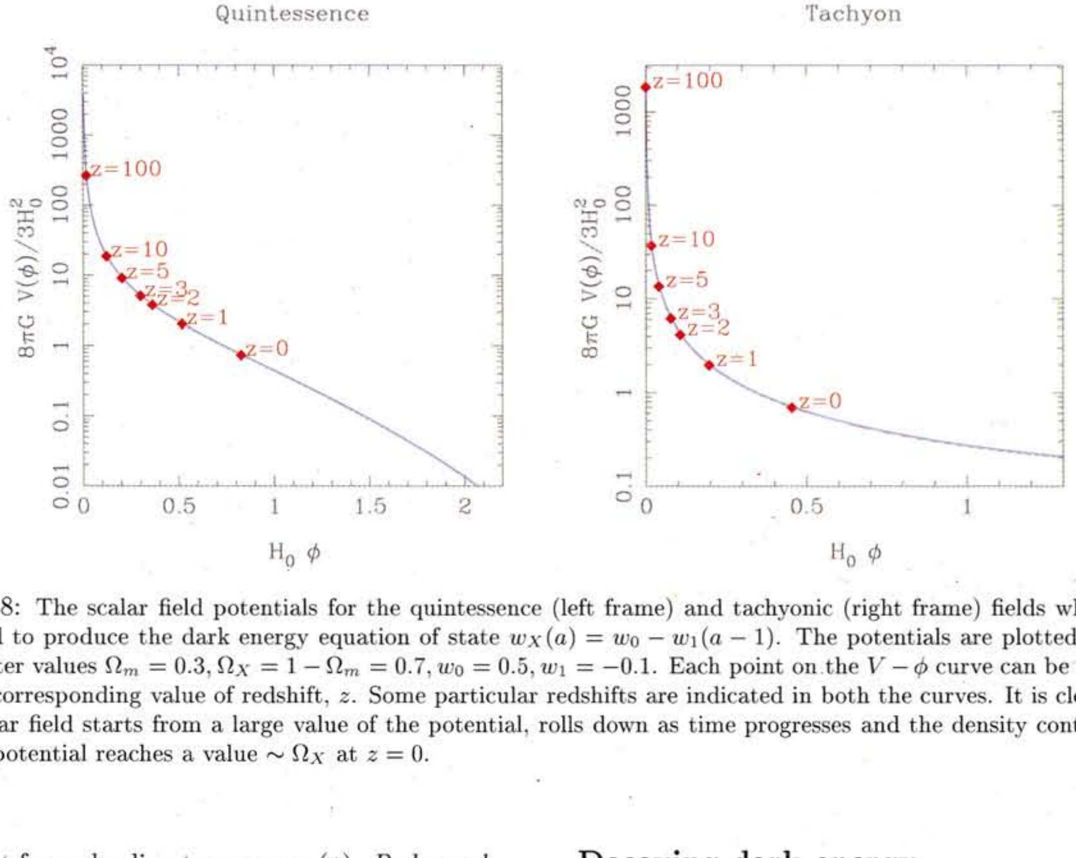


Figure 8: The scalar field potentials for the quintessence (left frame) and tachyonic (right frame) fields which are required to produce the dark energy equation of state $w_X(a) = w_0 - w_1(a-1)$. The potentials are plotted for the parameter values $\Omega_m = 0.3, \Omega_X = 1 - \Omega_m = 0.7, w_0 = 0.5, w_1 = -0.1$. Each point on the $V - \phi$ curve can be labelled by the corresponding value of redshift, z. Some particular redshifts are indicated in both the curves. It is clear that the scalar field starts from a large value of the potential, rolls down as time progresses and the density contributed by the potential reaches a value $\sim \Omega_X$ at $z = 0$.

different forms leading to same $w_X(a)$. *Padmanabhan* and *Choudhury* have considered two such Lagrangians, namely, the quintessence and tachyonic Lagrangians (discussed in detail in the later year's annual report), and have given explicit examples of potentials which lead to the same $w_X(a)$. The potentials corresponding to the two Lagrangians are shown in Figure 8 for the equation of state $w_X(a) = w_0 - w_1(a-1)$.

Decaying dark energy

Ujjaini Alam and *Varun Sahni* have been studying the enigma of 'dark energy', a mysterious negative-pressure component which appears to dominate the total energy content of the universe today. The presence of dark energy is indicated by several recent cosmological observations.

Different theoretical models have been suggested to explain the presence of this exotic form of energy. In the simplest model, that of the cosmo-

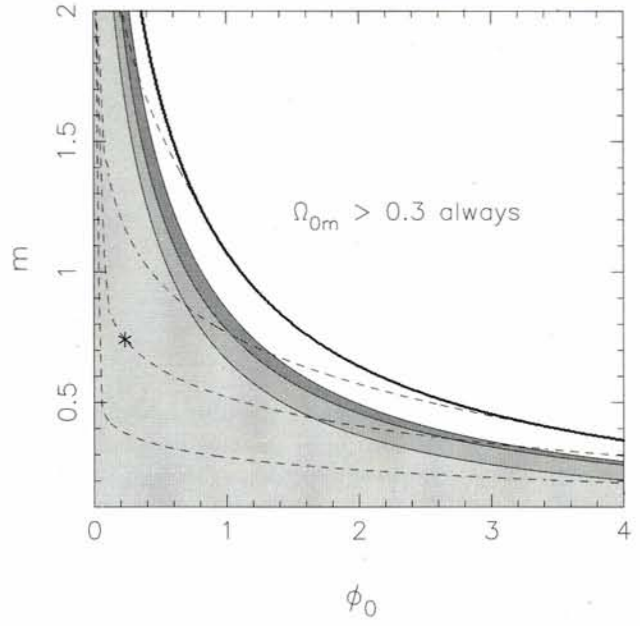


Figure 9: Confidence levels at 68.3% (light grey inner contour) 95.4% (medium grey contour) and 99.73% (dark grey outer contour) are shown in the m-ϕ_0 plane for the potential $V(\phi) = V_0\cos(m\phi/\sqrt{V_0})$. Here m is in units of $\sqrt{8\pi GV_0/3}$, ϕ_0 is in units of the reduced Planck mass $\tilde{M}_P = \sqrt{3/8\pi G}$, and $\Omega_{0m} = 0.3$. The best-fit point is marked as a star. In the region to the right of the thick solid line, parameter values are such that the matter density never reaches the present value, hence this region is disallowed by observations. Dashed lines represent the time $\Delta T_{\rm coll}$ until the universe collapses, measured from the present epoch: $\Delta T_{\rm coll}$(Gyrs)= 18.2, 55.9, 153.6, and 698.4 (top to bottom) if $H_0 = 70$ km/s/Mpc. The minimum time to collapse is $\Delta T_{\rm coll} \simeq 18$ Gyrs at the 95.4% confidence level.

logical constant, the constant value of dark energy density is about 120 orders of magnitude less than that expected from zero point vacuum fluctuations. This has led researchers to suggest models in which the dark energy density is a function of time. One way of achieving a variable dark energy model is by representing dark energy by a self-interacting scalar field, usually called quintessence. Other models have also been suggested, such as the higher dimensional braneworld models, k-essence models, etc. These different theoretical models open up a host of possibilities for the future of the universe. In some models, the universe goes on accelerating forever, in some, the acceleration of the universe is a transient phase sandwiched between two matter-dominated epochs, while in still others the universe collapses to a 'big crunch' singularity within a finite time. As such, depending on the model chosen to represent dark energy, the universe can suffer widely different fates.

Recently, *Alam*, *Sahni* and A. A. Starobinsky have studied the fate of the universe using a class of models called decaying dark energy (DDE) models. These models are similar to quintessence models in that the dark energy is described by a scalar field rolling down a potential, but in these models, the dark energy decays over time, i.e., there is a transition from a potential dominated regime to a regime where the potential and kinetic energies of the dark energy field become comparable. The fact that dark energy could be unstable is suggested by the analogy between the dark energy present today and the inflaton field which described the scenario of inflation in the early universe. The DDE models have various implications for the future of the universe. Firstly, in these models, the acceleration of the universe is a transient phase, after the dark energy has decayed to sufficiently small values, the universe can stop accelerating and will tend to a matter-dominated future. Another interesting possibility is realized if the potential of the scalar field can become negative. Under the influence of a negative potential, the dark energy steadily decreases and becomes negative until a time comes when the negative dark energy density cancels the positive matter density so that the expansion of the universe stops and after that the universe begins to collapse. This implies that even a spatially flat universe can collapse in the future.

To study these possibilities *Alam*, *Sahni* and Starobinsky examined a class of dark energy potentials which frequently arise in supergravity and

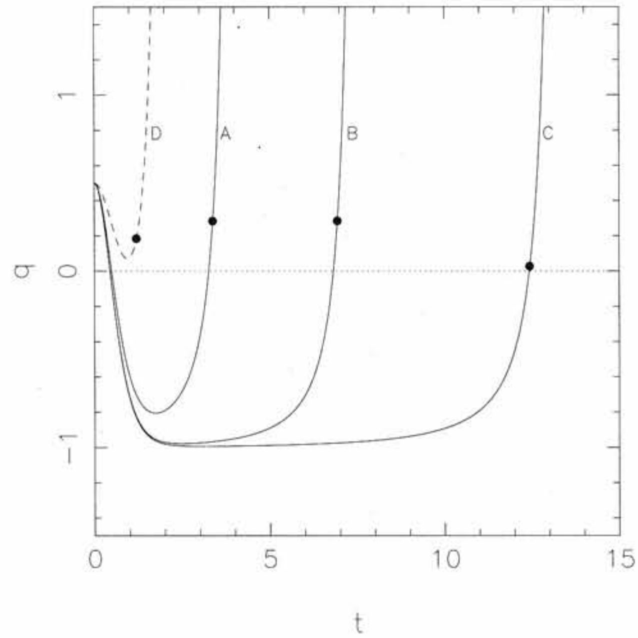


Figure 10: The evolution of the deceleration parameter q is shown for four different DDE models corresponding to different choices of m and ϕ_0 in the DDE potential $V(\phi) = V_0\cos(m\phi/\sqrt{V_0})$ ($\Omega_{0m} = 0.3$). Time t is in units of $\sqrt{3/8\pi G V_0}$. The models have parameter values: $m = 1.0, \phi_0 = 0.6$ (A), $m = 1.0, \phi_0 = 0.2$ (B), $m = 0.74, \phi_0 = 0.23$ (C), $m = 1.0, \phi_0 = 1.2$ (D). Models A,B,C are allowed by supernova observations at the 95.4% confidence level. The dashed line D shows the time evolution of q for a DDE model with $m = 1.0, \phi_0 = 1.2$. This model is disallowed by observations since the matter density always remains larger than 0.3 (see figure 9). The horizontal dotted line ($q = 0$) divides the plot into two regions. In the upper region $q > 0$ and the universe decelerates, whereas $q < 0$ in the lower region in which the universe accelerates. The points of intersection of $q = 0$ with A,B,C show the commencement and end of the acceleration epoch in these models. The solid circles show the epoch where the potential energy of the scalar field falls to zero.

M-theory. These potentials are characterised by the property that they contain one or more maxima. They considered two different types of DDE models. In the first, the potential of the scalar field is modeled by an analytical form which generically describes the potential near any of its maxima. The second is a cosine potential, which can become negative and, therefore, for this potential, the universe would first stop accelerating and then collapse. The parameters defining the system are the initial displacement of the scalar field, ϕ_0, the tachyonic rest-mass modulus, m, and the present day matter density, Ω_{0m}. It is known from observations that the physical properties of dark energy are close to that of the cosmological constant at present. Therefore, the variation in the scalar field must be on time scales of order of H_0^{-1}, since for a larger variation the equation of state of the dark energy would vary much too rapidly. This implies from the equation of motion of the system that the tachyonic rest mass is of the order of H_0. Thus, a superficial examination of the system shows that all characteristic time scales of the system should be of the order of H_0^{-1}, i.e., of the order of tens of Gyrs. Both theoretical models are then examined in greater detail in light of observations of the high redshift supernova data along our past light cone, and extrapolated to predict the behaviour of the universe in the future. This exercise determines the range of model parameters which agree with the supernova data, and also finds the time taken for the universe to stop accelerating and then to collapse. In the analysis, the value of the present day matter density is fixed to $\Omega_{0m} = 0.3$, which is in good agreement with the value obtained from galaxy redshift surveys.

From this analysis, it is seen that although a large region of the $m - \phi_0$ parameter space is disallowed by observations, the decaying dark energy model is fairly consistent with supernova data at reasonably small values of m and ϕ_0 (see Figure 9, which shows the confidence levels for the cosine potential). Also, there is a large spread in the time taken for the universe to collapse. At the 95.4% confidence level, the minimum time to collapse, measured from the present epoch, is as small as 18 Gyrs. Similarly, the minimum time taken for the acceleration epoch to end, measured from the present epoch, can be about 10 Gyrs at the 95.4% confidence level. The evolution of the deceleration parameter of the system as the scalar field rolls down the potential is shown in Figure 10. The time at which the acceleration commences in the past is seen to be nearly the same for different models allowed by observations, but the future time at which acceleration stops is widely different. Shortly after the acceleration stops, the potential energy of the field becomes zero, then as the potential becomes increasingly negative, the universe collapses. This analysis thus leads to the interesting possibility that we could be living in an universe which would collapse 18 Gyrs from now!

Cosmological constant and Mach's principle:

Another version of decaying cosmological constant models are the kinematical models which argue that Λ relaxes to its present small value through the expansion of the universe. Though, both quintessence and kinematical models are phenomenological in nature, the quintessence models have no predictive power and lead to similar late time behaviour of the universe. On the other hand the kinamatical Λ models, which generally follow either from some dimensional analysis, or further symmetries of spacetime or some dynamical laws, are consistent with Mach's Principle. This has been shown in a recent paper by *R. G. Vishwakarma* (which received 'Honourable Mention' from the *Gravity Research Foundation*, USA.)

Recent CMB and SN Ia observations and the decelerating models:

The SN observations cannot be explained by the decelerating Einstein-de Sitter model, which used to be the favoured model before theses observations were made. Although the best-fitting standard models to the SNe Ia data predict an accelerating expansion, it should be noted that the low density open models, which predict a decelerating expansion, also fit the SNe Ia observations reasonably well . Unfortunately, these models are ruled out by the recent measurements of the angular power fluctuations of CMB which predict that the universe is spatially flat.

Anisotropies in the CMB are caused by the density fluctuations in the early universe at $z \approx 1100$ when photons decoupled from matter. For models in which these fluctuations are of Gaussian random nature, the information carried by CMB is completely characterized by the angular power spectrum as a function of Legendre multipole ℓ. The comparison between the measured angular power spectrum and the predicted one by a model, can be used to test the model.

R.G. Vishwakarma has shown that both these observations – the high redshift SNe Ia and the angular power spectrum of CMB – can be explained in the framework of a decelerating model of the universe which has a dark energy component varying as the inverse square of the scale factor.

Higher dimensional braneworld cosmology

Ujjaini Alam, Varun Sahni and Yuri Shtanov have investigated interesting new higher dimensional cosmological models in which matter is confined to a three dimensional manifold (brane) whereas gravity can 'leak' out into a fourth spatial dimension (bulk). The idea that physical space has more than three dimensions is not new. Nordström (1914), and independently Kaluza (1921) and Klein (1926) suggested the presence of a fifth spatial dimension in their attempts to unify gravity with the electromagnetic force. The flowering of Kaluza-Klein cosmology took place in the 1980's and was associated with the development of non-Abelian gauge field theories. The major aim of this programme was to recover the gauge symmetries of the standard model from compact (hidden) dimensions, and it was assumed that the compactification scale was of the same order as the Planck length. A fresh impetus to this paradigm was given by Arkani-Hamed, Divopolous, and Dvali, who suggested that compact extra dimensions may be macroscopic, 1 mm, while our spacetime is described as a lower-dimensional domain wall (brane) where all the matter is concentrated. Within this setting, the fundamental higher-dimensional Planck scale could become as small as ~ 1 TeV, thus getting rid of the hierarchy problem. (The hierarchy problem arises because the Planck scale is so much higher than the known scales in physics, for instance $M_P/M_W \sim 10^{17}$, where M_W is the mass of the vector boson which mediates the electroweak force.)

More recently, many variants of superstring theory allow for the possibility that at least some of the extra dimensions of nature may be macroscopic. For example, the eleven -dimensional supergravity model of Horava and Witten assumes that ordinary matter fields are confined to a submanifold (brane) which is embedded in a higher dimensional space (bulk). In an important recent development, Randall and Sundrum (RS) examined a simplified variant of this model consisting of a three dimensional brane embedded in a four dimensional anti-de Sitter (AdS) bulk. Their results showed that gravitational excitations are confined close to the brane giving rise to the familiar $1/r^2$ law of gravity, and suggesting that one could identify the brane as our observable universe.

Sahni and Shtanov investigated a class of 'braneworld' models in which the action contains terms which are proportional to the five dimensional Ricci scalar as well as the four dimensional Ricci scalar. (The full gravity + matter action also contains contributions from the brane tension as well as matter fields. The bulk space-time is assumed to be AdS although the model is quite flexible and allows for a vanishing cosmological constant in the bulk.) The presence of the four dimensional Ricci scalar is required by one loop quantum gravitational effects which arise when one incorporates quantum effects generated by matter fields residing on the brane. (The origin of this idea goes back to Sakharov, who first suggested the possibility of inducing gravity through the backreaction of matter fields in the action.) The presence of the four dimensional Ricci scalar radically changes the form of the field equations on the brane and leads to many interesting new effects.

For instance a new length scale l emerges in the theory and an examination of the field equations reveals that braneworld dynamics approaches general relativity (GR) *on small scales* $r \ll \ell$. Departure from GR in this braneworld model therefore occurs at *late times* and on large scales. This unusual property stands in contrast to braneworld cosmology based on the Randall–Sundrum model, in which nonstandard behaviour is encountered at very early times. For $m \sim 10^{19}$ GeV and $M \sim 100$ MeV they find that $\ell \sim cH_0^{-1} \sim 6000$ Mpc. This suggests that important new effects will arise in this theory on length scales of the order of the present Hubble radius and on time scales which are comparable to the present age of the universe. One important property of the braneworld model proposed by *Sahni* and Shtanov is that the expansion of the universe *accelerates* at late times in qualitative agreement with current observations of high redshift supernovae.

However, the 'braneworld model of dark energy' examined by *Sahni* and Shtanov differs significantly from dark energy models based on the cosmological constant or 'tracker fields'. They found that braneworld models fall into two distinct classes which they call BRANE1 (B1) and BRANE2 (B2). The two classes exist because of the two separate ways in which the (four dimensional) brane can be embedded in the (five dimensional) bulk. The properties of braneworld models belonging to these two classes are radically different. For instance B1 models always have a Hubble parameter which is

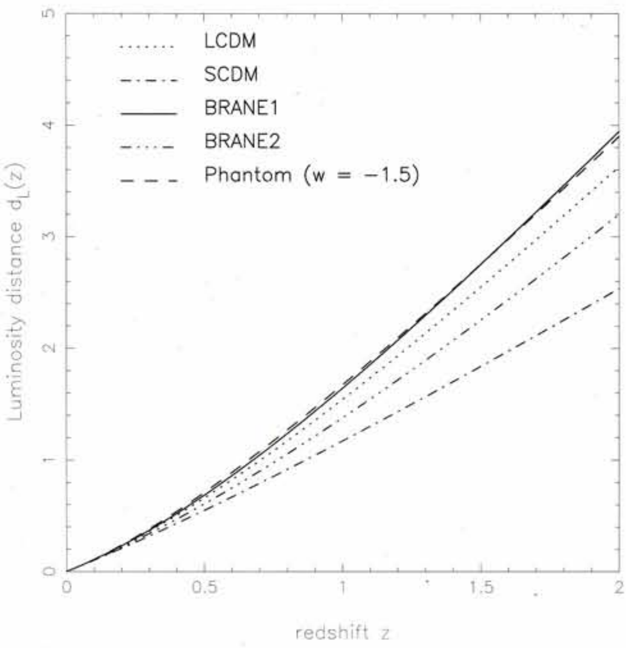


Figure 11: The luminosity distance is shown as a function of redshift for the two braneworld models BRANE1 & BRANE2, LCDM, SCDM, and 'phantom energy'. All models, with the exception of SCDM, have $\Omega_m = 0.3$. SCDM has $\Omega_m = 1$. LCDM and the phantom model have the same dark energy density $\Omega_\Lambda = \Omega_X = 0.7$. The equation of state for dark energy is $w_\Lambda = -1$ for LCDM and $w = p_X/\rho_X = -1.5$ for phantom. The luminosity distance is greatest for BRANE1 & phantom, and least for SCDM. BRANE1 & BRANE2 lie on either side of LCDM.

smaller than the one in LCDM cosmology, whereas the Hubble parameter in B2 models is *larger* than in LCDM, and smaller than in SCDM. Since most cosmological observables involve $H(z)$ either directly or indirectly, these properties of the braneworld models make them quite distinct from both LCDM and SCDM models, and from each other. For instance, in a spatially flat universe the luminosity distance is proportional to an integral over the inverse of the Hubble parameter. From this follows an important property of braneworld models, namely, the luminosity distance for the B1 models is always greater than that for the corresponding LCDM model, and the luminosity distance for the B2 models is always smaller than in LCDM, and larger than in SCDM.

This indicates that high redshift objects (QSO's, Supernovae) will appear brighter (fainter) in B2 (B1) relative to LCDM; see Figure 11. (Note however that high redshift objects in both braneworld models will be fainter than in SCDM.) This in turn implies that the effective equation of

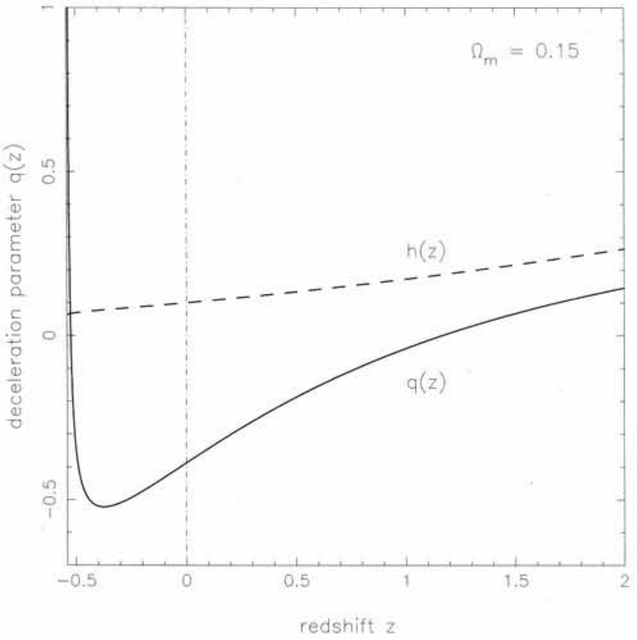


Figure 12: The BRANE2 universe can encounter a singularity lying in the *future* as demonstrated in this figure. The deceleration parameter becomes infinite as the singularity is approached while the Hubble parameter (and the density, pressure) remain finite. The vertical dot-dashed line corresponds to the present epoch $z = 0$ while the dashed line represents the dimensionless Hubble parameter. The solid line shows the deceleration parameter $q(z)$. Although permitted by supernovae observations this particular model appears to be disfavoured by clustering bounds on Ω_m.

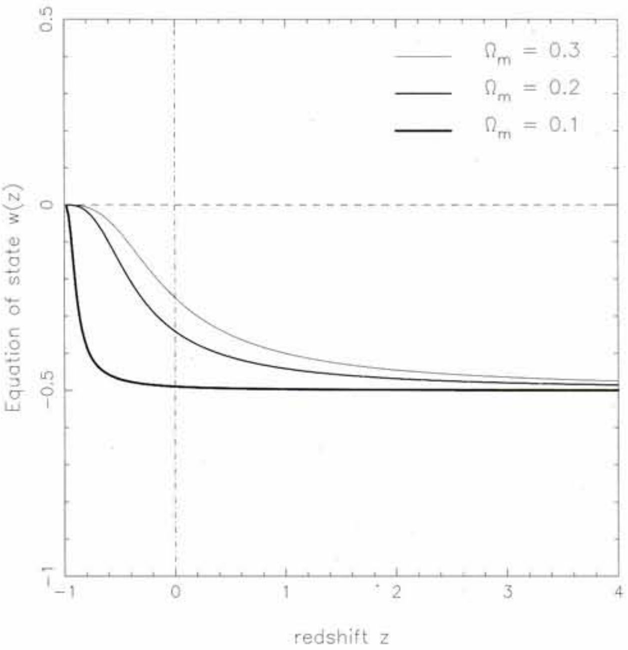


Figure 13: The effective equation of state of dark energy in a transiently accelerating braneworld is shown as a function of redshift for three possible values of the current matter density. The vertical line corresponds to the present epoch while the horizontal line refers to $w = 0$. The past and future behaviour of $w(z)$ turns out to be very different: $w(z) \to -1/2$ for $z \gg 1$, while $w(z) \to 0$ for $z \to -1$. Braneworld dark energy disappears in the future, resulting in the re-emergence of a matter dominated universe.

state of dark energy in B1 is $w < -1$ whereas $w > -1$ in B2 models. Thus dark energy can have an equation of state which is even more negative than that of a cosmological constant, since $w = -1$ in LCDM. (One should note that this possibility is not permitted in tracker-like quintessence models which have $w > -1$ generically.)

Thus braneworld models can have properties which are very different from quintessence models and it is important to examine how B1 and B2 compare against observations. *Alam*and *Sahni* have used maximum likelihood methods to compare Braneworld models against observations of high redshift type Ia supernovae made by the Supernova Cosmology Project. Their results show that B1 models (having $w < -1$) are favoured over LCDM if the density in clustered matter is large: $\Omega_m \gtrsim 0.3$. For smaller values ($\Omega_m \lesssim 0.25$) B2 (with $w > -1$) is favoured over LCDM.

Braneworld models can be distinguished by other important properties not shared by most models of dark energy. For instance:

As shown by *Sahni* and Shtanov a class of braneworld models admit cosmological singularities of a very unusual kind. In these models the expansion of the universe can culminate in a 'quiescent singularity' an example of which is shown in Figure 12. A 'quiescent singularity' is distinguished from conventional general relativistic singularities by the fact that: (i) such a singularity can arise even when the universe is expanding. (ii) The energy density and Hubble parameter remain finite, while higher derivatives of the scale factor ($\ddot{a}$, $\dddot{a}$ etc.) diverge, when the 'future singularity' is reached. Comparing models with quiescent singularities against supernova observations *Alam*and *Sahni* have shown that, assuming $\Omega_m \sim 0.1$, a B2 universe can encounter a quiescent singularity after only $T_S \sim 1$ Gyr, which is considerably shorter than the time elapsed before the sun ends its life as a red giant !

Another striking feature of the braneworld models examined by *Alam*, *Sahni* and Shtanov is that the current acceleration epoch can be temporary, and could soon come to an end. It is well known that conventional models of dark energy (cosmological constant, quintessence, etc.) give rise to an eternally accelerating universe with an event horizon, thus preventing the construction of an S-matrix describing particle interactions within the framework of string or M-theory. By contrast, a B2 model can be 'transiently accelerating' as demonstrated in Figure 13. Braneworld models could therefore succeed where quintessence models have failed, and reconcile an accelerating universe with the requirements of string/M-theory.

In another study, *R. G. Vishwakarma, P. Singh* and *N.K. Dadhich* have explored some brane models and studied their cosmological implications. Current observations, for example, magnitude-redshift measurements of SNe Ia, angular power spectrum measurements of CMB and angular size-redshift measurements of compact radio sources have also been studied in these models.

Tachyonic models for the universe and structure formation

Observations suggest that at present the expansion of the universe is accelerating. J. S. Bagla, *H. K. Jassal* and *T. Padmanabhan* studied cosmologies where, a homogeneous tachyon field plays the role of dark energy and drives the acceleration of the universe. Two different potentials were considered for the tachyon scalar field, the exponential potential and the inverse square potential (which leads to power law cosmology at late times). For a viable model one requires fine tuning of parameters comparable to that in LCDM or in quintessence models.

In the case of the exponential potential, the accelerated phase is followed by a phase with another decelerating phase thus eliminating a future horizon. String theoretic models have difficulty in incorporating cosmologies which approach de Sitter-like phase asymptotically; from this point of view, these models are theoretically attractive.

The tachyon models have a unique feature that the matter density parameter and the density parameter for tachyons remain comparable for a large range in redshift. The matter density parameter does not approach unity for most models. This is true for both exponential and inverse square potentials. The models in which density parameter is close to unity at high redshifts, the growth of perturbations is closer to that in the LCDM model. For models in which the matter density parameter does not reach unity, the growth of perturbations is slow, leading to a conflict with the observations of temperature anisotropies in the microwave background in these models. Since the latter is tightly constrained from CMBR measurements, models with slow growth of perturbations can be ruled out. This problem, however, does not exist for a subset of parameters. This subset of models is consistent with all the observations considered, and hence one can construct viable models of dark energy using tachyonic excitations.

Probing the dark ages with redshift distribution of GRBs

The usefulness of Gamma-ray bursts (GRBs) to probe the evolution of the universe is realized ever since the redshift measurements of GRBs became possible. There are also growing observational indications for the association of supernova-like components in several afterglows. If indeed the rate of formation of GRBs is related to the star formation rate of host galaxy, they can be used as an effective probe of the star formation history of the universe. *T. Roy Choudhury* and *R. Srianand* have explored the possibility of using the properties of GRBs to probe the physical conditions in the epochs prior to reionization. The redshift distribution of GRBs is modelled using the Press-Schechter formalism with an assumption that they follow the cosmic star formation history. The model reproduces the observed star formation rate obtained from galaxies in the redshift range $0 < z < 5$ as well as the redshift distribution of the GRBs inferred from the luminosity-variability correlation of the burst light curve. They show that the fraction of GRBs at high redshifts, whose afterglows cannot be observed in R and I band due to HI Gunn Peterson optical depth can, at the most, account for one third of the dark GRBs. The observed redshift distribution of GRBs, with much less scatter than the one available today, can put stringent constraints on the epoch of reionization and the nature of gas cooling in the epochs prior to reionization.

Alternative cosmologies

The two ongoing works on alternative cosmology, described in the last year's Annual Report, have been brought to a successful conclusion. These were on (1) modelling the inhomogeneities of the microwave background (MBR) in the quasi-steady state cosmology (QSSC) and (2) reviewing the claim that the universe is accelerating, with the help of the data on type Ia supernovae.

Figure 14 describes the angular power spectrum of the MBR in the QSSC, as obtained by *Jayant Narlikar, Tarun Souradeep, R.G. Vishwakarma, Amir Hajian* and Geoffrey Burbidge. The fit to the data is to be viewed considering this radically different model for the origin of the MBR proposed in this cosmology, suggesting that further

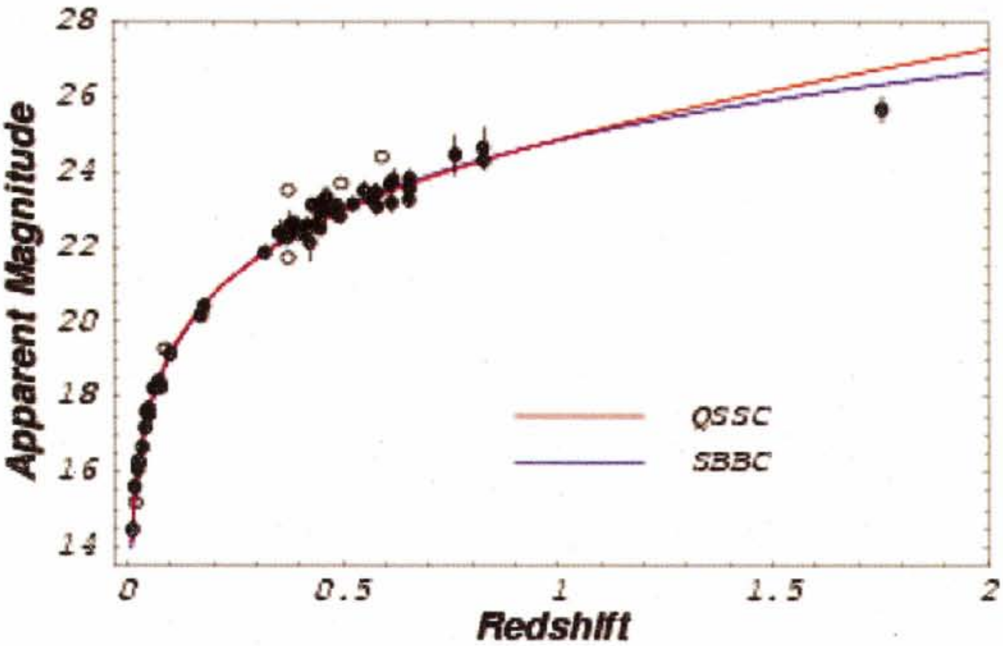


Figure 15: Hubble diagram for 55 supernovae: the theoretical curves represents the best-fitting models in, respectively, the flat quasi-steady state cosmology and the flat standard big bang cosmology

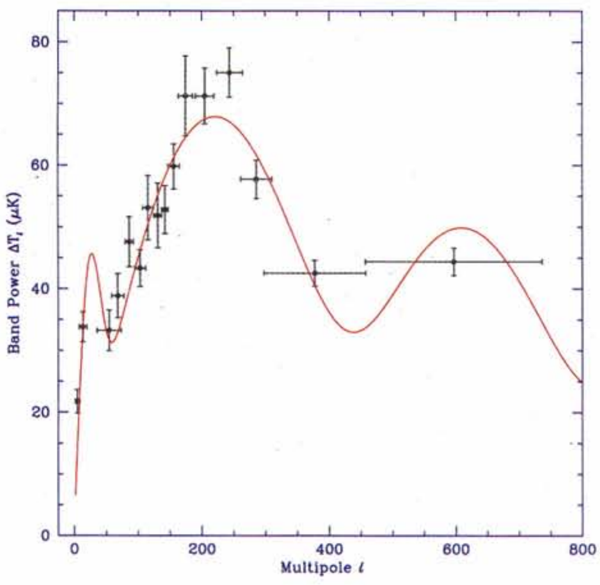


Figure 14: The best-fitting angular power spectrum curve in the quasi-steady state cosmology. The fitted data set is from Podariu et. al 2001 (ApJ 559, 9)

details would be useful in distinguishing between the QSSC and the 'standard model'.

Figure 15, likewise compares the standard model with the QSSC in the ability to fit the redshift-magnitude data for supernovae. *Narlikar*, *Vishwakarma* and Burbidge point out that with the possibility of getting a good fit to the data by alternative means, there is no compelling reason for invoking the esoteric ideas of dark energy, quintessence, etc.

Narlikar and Burbidge are working on the role of the QSSC as providing an oscillating universe for the study of various cosmogonic processes. They have reminded the current enthusiasts of oscillations with a negative energy field that the use of negative energy fields for this purpose dates back to the early 1960s work of Fred Hoyle and *Narlikar*. They have shown how an oscillating model with steady long term expansion helps to resolve many outstanding problems of cosmology. They also point out that anomalous redshifts and periodicity in the magnitudes of redshifts are phenomena for which no cosmological theory currently has an answer.

Cosmic Microwave Background Radiation

Cosmic microwave background anisotropy

Observational success in measuring the temperature anisotropy in the Cosmic Microwave Background over a range of angular scales has set off an intense interplay between theory and observations. A glorious decade of CMB anisotropy measurements has been topped off by the recent announcement and release of data from the Wilkinson

Microwave Anisotropy Probe (WMAP) of NASA. *Tarun Souradeep* has been working on a number of projects in CMB anisotropy that envisaged using the WMAP data. Consequently, current activity revolves around harvesting the recent release of WMAP data.

Statistical isotropy of the CMB sky

It is possible that the fluctuations in the Cosmic Microwave Background temperature violates statistical isotropy, i.e., the covariance of temperature fluctuations in two directions does not depend solely on the separation of the two directions. This could happen in case the universe has non trivial global topology on scales not far beyond the horizon scale but can arise due to less exotic reasons such as non-uniform coverage and residuals from foreground removal, etc.

Over the past couple of years, *Tarun Souradeep* and *Amir Hajian* developed a set of measures – the κ_ℓ spectrum, to detect deviations from statistical isotropy in observed CMB maps. They have now implemented rapid methods to compute the κ_ℓ spectrum from high resolution CMB maps. The measures are being applied to the CMB anisotropy maps obtained by WMAP. This effort is a collaboration with WMAP team of D. Spergel, G. Starkman and N. Cornish looking for signature of cosmic topology.

Recently, *Souradeep* and *Hajian* have also computed the κ_ℓ signatures of generic toroidal universe models. The κ_ℓ spectrum is shown to reflect the number, importance and relative orientation of principal directions in the CMB correlation dictated by the shape of the Dirichlet domain (DD) of the compact space and its size relative to cosmic horizon. Hence, besides detecting cosmic topology, κ_ℓ can discriminate between different topology of the universe complementing ongoing search for cosmic topology in CMB anisotropy data. The close connection between the Dirichlet domain of these spaces and the κ_ℓ spectrum are captured in the leading order approximation to the correlation function where κ_ℓ can be calculated analytically.

In absence of statistical isotropy, it is important to compute the CMB correlation function and not the angular power spectrum. A project student, Amir Aghamousa has made considerable improvement to the accuracy and speed of the numerical code developed by *Atul Deep* for obtaining the angular correlation of CMB anisotropy in terms of the spatial correlations of source functions. *Hajian* is engaged in combining this code with regularized method of images developed by Bond, Pogosyan and *Souradeep*, for computing the CMB anisotropy predictions in any multiply connected universe.

Initial power spectrum from CMB anisotropy

Cosmological parameters estimated from CMB anisotropy assume a spectrum of initial perturbations. *Arman Shafieloo* and *Tarun Souradeep* developed a method to address the complementary problem of estimating the initial power spectrum from angular power spectrum of CMB, given a cosmological model. In the past year, the method has been used to recover the initial power spectrum from a compilation of band power measurements of the angular power spectrum of CMB anisotropy. However, the details of binning of heterogeneous data sets overshadows the relevance of features found in the recovered spectrum. More recently, they have recovered the initial power spectrum from the angular power spectrum measured by WMAP. Assuming best fit cosmological parameters from WMAP, the method yield very interesting initial power spectrum. Besides a robust indication of an infrared cut-off, the recovered spectrum also shows interesting deviation from scale invariance. These features are under further scrutiny. There is also effort to link the initial spectrum to inflaton potential along the lines of work done by *Souradeep* and Jeremie Lasue.

CMB anisotropy measurements and parameter estimation

In the past year, *Tarun Souradeep* has continued to be involved with the analysis of Python-V data. The band power estimate of CMB anisotropy from Python-V has been recently published. The band powers from Python-V go from low multipole up to the first acoustic peak and bridge the data gap in multipole space. The angular power is simultaneously estimated spectrum in eight bands ranging from large ($\ell \sim 40$) to small ($\ell \sim 260$) angular scales, with power detected in the first six bands. There is a significant rise in the power spectrum from large to smaller ($\ell \sim 200$) scales, consistent with that expected from acoustic oscillations in the early Universe. The team has also published constraints on the foreground contamination to CMB anisotropy by cross-correlating the Python-V maps with foreground contaminant emission. The $100\mu m$ and $12\mu m$ dust templates and two point source templates based on the PMN survey were used. The analysis takes account of inter-modulation correlations in 8 modulations of the data that are sensitive to a large range of angular scales and also densely sample a large area of sky. As a consequence the analysis here is highly constraining. There is no evidence for foreground contamination in the analysis of the whole data set.

However, there is indication that foregrounds are present in the data from the larger-angular-scale modulations of those Python-V fields that overlap the region scanned earlier by the UCSB South Pole 1994 experiment. This is an independent consistency cross-check of findings from the South Pole 1994 data.

With other collaborators, *Souradeep* has been involved in a full likelihood analysis of the Owens Valley Radio Observatory data to constrain cosmological parameters. The analysis accounts for the OVRO beam-width and calibration uncertainties, as well as the uncertainty induced by the removal of non-CMB foreground contamination. At the 2 σ confidence level model normalizations deduced from the OVRO data are mostly consistent with those deduced from the DMR, UCSB South Pole 1994, Python I-III, ARGO, MAX 4 and 5, White Dish, and SuZIE data sets. The work has been accepted for publication.

With a group of collaborators, *Souradeep* has computed the combined likelihood function of a set of CMB experiment data over a grid of cosmological parameters. The constraints on cosmological parameters based on a full likelihood analysis that utilizes the entire information of each experiment. The results show interesting differences with the parameters estimation from faster but less exact analysis (post data compression) of recent CMB data sets. However, the computational cost and time involved in a full likelihood analysis limits the analysis to older (and smaller) data sets.

For a generic experimental scan pattern, non-circular beam the standard estimator of $\mathcal{C}_\ell$ is biased and the cosmic variance of $\mathcal{C}_\ell$ is enhanced. Using the formalism developed by *Souradeep* and B. Ratra for handling CMB experiments with non-circular beam, *Anand Shankar Sengupta* and *Souradeep* have been computing these effects. Recent results from WMAP have ignored the effect of non-circularity of the beam. With *Sanjit Mitra*, they are now looking at possible effects of beam non circularity in WMAP results.

Cosmic microwave background anisotropies due to primordial magnetic fields

An inhomogeneous cosmological magnetic field creates vortical perturbations that survive Silk damping on much smaller scales than compressional modes. This ensures that there is no sharp cut-off in anisotropy on arc-minute scales. *K. Subramanian* and J. D. Barrow had pointed out earlier that tangled magnetic fields, if they exist, will then be a potentially important contributor to small-angular scale CMBR anisotropies. Several ongoing and new experiments, are expected to probe the very small angular scales, corresponding to multipoles with $l > 1000$. In view of this observational focus, they revisited the predicted signals due to primordial tangled magnetic fields, for different spectra and different cosmological parameters. They also identify a new regime, where the photon mean-free path exceeds the scale of the perturbation, which dominates the predicted signal at very high l. A scale-invariant spectrum of tangled fields which redshifts to a present value $B_0 = 3 \times 10^{-9}$ Gauss, produces temperature anisotropies at the 10 micro Kelvin level of l between about 1000-3000. Larger signals result if the univese is λ- dominated, if the baryon density is larger, or if the spectral index of magnetic tangles is steeper. The signal will also have non-Gaussian statistics. They predict the distinctive form of the increased power expected in the microwave background at high l in the presence of significant tangled magnetic fields. Observations could be on the verge of detecting or ruling out the presence of tangled magnetic fields, which are strong enough to influence the formation of large-scale structure in the universe.

It is intriguing, in this context, that a signal has recently been detected by the Cosmic Background Imager (CBI) at large $l > 2000$ at a level of 14-31 micro Kelvin. This is much larger than expected in conventional scenarios, involving the Sunyaev-Zeldovich effect and may point to new physics like that discussed above. An independent test for distinguishing the influence of tangled magnetic fields in producing the small-angular scale CMBR anisotropy, is to look for the associated polarization signal.

In particular, unlike conventional signals, tangled magnetic fields lead to CMBR polarization dominated by the odd parity, B-type signal. Recently, E-type polarization has been detected by the DASI experiment, and T-E correlations by DASI and WMAP, albeit at smaller l. Several experiments are also expected to probe the large l regime. With this motivation, *Subramanian*, T.R. Seshadri and J.D. Barrow have calculated the predicted polarization signals due to primordial tangled magnetic fields, for different spectra and different cosmological parameters. A scale-invariant spectrum of tangled fields which redshifts to a present value $B_0 = 3 \times 10^{-9}$ Gauss, produces B-type polarization anisotropies of about (0.3 - 0.4) micro Kelvin between l of 1000-5000. Again, larger signals result if the spectral index of magnetic tangles is steeper. The peak of the signal shifts to larger l for a lambda-dominated universe, or if the baryon density is larger. The signal will also have non-Gaussian statistics. They also predict the much smaller E-type polarization, and T-E cross correlations for these models.

Extragalactic Astronomy

Galactic magnetic fields

K. Subramanian has generalized the constraints on large scale dynamos in galaxies, implied by the conservation of magnetic helicity, to take account of boundary effects. The gauge invariant relative helicity was used for this purpose. It had been thought that allowing for a flux of small-scale helicity out of the system, would enable the large scale dynamo to operate efficiently. There is indeed likely to be such a flux, but accompanied also by a flux of large scale helicity. It was shown by *Subramanian* that an equal amount of magnetic helicity flux in small and large scale fields, does ease the generation of large-scale magnetic fields, but the galactic dynamo can still only produce sub-equipartition large-scale fields.

Radio galaxies

Joydeep Bagchi and *Prasad Subramanian* along with Gopal-Krishna have taken data on an unusual one-sided jet-like radio source CGCG049-033 using the GMRT at 610 and 329 MHz. This source, which was serendipitously discovered in an NVSS image of the Abell cluster 2040, bears a striking morphological resemblance to the well studied one-sided source 3C273. It is, however, much closer and much larger than 3C273. It offers an opportunity to study the phenomenon of undecelerated relativistic jets in unprecedented detail. The GMRT data is currently being analyzed and future observations at other wavelengths are being planned.

Quasar Absorption Systems

The VLT-UVES survey of molecular hydrogen in the high redshift damped Lyman α systems

R. Srianand, along with Cedric Ledoux and P. Petitjean have completed a first ever systematic survey of molecular hydrogen (H_2) in high redshift damped Lyman α systems (DLAs). In this survey, they have searched for H_2 in DLAs and sub-DLAs at high redshift ($z_{\rm abs} \geq 1.8$) using UVES at the VLT down to a detection limit of typically N(H_2) $\sim 2 \times 10^{14}$ cm^{-2}. Out of the 33 systems in their sample, 8 firm and 2 tentative detection of associated H_2 absorption lines was possible. Considering that 3 detections were previously known, H_2 molecules are detected in approximately 15% of the newly surveyed systems. For all the systems, they have measured metallicity relative to solar ([X/H] with either X= Zn, S or Si) and depletion factor of iron, [X/Fe], supposedly onto dust grains, and compare the characteristics of their sample with those of the global population of the DLAs. Although H_2 molecules are detected in systems with [Zn/Fe] as low as 0.2, They find that the systems, where H_2 is detected, are amongst the systems with highest metallicities and depletion factors. In particular H_2 is detected in the three systems having the largest depletion factors. Moreover, two sub-systems where H_2 is detected have [Zn/Fe]$\geq$ 1.5, which are the largest depletion factors ever seen in DLAs. All these clearly demonstrate the presence of dust in a large fraction of DLA systems.

The molecular fraction, f = 2 N(H_2)/[2 N(H_2)+N(H I)], in DLA systems is generally small (typically log $f < -2.0$) and similar to what is observed in the Magellanic clouds (see Figure 16). There is no correlation between the amount of molecular and the neutral hydrogen column density; in particular, two systems where H_2 is detected have log N(H I)<20.3. This indicates that there is no characteristic scale in H I column where H_2 becomes optically thick, as in our galaxy. Approximately 50% of the systems have log $f < -6.0$. This can be explained if the formation rate of H_2 on to dust grains is reduced (probably because the gas is warm, T>1000 K) and the ionizing flux is enhanced compared to what is observed in our galaxy. As the emitting objects associated with DLA systems are faint and have moderate star-formation activity, this suggests that the gas giving rise to the DLA absorption lines is located inside regions where star formation occurs. This probably implies that star formation is diffuse in the systems.

A new measurement of zinc metallicity in a DLA at z $\sim$3.35:

A way to estimate the dust content of DLAs was first proposed by Pettini, et al., (1994), who suggested the use of Zn measurement, an element which is known to be poorly depleted onto dust grain, as an unbiased tracer of metallicities. However, such measurements are challenging, because of both the paucity and weakness of Zn features in quasar absorbers. In addition, the rest wavelengths of the Zn II doublet (2026–2062Å) correspond to large observed wavelengths at high-redshifts. *R. Srianand* in collaboration with Perox, Petitjean, Aracil present chemical abundance measurements in the $z_{abs} = 3.35045$ Damped Lyman-α (DLA) ob-

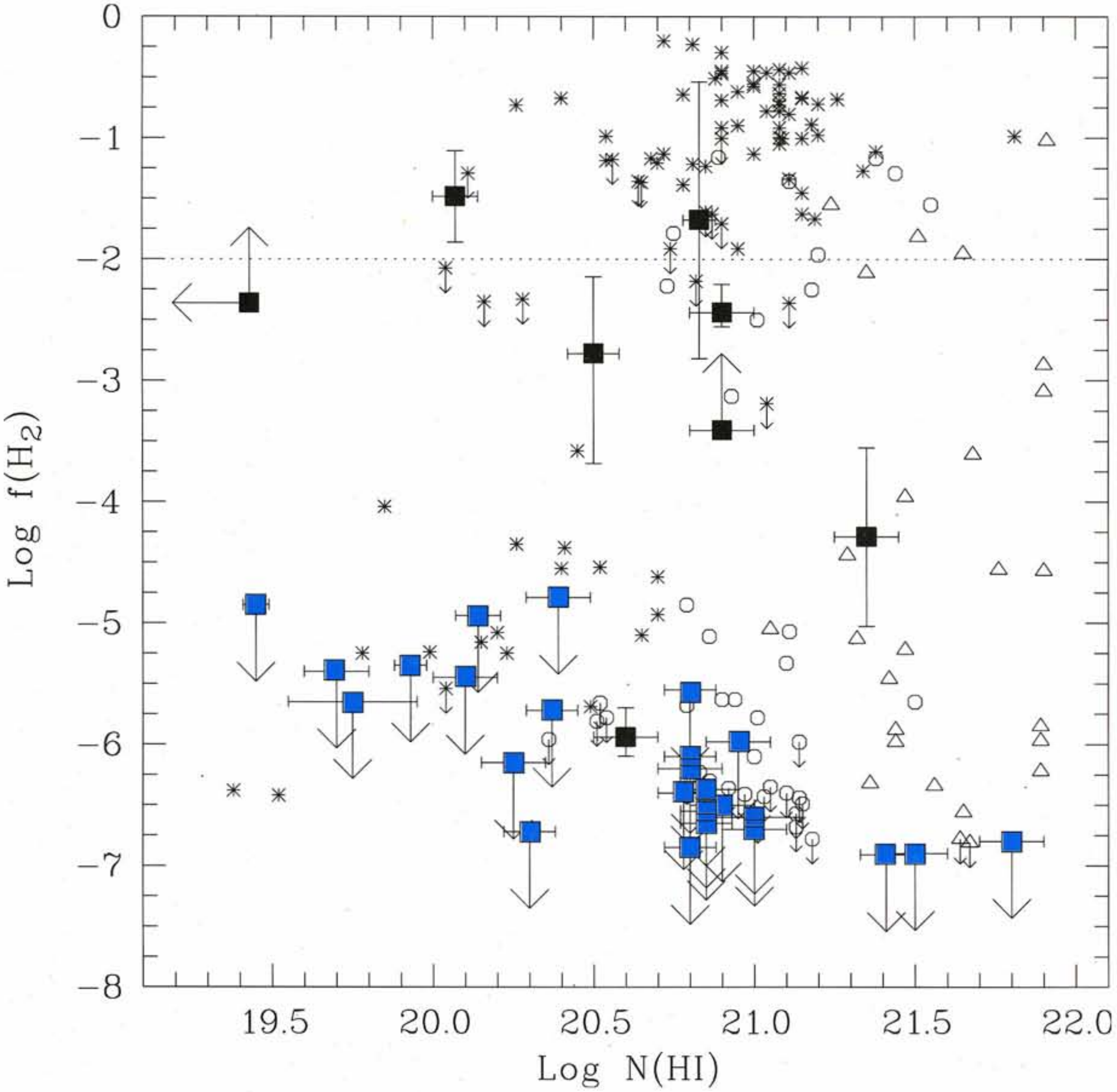


Figure 16: Logarithm of the molecular fraction ($f = 2N(H_2)/[2N(H_2) + N(\text{H I})]$) versus logarithm of the neutral hydrogen column density. Measurements in DLA systems are indicated by squares; dark squares are for H_2 detections and shaded ones for upper limits. Observations along lines of sight in the LMC and SMC from Tumlinson et al. (2002) and in the Galaxy from Savage et al., (1977) are indicated by, respectively, triangles, circles and asterisks. A clear jump in f value is seen both sides of log N(H I) =20.8 in the case of ISM where H_2 becomes optically thick. However, no such trend is noticed in LMC, SMC and DLAs.

served in the UVES spectrum of the BAL quasar BR 1117−1329. They measure a neutral hydrogen column density $N(HI) = 6.9 \pm 1.7 \times 10^{20}$ atoms cm^{-2}. They derive the mean abundances relative to solar:

$[Si/H] = -1.26\pm0.13$, $[Fe/H] = -1.51\pm0.13$, $[Ni/H] = -1.52 \pm 0.13$, $[Cr/H] = -1.36 \pm 0.13$, $[Zn/H] = -1.18 \pm 0.13$, $[Al/H] > -1.25$, $[O/H] > -1.25$ and $[N/H] < -2.19$. The detection of Zn in this DLA only constitutes the third measurement of Zn, an element mildly depleted onto dust grain, at $z_{abs} > 3$. The iron to zinc and chromium to zinc ratio, $[Fe/Zn] = -0.33 \pm 0.05$ and $[Cr/Zn] = -0.18 \pm 0.05$ demonstrate that the absorber has a low dust content. The nitrogen ratio $[N/Si] < -0.93$ suggests that the "secondary" N production process is taking place in this DLA. Finally, this absorber does not present a convincing α-enhancement as shown by the α over Fe-peak element ratios: $[Si/Fe] = 0.25 \pm 0.04$, $[Si/Cr] = 0.10 \pm 0.04$ and $[Si/Zn] = -0.08 \pm 0.04$.

Spatially resolved HST spectroscopy of APM08279+5255:

The $z = 3.911$ broad absorption line (BAL) quasar APM08279+5255 was identified serendipitously within a survey of carbon stars in the Galactic halo (Irwin et al. 1998). The discovery images revealed that APM08279+5255 is not a single point-like source, rather it is extended (Irwin, et al. 1998). Further observations, using NICMOS on the Hubble Space Telescope (Ibata, et al. 1999) and the Keck telescope (Egami, et al. 2000), uncovered a fainter third image between the brighter two, the colours of which suggest that it represents a third image of the quasar. While gravitationally lensed quasars are expected to display an odd number of images, systems are observed invariably with an even number of quasars. For this, lensing galaxies must have very small core radii; this provides strong demagnification of one of the images. High resolution imaging of the gravitationally lensed BAL quasar, APM08279+5255, reveals three point-like images. As these images possess similar colours, it has been suggested that each represents a lensed image. *R. Srianand* in collaboration with Lewis, Ibata, Ellison, Petitjean, Pettini and Aracil, has obtained spatially resolved spectra of the individual components with STIS on the HST. This observation clearly reveals that each is an image of the quasar (see Figure 17). This confirms that APM08279+5255 represents the first example of an odd-image gravitationally lensed system. The implications for the properties of the lensing galaxy are discussed. It is also found that the individual images possess spectral differences indicative of the influence of gravitational microlensing in this system.

High Energy Astrophysics

Knotty jets and Chandra

Recent observations by the Chandra Observatory of nearby galaxies have confirmed the presence of ultra-luminous X-ray objects (ULX). A large number of ULX, that are defined as off centre X-ray sources with luminosities $> 10^{39}$ ergs/sec. have now been detected. Since the luminosities of these sources are greater than the Eddington luminosity for a ten solar mass blackhole, it has been proposed that they harbour intermediate mass blackholes (IMBH) with a mass range of $10^2 - 10^5 M_\odot$. The existence of IMBH leads to a paradigm shift from the earlier view that there are two kinds of blackholes (stellar and super-massive) in the universe. One alternate model for ULX, is that they are sub-Eddington stellar mass black hole systems with beamed emission. It was thought that significant beaming could occur if the emission is from the inner regions of a geometrically thick (i.e. funnel shaped) disk. *R. Misra* and K. Sriram calculated the expected flux enhancement from such a disk geometry and found that even if the opening angle of the disk is very small (like 15 degrees) the flux enhancement is only a factor of 5. This implies that the above hypothesis cannot be true, making the case for ULX to be IMBH stronger.

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. S. Sahayanathan, *Misra*, *A. K. Kembhavi* and C. L. Kaul have modeled these knots as a spherically expanding plasma cloud, where there is a continuous injection of non-thermal electrons. This model is different from previous works in which, instead of a continuous injection of particles, a short injection period was assumed. They computed the time dependent electron distribution and resultant photon spectra taking into account synchrotron, adiabatic and inverse Compton cooling, and found that the the overall broadband spectral features can be reproduced. They argue that for some sources, constraints on the X-ray spectral index (by a longer Chandra observation) will be able to differentiate between the different models. This in turn will put a strong constraint on the acceleration mechanism active in these sources.

There is now growing evidence that in the inner regions of accretion disk around blackholes there are non-thermal electrons which Comptonize soft photons to high energies. It is possible that the same acceleration process may also accelerate protons to form a non-thermal proton distribution. These protons would, via p-p collisions, produce

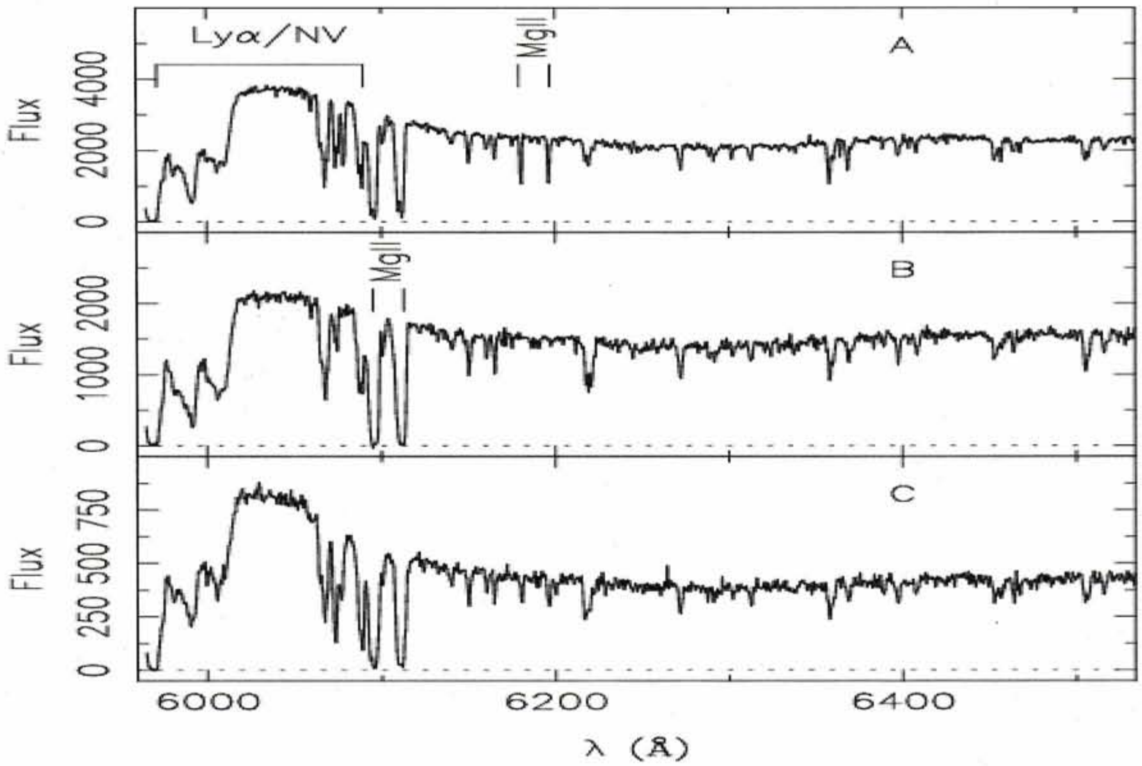


Figure 17: The spectra of the three QSO images A, B and C (from top to bottom). While differences in the individual spectra are apparent, the lower panel confirms that image C is of the quasar. As well as the prominent emission line structure due to Ly_{α}/N V, strong MgII $\lambda\lambda 2796, 2803$ absorption at z=1.18 due to a foreground galaxy is labelled. One striking feature is the presence of MgII absorption at z=1.21 (~ 6190Å), also labelled, which, while being strong in image A, is weaker in C and non-existent in image B, suggesting a non-uniform covering factor across the images (Petitjean et al. 2000).

electrons, positrons and γ-rays. For such a scenario, S. Bhattacharyya, N. Bhatt, *Misra* and Kaul computed the steady state electron-positron distribution taking into account Compton cooling, e^-e^+ pair production (due to $\gamma-\gamma$ interactions) and pair annihilation. They found that the resultant spectra has a broad feature around $1 - 10$ MeV which may be tested with observations by INTEGRAL and GLAST. Using the available OSSE data for the blackhole system, GRS 1915+115, they illustrated that an upper limit on the non-thermal proton fraction can be obtained, which may put constraints on the acceleration process active in this system.

Blackhole X-ray binaries are variable on a wide range of time scales ranging from months to milliseconds. A detailed analysis of their temporal variability is crucial to the understanding of the geometry and structure 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. An important constraint can be obtained on the origin, by quantifying the non-linear behaviour of these fluctuations. *B. Mukhopadhyay*, K. Harikrishnan, *Misra*, G. Ambika and *Kembhavi* have analyzed the light curve of the blackhole system GRS 1915+105, to obtain the correlation or fractal dimension of the system. They find that during certain temporal states the behaviour of the system can be quantified to be that of a low dimensional chaotic system.

Pseudo general relativistic description of accretion disk around compact objects

The full set of general relativistic accretion disk equations around a compact object is very tedious to handle, particularly if one is looking for the time dependent phenomena. To handle this difficulty, a concept of effective Newtonian potential was proposed more than twenty years back. A variant of the pseudo-Newtonian potential for accretion disk around rotating compact objects obtained by *B.Mukhopadhyay*, reproduces all the essential general relativistic properties, (like radius of marginally bound and stable orbit, luminosity and efficiency) of the disk quite accurately.

The methodology adopted by *Mukhopadhyay* in describing the accretion disk around rotating compact objects can be used to derive the pseudo-Newtonian potential for any metric. As the inclusion of rotation in a proper manner is very important near the inner edge of disk, the potential is directly derived from the metric. When the disk is around a blackhole, the potential is derived from Kerr metric, while for the case of a neutron star one uses the Hartle-Thorne metric. This model can reproduce all the essential properties of general relativity within 10% error even for rapidly rotating blackholes.

Apart from this pseudo-Newtonian potential, two other potentials, which approximate the angular and epicyclic frequencies of the relativistic accretion disk around rotating compact objects, were obtained by *Mukhopadhyay* and *R.Misra*. One of them, (the Logarithmically Modified Potential) is a better approximation for the frequencies while the other, (the Second-order Expanded potential) also reproduces the specific energy for circular orbits in close agreement with the general relativistic values. These potentials could be included in time dependent hydrodynamical simulations to study the temporal behaviour of such accretion disks.

General relativistic effects on hydrodynamical flow around compact objects

Once the self-consistent pseudo-Newtonian potentials for accretion disk are available, one can study the solutions of accretion disk around the rotating blackhole. One can study how the fluid properties get affected by different rotation parameters of the blackhole. *B. Mukhopadhyay* has studied these phenomena and has shown that, with the inclusion of rotation of the blackhole, the allowed disk parameter region changes dramatically and disk can become unstable. He has also studied the possibility of shocks in the accretion disk around rotating black holes. When the blackhole is rotating, the sonic locations of the accretion disk get shifted or disappear, making the disk as well as shock front unstable. To restore stability the angular momentum of the accreting matter has to be reduced/enhanced for co/counter-rotating disk by means of some physical process.

When the compact object is neutron star, the global solution for the accretion disk can be studied in a similar manner. It is known that there are several basic differences between the accretion disks around blackholes and neutron stars, particularly at the inner edge, and the disks should be treated separately at inner region. Thus, one can study the solution of viscous accretion disks around rotating compact/central object having hard surface i.e., neutron star, strange star or any other highly gravitating objects. *Mukhopadhyay* and Shubhrangshu Ghosh have been studying the accretion phenomena around stars in pseudo-Newtonian approach in Hartle-Thorne geometry. The Hartle-Thorne metric can describe geometry of star as well (as the spacetime out-side) and this metric is used to establish the Newtonian potential. Using this potential they have studied the global parameter space of the accretion disk and obtained the physical parameter regime, for which the stable accretion disk can be formed around gravitating object with hard surface. They also study how the fluid properties change with the rotation of the central star and show that the valid disk parameter region dramatically changes with the change of rotation.

The fluid phenomena of accretion disk have also been studied with the inclusion of Coriolis effect by *Mukhopadhyay* and A.R. Prasanna. Here, the effect of rotation of the central object is included through the Coriolis acceleration term into the fluid equation. The introduction of the Coriolis term into the fluid equation changes in the effective angular momentum of the fluid and affects the known parameter space of the non-rotating system. Further, the possibility of shock formation is reduced in several regions of parameters.

Theoretical model of quasi-periodic oscillations for low mass X-ray binary system

There is currently significant interest in analysing and interpreting the observed Quasi-Periodic Oscillations (QPOs) of various objects. It is observed that sometimes the QPOs are found as a pair in Kilohertz (kHz) range. A new model is proposed by *Mukhopadhyay*, Ray, J. Dey and M.Dey for the kHz QPOs using the hydrodynamical description of accretion disk around a rapidly rotating compact (strange) star, and the potential given by *Mukhopadhyay*. The higher kHz QPO frequency is described by the viscous effects of accretion disk leading to shocks, while the lower one arises from the Keplerian motion of the accreting matter. Comparing the results with the observations for two of the fastest rotating compact stellar candidates ($4U$ 1636-53 and KS 1731-260), it is found that they match very well thereby, suggesting that they are strange stars.

Angular momentum transfer in accretion disk:

Prasad Subramanian and Bhalchandra Pujari have recently concluded a brief study of angular momentum transport in quasi-Keplerian accretion disks. Angular momentum transport is a central issue in the theory of accretion disks. There have been several physically motivated simple treatments in popular textbooks that derive the form of the viscous torque between neighbouring annuli in such accretion disks. Some of these treatments have been shown to be wrong, and *Subramanian* and Pujari have found that some of the corrections proposed in the literature are also wrong.

Galaxy and Interstellar Medium

Discovery of micro-organisms in the Earth's atmosphere

The analysis of the findings of a cryosampler balloon experiment sponsored by ISRO have now been published in the FEMS Microbiology Letters, under the authorship of Milton Wainwright, Chandra Wickramasinghe, P. Rajaratnam and *J. V. Narlikar*. The balloon flight had been successfully completed on January 21, 2001, and the analysis of the samples collected at heights ranging from 19 to 41 km is being carried out.

The use of cationc dye technique has successfully revealed the existence of live cells in the samples of air collected at heights of 40-41 km, while viable but non-culturable bacteria (rod-shaped B. Simplex and coccoid S. Pasteuri, see Figure 18) have also been detected at these heights. It is now the challenge to explain how they got to this location. Normal terrestrial processes do not lift surface matter to any height beyond 15-20 km, and so unless some other cause is advanced, the conclusion seems to be that the bacteria came from the outer space.

Wainwright, Wickramasinghe and *Narlikar* have suggested that the current outbreak of SARS may be originally brought in from outside the Earth through a virus-shower from above. About twentyfive years ago, Fred Hoyle and Wickramasinghe had suggested that pathogenic viruses and bacteria could be brought to the Earth by comets and other bodies in the solar system coming close to the Earth.

Interstellar dust and extinction by composite porous grains

Ranjan Gupta is continuing the ongoing research on modeling of interstellar dust grains, (in collaboration with D.B. Vaidya and J.B. Dobbie and P. Chylek). Figures 19 (a) and (b) show the model fitting with composite grains for cometary polarization.

Further work was carried out on modeling the interstellar extinction with a new T-Matrix calculation and the first result of fitting of the observed curve for our Milky Way is shown in Figure 20. More results on LMC and SMC are in progress.

Stellar Physics

Digital spectral library

R. Gupta is involved in a DST-NSF Indo-US proposal entitled "A Comprehensive Digital Library of Stellar Spectra" in collaboration with H.P. Singh and Jim Rose and his team. They expect to release the spectral library by this summer which will have at least about 600 stars with full wavelength coverage of $\lambda 3500 - 9500$ Å .

Solar Physics

Energetics of solar coronal mass ejections

Prasad Subramanian and Angelos Vourlidas has recently concluded an extensive study of the energetics of flux rope-like coronal mass ejections (CMEs) from the sun between 1997 and 2001. They studied 39 well-observed CMEs from data taken by the Large Angle Spectroscopic Coronograph (LASCO) aboard the Solar and Heliospheric Observatory (SOHO) and drew significant conclusions regarding the driving energy of coronal mass ejections at heights above 2 solar radii. They concluded that the energy contained in magnetic fields advected by CMEs is a viable candidate for propelling them along at these heights. They also ruled out the hypothesis that coupling to the ambient solar wind alone can propel the CMEs.

Observations of the Sun with the Giant Metrewave Radio Telescope

Prasad Subramanian, together with S. Ananthakrishnan and M. R. Kundu have analyzed data on two very interesting solar flares observed by the Giant Metrewave Radio Telescope (GMRT). The first flare, observed with the GMRT at 1060 MHz

Cultures of B. simplex (Left) and B. pasteur (Right) grown on PDA from stratospheric samples at 41 km. Pictures x 1000 phase contrast light microscope.

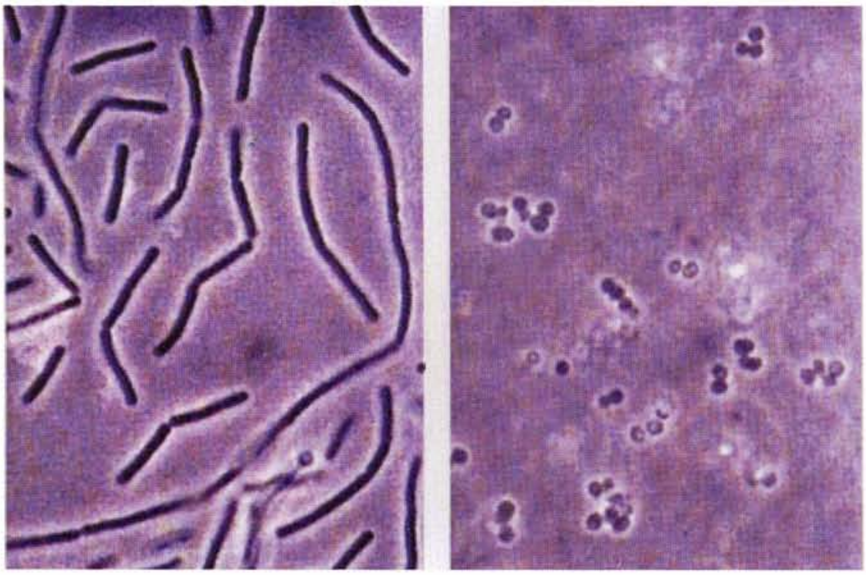


Figure 18: Cultures of B. Simplex (left) and S. Pasteuri (rights) grown on LB medium after isolation using soft PDA from stratospheric samples at 41 km. (x 1000 using phase contrast microscope)

on November 17 2001, was a long duration event and was associated with a halo CME. Together with the data from the Nobeyama radioheliograph, the Nobeyama radiopolarimeter, the Hiraiso spectrograph and the LASCO, the GMRT data provides vital clues to the initiation mechanism of the flare-CME energy release process. The multifrequency data set for this complex event suggests that the reconnection processes leading to its initiation start relatively higher up in the corona and proceeds downward, confirming a vital prediction of the 'breakout' model of CME initiation. The second flare observed with the GMRT at 610 MHz on October 6, 2002, was a classical impulsive flare with narrowband emission. This is, commonly known as a confined flare, where the electrons do not have access to open field lines through the corona. These findings represent some of the first observational studies of the Sun with the GMRT.

Instrumentation

Ultraviolet Imaging Telescope (UVIT)

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 IUCAA and several other Indian institutions. This instrument, called UVIT, 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 with an angular resolution of 1.5 arcsec, and a set of filters is available in each band for wavelength selection.

In addition to simultaneous observations of X-ray objects in the UV-visible bands, a large part of the sky would be surveyed to a depth of mag. 20, and observations would be made on individual objects of interest.

A technical proposal for UVIT has been submitted to ISRO by *Shyam Tandon* in collaboration with several astronomers from Indian Institute of Astrophysics, Bangalore, and Tata Institute of Fundamental Research, Mumbai. It is expected that the satellite would be ready for launch by the end of year 2006.

Photon Counting Detectors

The satellite ASTROSAT (see above), is not very well pointed and it suffers a drift of 0.2 arcsec/s.

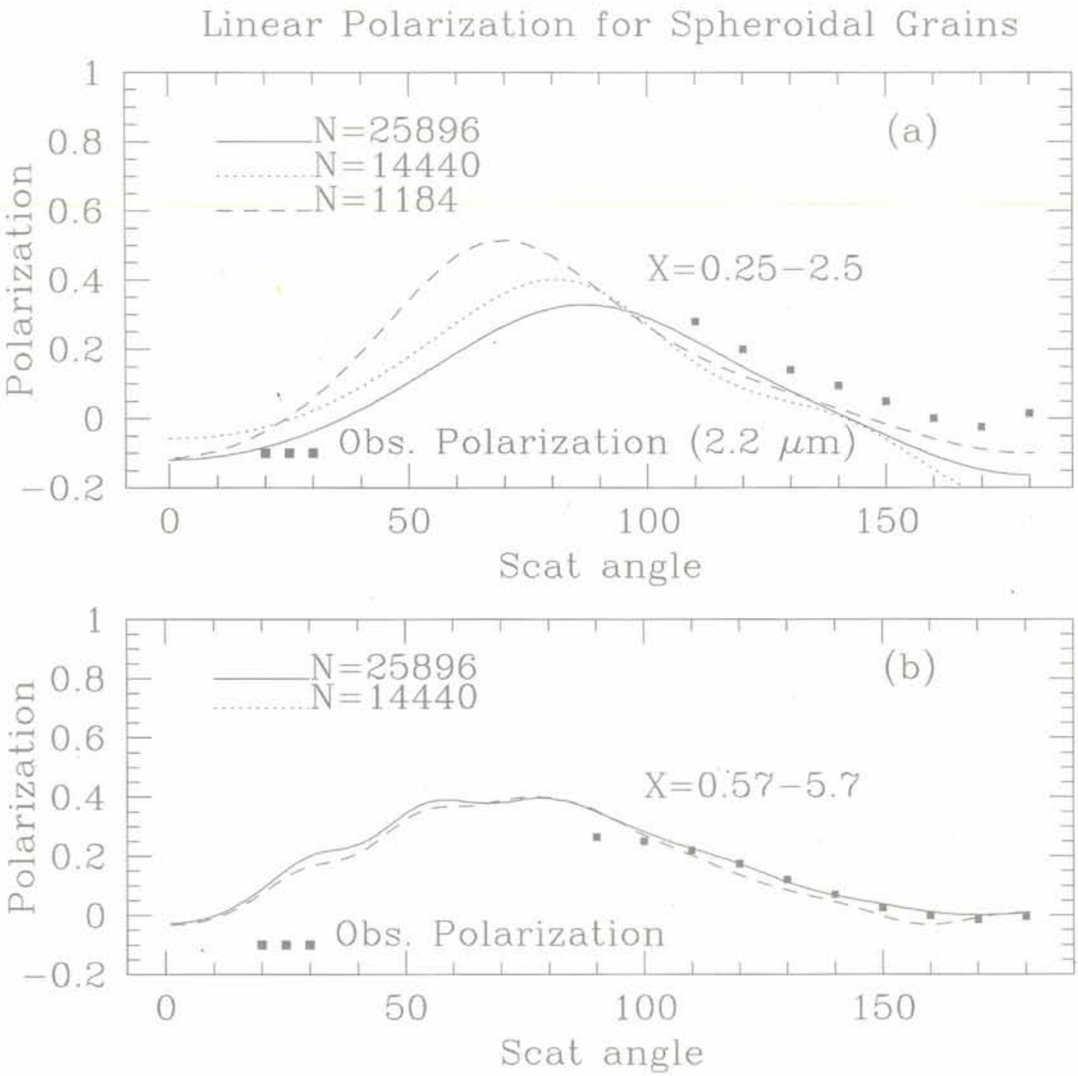


Figure 19: Panel a. Observed polarization in Comet Halley with three composite grain models at $2.2\mu m$. Panel b. Observed polarization for six comets (see Fig. 2 in Kiselev and Velichko, 1998 Icarus, 133, 286) with two composite grain models at $0.55\mu m$

Hence, in order to get an angular resolution of 1.5 arcsec for the images, it is required that the frames be recorded at a rate $> 1/s$. Therefore, in order to minimise the detector noise, photon counting detectors are used. The detectors would consist of an image intensifier and a CCD/CMOS read out.

In the IUCAA Instrumentation Laboratory, *Mahesh Burse, Pravin Chordia, Abhay Kohok,* and *Shyam Tandon* have been studying suitability of various CCDs and CMOS imagers for the purpose, and have been developing read out electronics for these; the electronics is somewhat similar to that already developed for CCD cameras for ground based optical astronomy, but the frame rates, and hence, data rates are two orders of magnitude faster.

A detailed study has been made of a CMOS detector (Star 250, made by Fill Factory NV, Belgium), to check its suitability for finding centroids of the intensified light pulses from individual photons. It has been found that if the light pulses have a FWHM of 2 pixels, the signals in a 3 x 3 cluster of pixels, centred on the brightest pixel, can be used to get position of the centroid with an accuracy < 0.1 pixels. Such an accuracy of centroiding is adequate to give a resolution > 2000 with an imager with 512 x 512 pixels, i.e., an angular resolution < 1 arcsec in the UVIT's field of 30 arcmin.

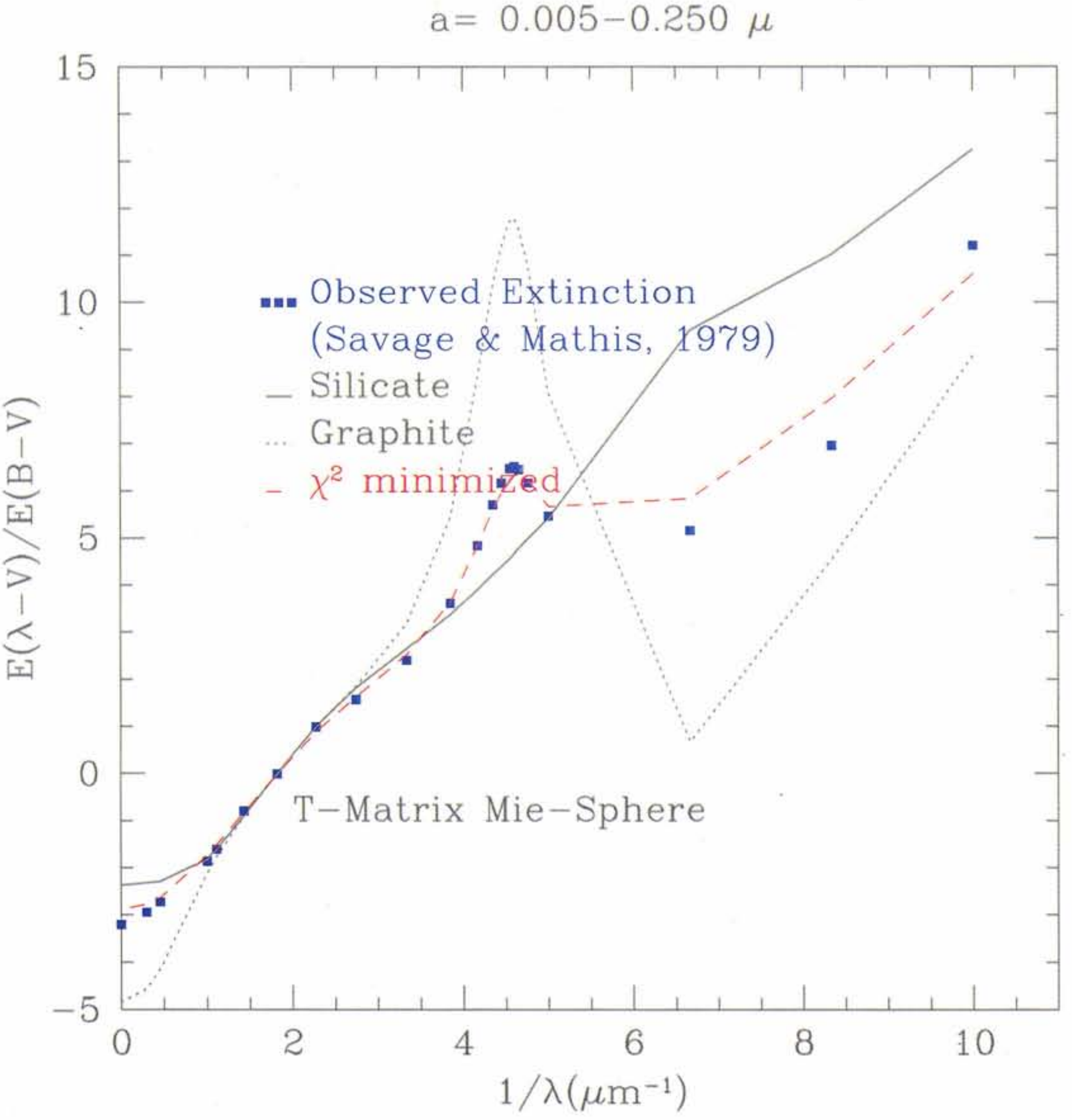


Figure 20: T-Matrix calculated extinction curve and its fitting to observed interstellar extinction curve

Near Infrared PICNIC Imager (NIPI)

The preliminary design and specifications of the near-IR camera which is being developed for the IUCAA telescope was reported last year. The optical design has now been finalised and the orders for all the optical components, viz. lenses, filters, mirrors and window, have been placed with various vendors. The optics was modified to include the window and the filter in the design and to optimise their position in the layout. Aluminium spacers have been put between collimating and imaging doublets to account for the effect of lens mounts on the design. A preliminary investigation showed that the design needed very tight manufacturing tolerances on the lenses. The distance between collimating and imaging lenses was then increased, i.e., the camera was slowed down, to bring the tolerances within acceptable limits. The size of the instrument from the telescope focus to the detector is thus, increased to 900 mm. This might have caused a flexure in the instrument during its mounting on the telescope. So the optical design was folded using three mirrors. The radii of the lenses of the final design were matched with the test plates of ISP optics. Design was optimised at -100^oC, but the temperature might change during the course of operation of the camera. The thermal analysis of the design shows that a temperature change of 50^oC can easily be compensated by adjusting the telescope focus. Figure 21 shows the optical layout of the camera.

The design of mechanical structure for housing the optics is still in progress. The entire optics

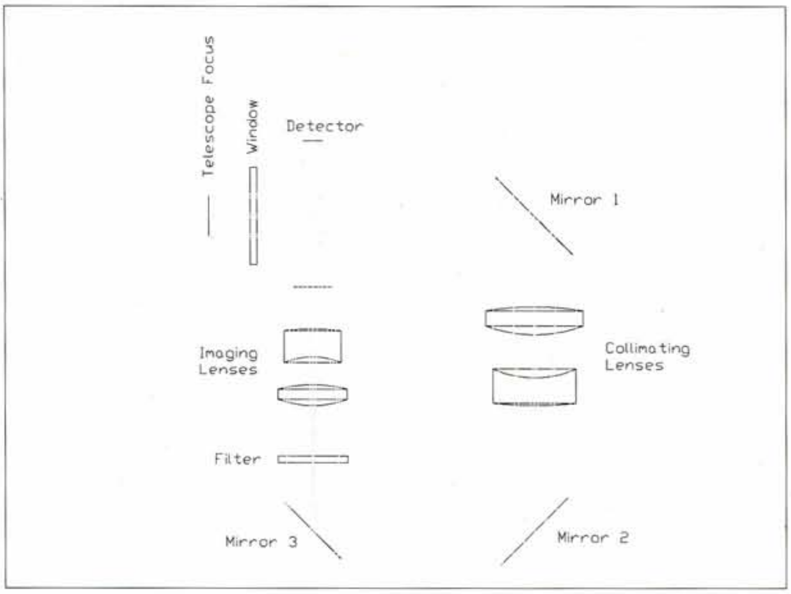


Figure 21: 3-D layout of NIPI. The focal plane of the telescope is reimaged onto the PICNIC detector with a image scale reduction by a factor of 2.

will sit inside a standard size dewar. The CaF2 window would be attached to the wall of the dewar and the lenses and mirrors would sit in vertical mounts attached to the cold plate of the dewar. To check if the light rays pass unhindered from the telescope focus to detector a rough prototype of the design using thermacol and cardboard sheets has been made. The filter wheel would be driven by a stepper motor. On the basis of timings of the wheel, the torque required by stepper motor was calculated and the correct motor identified.

In order to calculate the amount of charge stored in each of the pixels, it is necessary to send some electronic signals to the array. These signals are generated by IR controller through some input tables. These tables are now incorporated in the controller software and the clock, and bias signals for reading out the PICNIC array have been tested on the oscilloscope. The cable for sending the signals from the controller to the array (which sits in a socket on a PCB) has been made and tested. *A. N. Ramaprakash, S. N. Tandon, R. Gupta, A. Deep, M.P. Burse, P. A. Chordia, H.K. Das, S. Engineer, A.A. Kohok* and *V. B. Mestry* of the Instrumentation Lab are actively involved in this.

They have also made arrangements for testing the PICNIC array inside a dewar and for multiplexer testing at room temperature (see Figures 22 and 23).

The main science drive of NIPI would be the observations of supernovae of type 1a. In this regard, they have estimated the exposure time needed to achieve different values of S/N for 15, 16 and 17 magnitude supernovae. They plan to observe at least 5 supernovae with this instrument and combine them with data sets of other supernovae to calibrate their light curves in J, H and K bands.

CIRPASS Collaboration:

Cambridge Infra-Red PAnoramic Survey Spectrograph is an integral field, fibre-fed instrument which was built at the Institute of Astronomy, Cambridge, UK. As part of on going collaboration with the group, *A.N. Ramaprakash* joined the team for commissioning the instrument on the 8m Gemini South Telescope on Cerro Pachon, Chile in July-August 2002. The commissioning run was extremely successful and the instrument is now being offered for observations on the telescope. The latter part of the commissioning period was used for observing science targets that demonstrated the unique capabilities of CIRPASS such as the large field of view (13x5 at 0.36 resolution), optimal suppression of atmospheric airglow lines, etc. On the

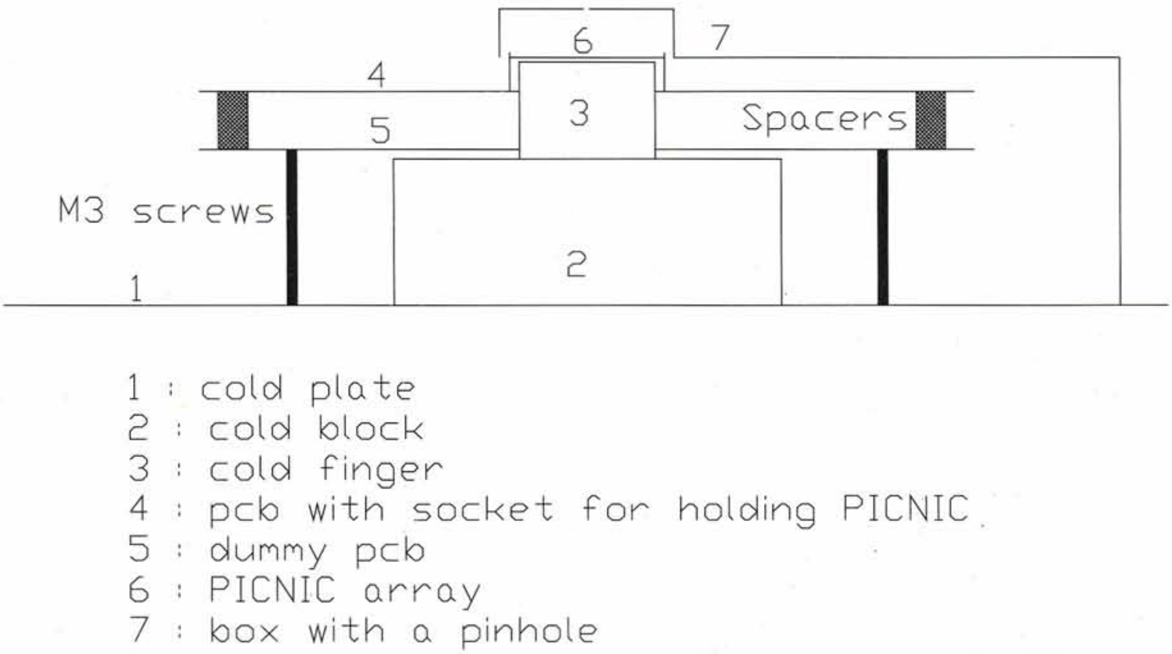


Figure 22: Schematic drawing of the set-up for PICNIC testing

basis of the experience of the commissioning observations, some steps were identified to improve the instrument's performance and observing efficiency.

IMPOL Observations:

(1) Polarimetry of Galactic Molecular Clouds: IUCAA's Imaging Polarimeter (IMPOL) was designed and built to be compatible with two of the major telescope facilities which existed in India at the time. The instrument has been successfully used for observations with the 1.2 m Gurushikhar Infrared Telescope, Mt. Abu for several years now. In July 2002, a project was undertaken by *A. N. Ramaprakash* and *S. N. Tandon* to interface IMPOL to the 2.3m Vainu Bappu Telescope (VBT), Kavalur and obtained polarization data for a set of galactic dark molecular clouds in December 2002, the analysis of which is currently underway. The work was done in collaboration with M. Gopinath, a Ph. D. student of H. C. Bhatt at IIA, Bangalore, who plans to further utilize IMPOL on VBT for observing a sample of dark molecular clouds and Galactic high velocity clouds, for which he has complementary extinction and spectroscopic data. This will form part of his thesis.

(2) Brown Dwarf Polarimetry: The primary aim of interfacing IMPOL with VBT was to undertake a polarimetric study of brown dwarfs. Recent models predict small levels of polarization due to the presence of unsettled dust in the atmospheres of brown dwarfs warmer than about 1800K. The extremely low instrumental polarization of IMPOL (0.05%) makes it capable of detecting polarization in brown dwarfs brighter than about V=17 when used with the VBT. *Ramaprakash*, *Tandon* and S. Sengupta (IIA, Bangalore) are involved in this project and they have identified a sample of warm brown dwarfs and an observing strategy to undertake a multi-wavelength polarization campaign. Unfortunately, the three attempts till date were affected by bad weather conditions and an incident of instrument failure.

(3) Gamma-ray Burst Optical Polarization: GRB afterglows are expected to be polarized up to a few percent, with the polarization and its position angle predicted to change with time differently in different afterglow models. However, to do polarimetry of such transient sources it is necessary to measure the two orthogonal components of polarization, which define a Stokes parameter, simultaneously. Since IMPOL does exactly this, it

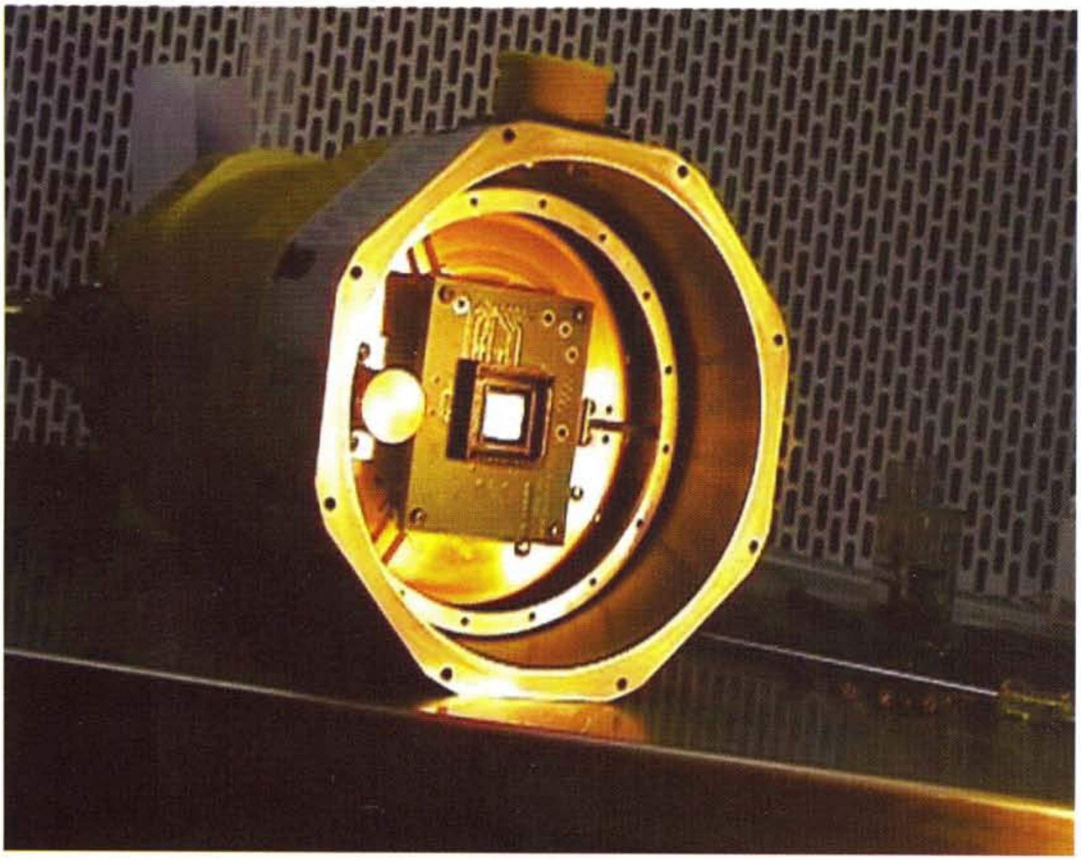


Figure 23: Set-up for PICNIC testing inside a liquid nitrogen dewar

is particularly suited for measuring afterglow polarization. As quick response to a GRB afterglow identification alert is crucial to the success of this experiment since most afterglows will fade below observable limits in about a day or two, a simplified mounting procedure for IMPOL has been developed by the instrumentation groups at IUCAA and IIA, Bangalore, so that it can be set up for observation on a telescope in less than three hours.

Telescopes at universities

R. Gupta was involved in the installation of telescopes at: (i) J.E.S. College, Jalna and Assam University, Silchar (two telescopes of 8" and 16").(ii) Gauhati University, Guwahati (CCD camera for their 12" telescope). All these telescopes and backend instruments are primarily for teaching purposes at the respective college/universities.

(II) RESEARCH BY VISITING ASSOCIATES

Gravitational Theory and Gravitational Waves

Ahsan, Zafar

Zafar Ahsen has considered the problem of generalised symmetries of the electromagnetic fields in general relativity. He has introduced the concept of Maxwell inheritance and illustrated it through the spacetime solution corresponding to strong gravitational waves propagating in generalised electromagnetic universes and the algebraically general twist-free solution of Einstein-Maxwell field equations for non-radiative electromagnetic fields.

Banerjee, Asit

The cosmic censorship conjecture states that in all generic situations, the singularities will be covered by event horizon and hence not visible to outside observers . This is yet an open question. However, there exist many exact solutions of Einstein's equations, where naked singularities do occur. Inspite of many such situations in 4D space, comparatively much less is known about the singularity formation as well as the appearance of naked singularities in higher dimensions. Asit Banerjee has recently studied in details, the spherically symmetric inhomogeneous dust collapse (Tolman-Bondi spacetime) in higher dimensional spacetime. The non-marginally bound case in five dimensions is analyzed in details and the degree of inhomogeneity, which is necessary to form a naked singularity in the collapsing system is examined.

The inclusion of heat flow in the gravitational collapse gives rise to many interesting situations. A class of solutions in the interior are obtained, which satisfy all the energy conditions and at the same time possess in certain special cases an interesting property that the horizon does not appear at the boundary at any stage of the collapse. This simple model shows that there is no accumulation of energy due to collapse, since it radiates out at the same rate as it is being generated. Such models with heat flow but without horizon can also be generalized in the higher dimensional spacetime.

Chaudhury, Sarbeswar

A relativistic treatment of the gravitational field of an accretion disk around a blackhole is of much importance in astrophysics. S. Chaudhuri is in search of some new disk-blackhole solutions using the formalism developed by Lemos and Letelier. Both the disk and the blackhole are assumed to be static. The energy density and the pressure of the disk-blackhole combination are evaluated. The energy density is found to be zero in two regions : (i) at R=infinity and (ii) at a distance R= m from the centre of the disk. In between these two limits, it has some maximum value.

Chaudhuri is also investigating the exterior gravitational field of a Kuzmin disk surrounding a Curzon blackhole.

Ghosh, S. G.

A singularity would not be visible as indicated in the relativistic literature by the phrase "cosmic censorship conjecture" and was articulated by Penrose. It will not be visible to an observer outside the event horizon, is the weak form, while it will not be visible to any observer, even the one who is sitting on the collapsing star, is the strong form of the conjecture. As the singularity is approached, density diverges and it would, therefore, be of relevance to consider the state of matter at ultra high density like strange quark matter. S. G. Ghosh and N. Dadhich have found the general solution of the Einstein's equations for spherically symmetric collapse of strange quark fluid, having the equation of state, $p = (\rho - 4B)/k$, where B is the bag constant. The solution is utilized to study end state of collapse. An interesting feature that emerges is that the initial data set giving rise to naked singularity in the Vaidya collapse of null fluid gets covered due to the presence of strange quark matter component. Both naked singularities and blackholes are shown to be developing as final outcome of the collapse. Further, it turns out that the nakedness and curvature strength of the shell focusing singularities carry over to higher dimensions as well.

Ghosh, in collaboration with S.B. Sarwe, R.V. Sarayakar and D.W. Deshkar, has investigated the occurrence and nature of naked singularities in the gravitational collapse of an adiabatic perfect fluid in self-similar higher dimensional spacetimes. It is shown that strong curvature naked singularities could occur if the weak energy condition holds. Its implication for cosmic censorship conjecture is discussed. Known results of analogous studies in four dimensions are also recovered.

Ghosh and A. Banerjee have investigated the occurrence and nature of a naked singularity in the gravitational collapse of an inhomogeneous dust cloud described by a self-similar higher dimensional Tolman-Bondi spacetime. Bound, marginally bound and unbound spacetimes are analyzed. The degree of inhomogeneity of the collapsing matter necessary to form a naked singularity is given.

In order to study gravitational collapse, it is necessary to describe adequately the geometry of interior and exterior regions and to give conditions that allow matching of them. Ghosh, in collaboration with D.W. Deshkar, has studied the junction conditions for non-spherical (plane symmetric) collapsing radiating star, consisting of a shearing fluid undergoing radial heat flow with outgoing radiation.

Ibohal, Ng.

By applying Newman-Janis algorithm to a spherically symmetric 'seed' metric, Ibohal presents general rotating solutions of Einstein's equations, in terms of NP quantities involving Wang-Wu functions. From these rotating solutions, he derives a rotating Kerr-Newman-Vaidya blackhole representing Kerr-Newman black hole embedded in rotating Vaidya null radiating space. It is shown that this blackhole could probably prevent the direct formation of 'instantaneous' naked singularity with zero mass and 'negative mass naked singularities' after the primordial Hawking evaporation of the mass of Kerr-Newman blackhole during its electrical radiation process. His new solution describes an extension of Glass and Krisch superposition, which is further the extension of Xanthopoulos superposition. Ibohal also proves that the rotating charged Vaidya blackhole may be an 'instantaneous' blackhole during the primordial Hawking evaporation process of the electrical radiation of Kerr-Newman-Vaidya blackhole. It has also been shown, by incorporating primordial Hawking evaporation of radiating blackhole in the form of classical spacetime metric, that every electrical radiation of variable-charged rotating blackhole may produce a change in the mass of the body without affecting the Maxwell scalar.

Ibohal further discusses the primordial Hawking's evaporation of the masses of 'variable-charged' Reissner-Nordstrom and Kerr-Newman, black holes embedded into the de Sitter cosmological space. It has been shown, by incorporating primordial Hawking's evaporation of radiating black holes in the form of classical spacetime metric, that every electrical radiation of variable-charged rotating cosmological black hole may produce a change in the mass of the body without effecting the Maxwell scalar and the de Sitter cosmological constant.

Nandi, Kamal Kanti

A very fundamental question in quantum gravity is whether or not the principle of equivalence holds at a quantum level. To answer this question, one plausible way is to investigate the geometric effects arising from general relativity on quantum interference of thermal neutrons. K.K. Nandi and Y.Z. Zhang have proposed a unified approach, which reveals the geometric contributions to the fringe shift. It has also been shown that the exact geodesic equation contains in a natural way, what may be termed as a "Gravitational Aharonov-Bohm" effect.

In another investigation, Nandi et.al. have proposed an analogue of the Fizeau effect in a gravity field portrayed as an effective optical medium. This investigation has been inspired by the possibility of creating laboratory blackholes in the Bose-Einstein condensates. Various expressions for the Fresnel drag coefficients have been worked out. Some of the results do indeed complement the recent works dealing with "optical" blackholes.

Patil, K.D.

The cosmic censorship hypothesis (CCH) is one of the most important open problems in general relativity, since it plays an important role in Theories of blackhole physics. The CCH roughly states that singularities forming in gravitational collapse must be hidden behind event horizons and hence, invisible to outside observers. In this context, a few questions, which could naturally arise are : Does cosmic censorship hypothesis hold in higher dimension ? Are naked singularities in higher dimensional collapse strong ?. K.D. Patil has studied Tolman - Bondi dust collapse along radial null geodesics and showed that higher dimensions ($D \geq 6$) respect the CCH, if one choses a smooth analytic density profile as an initial data. Further, his investigation shows that naked singularities in (N + 2) - dimensional dust collapse are strong only up to the fifth dimensions, and for ($D \geq 6$), naked singularities are gravitationally weak. An interesting finding that has emerged from investigation of Patil is that as the dimension of the spacetime increases, the calculations of less number of derivatives of the density at the centre are required to decide the nature of the singularity. This might be the effect of the increase in strength of gravity as the gravitational force is directly proportional to the size of the extra dimensions.

Rahaman, Farook

Modifications and extensions of general relativity have intrigued theorists for a long time. Lyra [Math, Z 54, 52 (1951)] proposed a modification of the Riemannian geometry by introducing a gauge function into the structure less manifold. On the basis of the Lyra geometry, Sen [Z, Phys. 149, 311(1957)] constructed an analogue of the Einstein's field equations. Analysis of Halford [J. Math. Phys. 13, 1699 (1972)] indicates that for classical solar system tests, this theory predicts effects within the observational limits similar to general relativity. So far, the Lyra-Sen theory has been applied mainly in the cosmological context. Farook has studied several topological defects within the framework of Lyra geometry, and has compared the results with the classical cases. He has shown that in most of the cases, the gravitational fields are changed due to the introduction of the gauge function in the Riemannian geometry.

Ray, Saibal

The energy density problem of the electron has been studied by S. Ray in collaboration with S. Bhadra with a general relativistic treatment. They have investigated a possible role of cosmological constant which indicates dependency of energy of electron of finite physical radius on a variable gravitational constant. In the framework of Einstein-Cartan theory of gravitation, it is also argued by them that the gravitational mass, which is a priori a positive quantity in Newtonian mechanics, can be obtained as a negative gravitational mass and hence, negative energy density with a better physical interpretation. The mass here represents "electromagnetic mass" model, such that gravitational mass of an electron originates from the electromagnetic field alone.

Sarmah, Bhim Prasad

Gravitational wave window, being a new window to the universe, can supplement the information accumulated from the electromagnetic waves and helps in understanding various astrophysical events, taking place particularly in the general relativistic regime.

A system having a non zero second order time derivative of its quadrupolar mass distribution will emit gravitational waves. There are various astrophysical processes causing the system to have such a time varying quadrupolar mass distribution. It has been in recent literatures that relativistic instabilities operating on highly compact objects can be a copious source for emission of gravitational waves.

Detectors of different variety with increased sensitivity are also being built around the world to detect the very weak gravitational wave signals. To exactly characterise the sources through these detections, one needs to calculate the signal to noise ratio pertaining to the source, for a given detector parameter set.

Bhim P. Sarmah is presently studying generation of gravitational waves from instabilities that can develop in relativistic stars particularly the neutron stars. It is further aimed to estimate the waveform and the signal to noise ratio in different detectors, for this type of sources. He is further engaged in calculation of signal to noise ratio of gravitational wave emission that can be expected from the 'Mini Creation Events' -the key component of the quasi steady state model of cosmology.

Srivastava, S. K.

Curvature tensors play a very crucial role in the theory of gravity. It is found that the Ricci scalar, which is trace of the Ricci tensor and obtained from the Riemannian curvature tensor, also behaves like a physical field having mass at high energy levels, though it is a geometrical field basically. The dual role of the same is obtained if one considers higher-derivative gravity taking coupling constants in a suitable manner to avoid the ghost problem. Extending his work in this area, S. K. Srivastava has obtained dual of the Ricci scalar from higher-dimensional higher-derivative gravity, taking the (4+D)-dimensional spacetime as product of the 4-dimensional space-time and the D-dimensional sphere as a compact manifold. It is found that the resulting 4-dimensional theory after compactification is one-loop renormalizable. Results indicate fractal dimensions above the scale of phase transition. Here, it is obtained that above the scale, spontaneous symmetry breaking the maximum dimension of the spacetime can be 10. It is also found that the gravitational constant increases with the increasing energy mass scale.

Cosmological Models

John, Moncy

Recent observations have brought classical cosmology to square one, since they make the exact form of the energy-momentum which drives the universe quite speculatory. When there are more than one component in the cosmic fluid, which are not known to be separately conserved, the solution of the Einstein's equations becomes impossible, since the effective w-factor in the total equation of state $p = w\rho$ remains unknown. Moncy John, C. Sivakumar and K. Babu Joseph have shown that the scatter in the Hubble is due to a fluctuating w-factor. This scenario is now refined by them.

Pradhan, Anirudh

The standard Friedman-Robertson-Walker (FRW) cosmological model prescribes a homogeneous and an isotropic distribution for its matter in the description of the present state of universe. At the present state of evolution, the universe is spherically symmetric and the matter distribution in the universe is on the whole isotropic and homogeneous. But in early stages of evolution, it could have not had such smoothed out picture. Close to the big bang singularity, neither the assumption of spherical symmetry nor that of isotropy hold strictly valid. So it has been considered plane-symmetric, which is less restrictive than spherical symmetry and can provide an avenue to study inhomogeneities.

A. Pradhan and A. K. Vishwakarma have studied LRS Bianchi type-I cosmological models with a perfect fluid. There has been considerable interest in alternative theory of gravitation. [Barber (Gen. Rel. Grav. 14 (1982), 117)]. Pradhan has studied Barbers second self creation theory.

The problem of the cosmological constant is one of the most salient and unsettled problem in cosmology. A. Pradhan, V. K. Yadav, I. Aotemshi, and O. P. Pandey have investigated bulk viscous cosmological models with variable cosmological constant. This class of solutions is consistent with recent observations of supernovae Ia, which require the present universe to be accelerating.

Singh, G.P.

In recent years, cosmological models which include dissipative process, cosmological and gravitational constants have been extensively investigated in attempts to explain the formation and evolution of the early universe. During the year, G. P. Singh and his coworkers have studied the effect of viscosity on the evolution of the Friedmann-Robertson-Walker models in the context of open thermodynamic systems, which allow particle creation within the framework of Brans-Dicke theory. They have continued their studies on higher dimensional cosmological models in with cosmological and gravitational constants in the presence of bulk viscosity within the framework of general relativity and Lyras geometry. It is observed that the new models obtained in these investigations generate several known models and results are well within the range of observational limits.

Suresh, P. K.

Although the present universe in its overall structure seems to be homogeneous and isotropic, there are reasons to believe that it has not been so in all its evolution and that inhomogeneities and anisotropies might play an important role in the early universe. The isotropic model is adequate enough for the description of the later stage of evolution of the universe, but this does not mean that the model is equally suitable for the description of early stages of the evolution, especially near the singularity. Among the anisotropic cosmological models, the Bianchi type-I universe is the simplest one. In contract to the Friedmann-Robertson-Walker model, the Bianchi type-I has different scale factor in each direction. Therefore, the expansion in this model can be visualized as anisotropic expansion. P.K. Suresh has studied inflaton (a homogeneous and massive scalar field) minimally coupled to the gravity, in the Bianchi type-I universe, in the framework of semiclassical gravity. The approximate leading solution to the semiclassical Einstein's equations, in the oscillatory phase of inflaton, is obtained peturbatively. The solution for scale factor in each direction shows same power law of expansion and their evolutions are mutually correlated.

Quantum Cosmology, Brane World and Quintessence

Banerjee, Narayan

Narayan Banerjee is involved in the search for a quintessence model, i.e., some scalar field which provides a sufficient effective negative pressure, which could drive an accelerated expansion for the present universe. The work involves both minimally and non-minimally coupled scalar field with a potential. It is not difficult to find solutions with the property that it drives acceleration, but the problem is to make the model competent to take care of the nucleosynthesis in the early universe and start accelerating only in the late stage of the matter dominated universe. Attempts towards achieving this is in progress.

Chakraborty, Subenoy

Cosmic No Hair Conjecture (CNHC) is an important issue in cosmology regarding the asymptotic nature of spacetime. So far, there is no formal proof of it. Wald gave a proof for Bianchi class of models with a positive cosmological constant. Subsequently, it has been proved for a scalar field with arbitrary potential. Recently, there is renowned interest in cosmological solutions for brane world scenario. So it is natural to study CNHC in brane scenario. Subenoy Chakraborty and his collaborators have studied this conjecture for Bianchi models in brane scenario with a positive cosmological constant and then with a varying cosmological constant and they are able to prove this conjecture without any more assumption.

Further, Chakraborty has studied inflation and quintessence problem when velocity of light varies. Also he and his collaborators have investigated Brans-Dicke theory in varying speed of light to resolve some of the standard cosmological problems. Finally, they have presented inflationary scenario for Bianchi models using the BD theory.

John, Moncy

When the standard (Copenhagen) interpretation of quantum mechanics (CQM) is used to describe the whole universe as a single quantum mechanical system, several conceptual problems arise. For example, how could one discern the 'observer' from the 'observed' in this case? This and other problems force quantum cosmologists to look for alternative interpretations of quantum mechanics, which can perform equally good at the experimental level. One such interpretation is the de Broglie-Bohm quantum mechancis (dBBQM). Though, this theory is constructed in such a way as to give the same statistical predictions as that of CQM, the physical picture offered by this is not satisfactory when bound state problems are considered. The Floyd-Faraggi-Matone trajectory interpretation of quantum mechanics claims to have a solution to this problem too. Moncy John has developed a new modified dBBQM having many of the positive features of these two interpretations. This scheme allows developement of quantum cosmology in a very natural way.

Mukherjee, S.

S. Mukherjee has used the instanton techniques, which have been used to study a number of processes of current interest. These include (i) creation of an inflationary universe with a pair of primordial blackholes and (ii) the quantum creation of an open inflationary universe. While the first makes use of the standard non-singular instanton, the second process has been described by a singular Hawking-Turok instanton. The processes have been studied also in higher derivative theories, including R^2 and R^3 terms to the Hilbert action. The work was done in collaboration with B. C. Paul and R. Tavakol.

Paul, B. C.

Brane world Cosmology: In the brane world scenario, the field equations induced on the brane from a five dimensional (bulk) spacetime are derived by Shiromizu, et al. elegantly. Using geometric approach they obtained new terms which carry bulk effects on the brane, as a result, one gets a modified dynamical equation on the brane. Cosmic no hair theorem is studied assuming anisotropic Bianchi models with inflation field as the source. Using Walds approach, it is shown that during slow-roll inflation, anisotropy in all Bianchi models except Bianchi IX universe washes out. Brane worlds admit both the exponential and power law inflation. The exponential expansion of the universe and its subsequent isotropization has been studied. It is found that in brane, an anisotropic universe isotropizes faster than that in the general theory of relativity.

Gravitational instantons and quantum Cosmology: Recent developments in the semiclassical quantum cosmology have been reviewed with S. Mukherjee. Instantons are the Euclidean time solutions of the Einstein's field equations with finite gravitational action. We reviewed the use of these instantons to describe two processes in detail : (i) creation of an inflationary universe with a pair of primordial blackholes, (ii) the quantum creation of an open inflationary universe. The first makes use of the non-singular de Sitter instanton, while the second process has been described by the singular Hawking-Turok instanton. To examine the efficacy of the techniques and also to check the robustness of the results, the processes have been studied in higher derivative theories. Although, considerable activities in this field have been reported, the legitimacy of HT instantons remains to be established.

Cosmology and Structure Formation

Ahmed, Farook

The physics of gravitational condensation of galaxy clustering is poorly understood compared with its laboratory counter parts. In general, the condensation involves a change in thermodynamic properties of the system and in the mutual arrangement of particles of the system, i.e., symmetry of the system changes. In most cases, we characterize condensation as the manifestation of a certain singularity or discontinuity in the thermodynamic functions of the given system. The gravitational condensation of particles differs from ordinary atomic or molecular condensations. In case of gravitational condensations, the system changes from homogeneous state into a state with two components. Here, clusters with negative total energy break the symmetry of the galaxy distribution on a new larger scale. With the effect, correlations among various particles develop to form clusters of galaxies. Moreover, unlike chemical condensations, gravitational condensations do not reach final equilibrium and strive towards a more clustered arrangement. As the universe evolves, the first clusters combine into second order clusters, then second into a third order clusters and so on as a continuous hierarchy of clustering grows over larger and larger scales. Thus, we may call this as continuous phase transitions or condensation.

An attempt in this direction has been made by Farooq Ahmad and his two collaborators Willium Saslaw and M.S.Khan (a Ph.D student) to understand the gravitational condensation of galaxy clustering on the basis of statistical mechanics. A recent study ensures the application of statistical mechanical approach to the gravitational galaxy clustering (Ahmad, Saslaw and Bhat, 2002, Ap.J, 571, 576). Therefore, it has become reasonable to expect that a statistical mechanical description of the cosmological many-body system is possible, and they have found it by evaluating the partition function analytically. They studied the problem of condensation of galaxy clustering on the basis of three different approaches. Specific heat, Lee-Yang theory of condensation and fluctuation theory by using statistical mechanics of cosmological many-body problem. The behaviour of specific heat at constant volume as a function of temperature plays an important role for stability of a system. They define critical temperature Tc, when specific heat corresponds to its maximum value. An interesting feature is clear if T = Tc, the system breaks the symmetry from homogeneity and there is a growth of correlation functions. This new phase corresponds to the formation of binary systems of galaxies. An interesting feature for galaxy clustering can be observed when the value of specific heat changes from positive to negative values and this occurs when specific heat becomes zero. In general, as clustering progresses, the scale and amplitude of density correlations among particles increases. This flow of gravitational correlation energy into hierarchy of clusters represents the tendency of gravitational systems to maximize the total entropy. On the basis of Lee-Yang theory of condensation, they found that the application of Lee-Yang theory to the system of galaxies, clustering under its gravitation ensures earlier results obtained from specific heat study. Further, the results on the basis of fluctuation of various thermodynamic quantities also confirms earlier results. Their studies is a beginning for understanding gravitational condensation of galaxy clustering. However, much remains to be understood like its counter part of material sciences.

Kuriakose, V. C.

The standard theory of structure formation is based on the idea of gravitational instability according to which, small initial irregularities in the matter distribution become amplified, resulting in formation of structures in the universe. The matter distribution may not be uniform and then it is of interest to study the influence of local anisotropy on the formation of structures. Minu Joy and V.C. Kuriakose have studied such a case using a field theoretic approach. They have considered a massive scalar field coupled to gravity in a Bianchi - I background spacetime. In this calculation, they have used a coherent state representation of the field variable. By evaluating the energy density and the pressure associated with the density perturbations, exact expressions for Jeans wave number is evaluated. Considering the metric and matter field perturbations they found that the perturbation, of pressure in radial and tangential directions are different. They have also found that the Jeans length depends on the velocity components of fluctuations in radial and tangential components.

Blackhole thermodynamics is still a topic of interest. P. I. Kuriakose and V.C. Kuriakose have studied the back reaction problem in the case of extremal Reissner-Nordstorm blackhole in thermal equilibrium. They used a thermodynamic approach of Li-Xin Li and the method of York to calculate the change in entropy and obtained identical results in both approaches.

Lohiya, Daksh

Daksh Lohiya has demonstrated that a Friedmann Robertson Walker cosmology with a linear evolution of the scale factor right from the creation event, is an excellent fit to a host of cosmological observations. These observations are: (i) the Hubble diagram for both small and the large redshift 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. While, these results are of interest to a host of alternative gravity models that support such a linear coasting, Lohiya has conjectured that a linear evolution would emerge naturally from general relativity itself. The consistent dynamics of a spin two field coupled to a homogeneous universe yields a linear coasting FRW universe with a vanishing cosmological constant. With Ashok Mittal, Lohiya has constructed a fractal dust model of the universe based on Mandelbrot's Conditional Cosmological Principle. This model turns out to be free from the de-Vaucouleurs paradox and is consistent with the SNe1a observations.

Mittal, Ashok Kumar

Ashok K. Mittal and D. Lohiya have examined some of the implications of the fractal dust model of the universe proposed by them earlier. This model is motivated by the claims of some investigators that the galaxy distribution in the universe does not become homogeneous up to the largest scales observed. Instead, the galaxy distribution follows fractal scaling. The number of galaxies in a sphere of radius R centred on any galaxy is not proportional to the cube of R as expected of a homogeneous distribution, but to some other power of D, which is approximately equal to 2. Standard cosmology is based on the assumption that the universe is homogeneous and isotropic on large scales. This assumption is called the Cosmological Principle. In view of the observed fractal scaling and isotropy of the galaxy distribution, Mandelbrot proposed that the Cosmological Principle should be replaced by Conditional Cosmological Principle, according to which the universe is not homogeneous in the sense of uniform number density, rather it is homogeneous in the sense that the same scaling behaviour is observed from any galaxy and the universe appears to be statistically the same from occupied points of the fractal. The Friedmann metric and the Hubble law follow from the Cosmological Principle. Although, the metric is expected to be valid only on scales larger than the scale of homogenization, observationally the Hubble law is found to hold on smaller scales also. This contradiction, called the Hubble-deVaucouleurs paradox, has no satisfactory explanation in standard cosmology. The fractal dust model presented by Mittal and Lohiya incorporates Mandelbrots Conditional Cosmological Principle within the framework of General Theory of Relativity. It turns out to be free from the Hubble-deVaucouleurs paradox and is consistent with the SNe1a observations. An interesting variation of this model is a steady state version, which can account for an accelerating scale factor without any cosmological constant in the model.

Pandey, Sanjay K.

Quantifying large scale structure in the universe has been one of the most interesting and challenging problem of modern cosmology. Many different theories have been proposed to explain the observations. Gravitational instability is one such mechanism. Different statistical descriptors measure different aspect of the clustering pattern revealed by a survey. Correlation functions are very powerful statistic to describe large sclae structure in the universe. Two-point-correlation function has been widely used to measure clustering strength of galaxies. The 3-point correlatin function is a further statistic useful in characterizing the clustering of galaxies. It is the lowest-order intrinsically non-linear statistic and can, therefore, place strong constraints on models of structure formation. The full treatment of gravitational instability cannot be solved exactly without resort to N-body techniques. One, therefore, uses some approximation. Zeldovich approximation is one such approximation in which we work out the initial displacement of the particles and assume that they continue to move in this initial direction. The advantage of this approximation is that it normally breaks down later than Eulerian linear theory. So it can give results comparable in accuracy to Eulerian theory with higher order terms included. S. K. Pandey, is therefore, considering the evolution of 3-point correlatin function under Zeldovich approximation and like to study effect of different length scales on it. He also plans to compare these with results of N-body simulations and see how well the calculation does.

Seshadri, T. R.

Tangled, primordial cosmic magnetic fields create small rotational velocity perturbations on the last scattering surface (LSS) of the cosmic microwave background radiation (CMBR). Such fields, can then be a potentially important contributor to CMBR temperature and polarization anisotropies at small angular scales, corresponding to multipoles with $l > 1000$ or so. The recently detected excess power at large l by the CBI experiment, could have a contribution from such magnetic modes. Polarization anisotropies can be used to distinguish the magnetic contribution from more conventional sources. In particular, unlike conventional signals, tangled magnetic fields lead to CMBR polarization dominated by the odd parity, B-type signal. Recently, E-type polarization has been detected by the DASI experiment, and T-E correlations by DASI and WMAP, albiet at smaller l. Several experiments are also expected to probe the large l regime.

In view of this observational focus, T. R. Seshadri, K. Subramanian and J. D. Barrow have studied the predicted polarization signals due to primordial tangled magnetic fields, for different spectra and different cosmological parameters. They have shown that a scale-invariant spectrum of tangled fields which redshifts to a present value $B_0 = 3 \times 10^{-9}$ Gauss, produces B-type polarization anisotropies of $\sim 0.3 - 0.4\mu K$ between $l \sim 1000 - 5000$. Larger signals result if the spectral index of magnetic tangles is steeper, $n > -3$. The peak of the signal shifts to larger l for a lambda dominated universe, or if the baryon density is larger. The signal will have non-Gaussian statistics. They also predict the much smaller E-type polarization, and T-E cross correlations for these models.

Theoretical Physics

Gangal, A. D.

A. D. Gangal has developed a formulation of fractional calculus on fractal structures. Appropriate generalisation of Riemann integration and process of differentiation are carried out. A new fractal dimension is introduced. This formulation can be used for study of fractal spacetime processes.

Kaushal, R. S.

It is well known that the stellar objects all through their history of evolution undergo different types of changes. As a result, the studies pertaining to their existence in a particular phase vis-a-vis its stability have become of considerable interest. In this connection, the physical factors (through the use of a convenient equation of state) have been known to play the important role, R. S. Kaushal has emphasized the importance of a mathematical factor, i.e., the role of non-linearity involved in the underlying mathematical formalism. In particular, the case of an effective ϕ^4-theory in the studies of an extended scalar diquark star is investigated.

Kaushal with his collaborators has also been developing the classical and quantum mechanics for one-dimensional complex Hamiltonian systems in an extended complex phase space characterized by $x = x_1 + i\ p_2, p = p_1 + i\ x_2$. Within this framework, the integrability of several two-dimensional real Hamiltonian systems has been explored in the classical domain and the problem of real eigenvalue spectra for a viriety of complex potentials has been investigated in the quantum domain.

Malik, Usha

Recently, Usha Malik has obtained new exact solutions of the historic sine-Gordon equation and drawn attention to their possible use in superconductivity. While it may be generally known that the equation has solutions in terms of Jacobian elliptic functions (JEFs), she considers it worthwhile to give explicit expressions for them, and to point out that only six (and not all 12) of these functions solve the equation.

Given that the mixed state of a type-II superconductor displays double periodicity, which is also the hallmark of a JEF, it is not surprising that the latter should provide a description of the former. What seems to be remarkable is the manner in which the inverse-sine function of the sG theory quenches the infinities of the JEF and thus overcomes the undesirable feature mentioned above.

The solutions obtained pertain to any given values of the parameters M and λ of the sG system. If the system is embedded in a thermal/magnetic environment, M and λ and hence the parameter m of any of its solutions in terms of a JEF will become functions of temperature/magnetic field.

The structures of lattices in the mixed state that have been obtained in respect of different type-II superconductors (particularly those of the intrinsic type-II superconductors) and to see if any of them conform to the structures reported here. Should this succeed, one may hope to get a deeper insight into the occurrence of superconductivity through all the known properties of the sGE.

Malik also made an attempt to provide an alternative explanation of high temperature superconductivity, wherein, we suggest that the high T_c of a multi-component superconductor comes about owing to multiple phonon exchanges, represented by a superpropagator, between electrons in it.

Furthermore, she investigated some of the results in superconductivity as corroborative evidence of the soundness of temperature-dependent approach to identify soft X-ray emission lines.

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 unstable under radiative corrections. Supersymmetry is at present the only known framework in which the Higgs sector of the standard model is stable. Since in nature, there are no supersymmetric particles with the same mass as ordinary particles, supersymmetry must be a broken symmetry at low energies. The minimal supersymmetric extension of the standard model (MSSM) is constructed by simply doubling the number of degrees of freedom with explicit soft supersymmetry breaking terms. The MSSM contains a combination of supersymmetric partners of the neutral gauge bosons and the Higgs bosons, called the lightest neutralino, which is supposed to be the lightest supersymmetric particle. In models with R-parity conservation, the lightest neutralino is stable, and is an end product of all superparticle decays. It is, therefore, important for the discovery of supersymmetry to have a knowledge of its mass.

P. N. Pandita, together with K. Huitu and J. Laamanen, has investigated the neutralino mass matrix in order to obtain a theoretical upper bound on the mass of the lightest neutralino. This has been done in various models of supersymmetry breaking, including models with gravity mediated as well as anomaly mediated supersymmetry breaking. The effect of next-to-leading order corrections have been included in our computations. It has been found that the upper bound on the lightest neutralino mass does not exceed 200 GeV for a gluino mass of 1 TeV.

Verma, R. C.

There have been recent measurements of spin baryon magnetic moments with good precision. But there are serious discrepancies between experimental values and theoretical predictions based on nave quark model. Various theoretical efforts have been made to improve the situation but with partial success. Bains and R.C. Verma have reinvestigated the problem of baryon moments using the concepts of effective mass and effective quark charge. It has been proposed that, when a quark is probed by a soft photon, the mass of the quark gets modified due to its interaction with other quarks inside the baryon through hyperfine gluon exchange mechanism. Effective quark mass is obtained from the baryon mass spectra by including its spin-dependent interaction with other quarks. With these effective quark masses, the baryon moments are obtained by sandwiching the magnetic moment operator between their flavour-spin wave functions. In addition to the variation of the quark mass caused by its environment, its charge may also be screened due to the presence of neighbouring quarks. This situation is similar to the shielding of the nuclear charge of the helium atom due to its outer electron cloud. Effective charge is taken to depend linearly on the charge of the shielding quarks. To reduce the number of screening parameters, SU(3) flavour symmetry is assumed for the shielding effect and the hyperfine splitting parameters obtained from the baryon masses are used. Also, an ansatz is developed to re-determine the shielding parameters. Theoretically obtained values show a good agreement with experiment.

Non-Linear Dynamics

Ambika, G.

G. Ambika, has done detailed analysis of the stability and other dynamical and geometric features during onset of chaos in non-linear systems. Taking the Froude pendulum with cubic and linear damping, approximate solutions using the harmonic balance method are worked out and reduction to the Matheu equation is done to isolate stability regions in the parameter space.

For unimodal and bimodal maps, the critical exponents associated with the scaling of the Lyapunov exponent and fractal dimensions are evaluated numerically. The cross over behaviour for the full f-alpha spectrum is studied from the point of view of multifractal analysis.

The existence of stochastic resonance in bimodal maps with bistability is established both with external noise and chaotic input. It is found that the weak signal amplification is optimum for coupled maps for a range of values of the coupled parameter.

In coupled map lattices for nearest neighbour coupling and periodic boundary conditions with the on site dynamics decided by the logistic map, spatial fractal sets during onset of coherent collective modes are identified for the first time. A modified procedure is designed for the evaluation of their mutifractal dimensions and f- alpha spectrum. The behaviour and the geometric features of the set, for different values of the control parameter are analysed by an extensive numerical algorithm.

Harikrishnan, K. P.

An extensive numerical study of the phenomenon of stochastic resonance in a bimodal cubic map has been done. Both Gaussian noise as well as deterministic chaos were used as input to drive the system between the basins. The main result is that when 2 identical systems capable of stochastic resonance are coupled, the signal to noise ratio (SNR) of either system is enhanced at an optimum coupling strength. The results are relevant for the study of SR in biological systems. Studies on the scaling indices of Lyapunov exponent of 2 specific classes of 1 -d discrete systems have also been carried out.

Kuriakose, V. C.

When the dynamics of light propagation through optical fibres are studied, one has to consider the variations in the lattice parameters in the fibre medium as well as the fibre geometry, which induce non-uniformity in the fibre. This will cause distortion of the soliton pulse propagating through the fibre. But by employing fibres with dispersion decreasing the distortion in the pulse can be avoided. Ganapathy, Vinoj and Kuriakose have studied pulse propagation through slowly dispersion decreasing fibres with different mathematical forms and found the conditions for maintaining the soliton shapes and for achieving pulse compression, the nature of soliton-soliton interactions, etc. The conventional geometries of Josephson junctions are either rectangular or annular. Non-rectangular and non-uniform junctions find applications in certain Josephson devices. Shaju and Kuriakose modified these geometries to semi annular and quarter annular. They have studied the fluxon dynamics in these systems and found that these junctions can be used as fluxon diodes, magnetic field rectifiers, flux flow oscillators, etc.

Mittal, Ashok Kumar

Seasonal mean rainfall anomalies are largely determined by sea surface temperature anomalies. In particular, it is known that year-to-year variation of tropical Pacific sea surface temperature associated with the El Nino/Southern oscillations event have a strong influence on the inter-annual variations in the monsoon. During the summer monsoon season, the large-scale rainfall oscillates between active spells with good rainfall and weak spells with little rainfall. Typically, the transition time between active and weak spells is shorter than the residence time of the spells themselves. Constant forcing terms have been introduced by Palmer to give a paradigmatic model for discussing long-range monsoon predictability. The forcing terms in this model represent the tropical Pacific sea surface temperature anomaly. These terms cause a shift in the probability distribution function between the two wings of the Lorenz butterfly, which represent the regimes of active and weak spells of the monsoon. Mittal, Dwivedi and Pandey have investigated the local and global bifurcation structure of this forced Lorenz model. They have also explored how the correlation dimension of the attractor varies with forcing and with sliding average duration. It is hoped that mathematical analysis and simulation results of these investigations will provide greater insight into the effect of different types of forcing on climate change.

Dwivedi, Mittal, and Pandey have also computed the correlation dimension and Lyapunov exponents of NINO3 sea surface temperature anomaly and Indian monsoon rainfall anomaly time series data. These results suggest that both these data sets could belong to a common low dimension attractor. On the other hand, their analysis of Antarctic oscillation index did not reveal existence of any strange attractor.

Galaxies and Quasars

Chakraborty, D. K.

Realistic mass models, capable of reproducing observed photometric data of triaxial galaxies are investigated. The triaxial models as obtained by considering a spherical model and adding two suitable radial functions, each multiplied by spherical harmonics of lowest order to the potential, produce a variety of profiles of axial ratio and position angle. However, the 3D mass distributions have unrealistic dimples. Chakraborty and Das have extended this model by adding two more radial functions in the expression of the potential, each multiplied by spherical harmonics of higher order. The 3D mass models are closer to ellipsoid and the projected surface density is either boxy or pointy, depending on the viewing direction. In addition, the usual properties of variations in axial ratio and in position angle are also exhibited. It has been suggested that the specific features of the variations in high-order residuals of these models, may be useful to select out a galaxy, which might be a suitable candidate for the investigation of its intrinsic shape, using photometric data.

Chatterjee, Tanuka

Observations on HI rotation curves of spiral galaxies beyond optical radii have shown that all of them are not entirely featureless. Inside the optical radius their shapes probably correlate with the light distribution (Kent, 1987), but some degree of velocity variation is often seen in the outer regions and such features might relate the over all mass distribution (van Alabada and Sancisi, 1986). Moreover, rotation curves of dwarf galaxies are often still rising at their optical radii. New observations have shown that some galaxies posses declining rotation curves between 1 and 3 optical radii. The velocity decrease is more than 50 km per sec on both sides of the galaxies (Casertano and Gorkom, 1991). Some correlations have also been found among surface brightness, maximum rotational velocity and slope of the rotation curves, e.g., rotation curves rise for faint galaxies, while fall for brighter and more compact ones. This interprets that the match between luminous and dark matter producing flat rotation curves (suggested by van Alabada and Sancisi,1986) is applicable only to galaxies of intermediate luminosities . For bright and faint galaxies, luminous or dark matter respectively appear to prevail. This may provide evidence in favour of the idea that dark matter is aryonic. Similar conclusions have also been arrived by Salucci and Frenk (1989), that in bright and disc dominated galaxies the rotation curves should drop by a few tens of km per sec immediately outside the disc, even in the presence of an extended dark halo. Only in faint halo dominated galaxies, we expect the rotation curve to remain flat or even to rise beyond the optical radius.

Also some authors (Elmegreen and Elmegreen, 1990) have found striking correlation between decline in rotation velocity inside optical region and the presence of grand design spiral arms. All these works can be reconciled to the fact that the shapes of rotation curves are nothing but the outcomes of different morphological or photometric parameters of galaxies. In the above studies various correlations among the parameters were calculated to properly study the variations without using a sophisticated statistical technique.

Tanuka Chatterjee's primary objective is to compile observational parameters for a sample of galaxies and to search for parameters using multivariate statistical technique, which are mainly responsible for the overall variations. For this a principal component analysis (PCA) has been carried out to determine how many independent parameters are responsible for the overall variation and how they are related to the observed parameters. A PCA shows that almost 91% of the total variation is due mainly to two dominant factors - one is the combination of maximum rotational velocities, optical radius, absolute blue magnitude and the other is the central density of the halo.

Jog, Chanda J.

It is generally accepted that the vertical scale-height of the stellar disk in a spiral galaxy is constant with radius, however, there is no clear physical explanation for it. C.J. Jog with C.A. Narayan, treat a galaxy as a gravitationally coupled three-component disk consisting of stars, interstellar molecular hydrogen gas, atomic hydrogen gas, and dark matter halo, and apply their model to two edge-on galaxies, NGC 891 and NGC 4565. The resulting stellar scaleheight shows a small increase of a factor of two within the optical disk. They also show that the observed data when looked at closely, do not imply a constant scale-height as was long believed, but actually support this moderate flaring in scale-height.

C.A. Narayan and C.J. Jog have studied the vertical distribution of the stars and gas in the Milky Way Galaxy by applying the above model. It is shown that the self-gravity of gas is crucially important in deciding the scale-heights of all the three disk components- namely, the stars, the molecular and the atomic hydrogen gas. This approach physically explains the long-standing puzzle (Oort, 1962) of the nearly-constant scale-height of atomic hydrogen gas as observed in the inner Galaxy. It also explains naturally the observed detailed radial variation of the molecular gas scale-height in the Galaxy.

A. Chitre, and C.J. Jog have analyzed the new 2MASS near-IR archival data for twenty-seven advanced mergers of galaxies and have shown that half of these have luminosity profiles that decrease exponentially with radius, as in a spiral galaxy. This puzzling result cannot be explained by the standard N-body models of equal-mass mergers in the literature, and hence mergers of unequal-mass galaxies are probably required to explain these.

In order to understand these systems better, C.J. Jog and A. Chitre, have also done analysis of the kinematical data available from the HYPERCAT archival database for two of these mergers, namely ARP 224 (NGC 3921) and Arp 214 (NGC 3718). Surprisingly, these mergers show large velocity dispersion values and thus are mainly pressure-supported as in a typical elliptical galaxy and yet show an exponential mass profile as in an isolated spiral galalxy. The origin and the dynamical evolution of this new class of merger remnants with their unusual, mixed properties are open questions.

C.J. Jog has shown that the observed large-scale or global asymmetry of rotation curves in some galaxies such as M101 or NGC 628 can be explained as arising due to the disk response to a lopsided halo potential. The typical resulting asymmetry in lopsided galaxies is calculated to be $\sim$ 20-30 km s^{-1} on two sides of the major axis, which is detectable. In fact, from the observed isophotal elongation in a typical spiral galaxy, it is predicted that a significant rotational asymmetry can be expected to be present in all spiral galaxies. It is stressed that, instead of giving azimuthal average values as is usually done, observers should give the full 2-D velocity plots, which will allow the detection of the rotational asymmetry in galaxies.

Khare, Pushpa

Pushpa Khare along with her collaborators was awarded three nights in October, 2002 for observations at the Multiple Mirror Telescope at Arizona, USA for the observations of damped Lyman alpha systems in the spectra of QSOs. She observed 4 QSOs. The observing trip was sponsored by IUCAA. The data analysis is completed.

She studied the kinematics of damped Lyman alpha systems in the frame work of the unified model of QSO absorption lines proposed by her. Absorption line profiles were generated and the simulated spectrum was subject to various statistical tests to compare them with the observations. The model in its present form is found to be incompatible with the observed data. Modifications to the model are being considered.

She along with a team of astronomers from the University of Chicago is involved in the preparation of a catalogue of absorption lines in the QSO spectra observed by the Sloan Digital Sky Survey. The early data release consists of several thousand QSO spectra and the continuum fitting, line finding and identification has to be automated.

Neutron Stars and Quark Matter

Chakrabarty, Somenath

Somenath Chakrabarty and his Ph.D. student Sutapa Ghosh have studied the transport properties of dense electron gas in compact astrophysical objects in the presence of strong quantizing magnetic field and obtained the shear viscosity coefficient for the gas. They have shown that at extremely high magnetic field, when electrons occupy only the zeroth Landau level, shear viscosity of electron gas vanishes. The system then behaves like a super fluid without super conductivity.

It has been shown by Somenath Chakrabarty and his Ph.D. students Soma Mandal and Sutapa Ghosh that spin polarized neutron matter states are not possible in neutron star if the matter is in β-equilibrium. They have concluded that ferromagnetic transition is not possible in very old and cold neutron stars. The paper has been published in Mod. Phys. Lett A.

They have also shown that in presence of ultra strong magnetic field in dense stellar objects (in particular magnetars), when electrons occupy only their zeroth Landau level, the matter can not exist. They have concluded that if the interior magnetic field of magnetars are too high ($\sim 10^{17}$G), the constituents are not simply $n-p-e$ or quark matter, it could be colour neutral and charge neutral CFL phase.

Chandra, Deepak

Deepak Chandra along with Ashok Goyal continues his studies on the effects of QCD and hadronic interactions on the dynamics of deconfinement phase transition for QGP and hadron resonance gas. They have studied 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.

Deepak Chandra along with Meenu Dahiya and Ashok Goyal is also working on the properties of strange quark matter in the Nambu-Jona-Lasinio model by introducing vector interactions. Phase transition in large densities and temperatures are being investigated along with the mixed phase properties.

Goyal, Ashok

Ashok Goyal with his collaborators Deepak Chandra and Meenu Dahiya continues his studies of symmetry restoration in the context of early universe, neutron stars and heavy ion collisions. Dynamical evolution of phase transition through bubble nucleation, amount of supercooling achieved and formation and survival of nuggets are the topics of interest.

Recent developments in the determination of neutron star masses and the exciting possibility of identifying quasi-periodic oscillations in low mass X-ray binaries as strange stars has led Ashok Goyal, V.K.Gupta, Deepak Chandra, Vinita Tuli and Kanupriya Goswami to investigate in detail properties of hybrid stars and the possibility of forming stable strange stars in the frame work of quark dynamics modeled by Nambu-Jona-Lasinio. With Sukanta Dutta and Poonam Mehta, Goyal is investigating the opportunity offered by the muon storage ring in the proposed neutrino factories to explore physics beyond the standard model, in particular to test theories involving lepto-quarks and theories of large extra dimensions.

Hasan, S. N.

In the past year, Hasan has been working on the applications of Clifford Algebras in Celestial Mechanics. Various aspects of the three-body problem have been studied in this formalism. The concept of Clifford Algebra is extended to devise a new formalism for mathematics and physics and is termed geometric calculus. The proofs of existence and uniqueness of geometric algebra are given and geometric calculus is developed. The three-body Sun-Earth-Moon system is studied in this new formalism and the precession of the Moon's orbit computed, which is in close agreement to the observed value.

Besides the above work, progress has been made in the studies of mergers induced in triple galactic encounters using N-Body simulations. A variety of computer programmes have been developed to perform N-Body simulations of galactic interactions.

Narain, Udit

The million degree solar corona lies in between two cooler regions, namely, chromosphere/transition region and interplanetary space. It loses energy predominantly by conduction, radiation and solar wind. In order to replenish these losses and to maintain its temperature to million degree Kelvin, some source of energy must be present. A number of mechanisms have been proposed for the heating of the solar corona. Heating by Alfven waves and micro- and nano- flares are two important mechanisms.

Pandey and Udit Narain have started the study of heating by micro- and nano- flares. These are transient phenomena which occur when two oppositely directed magnetic field lines reconnect and the material in between them is highly compressed so that it moves with large speeds in opposite directions. Due to viscosity, the energy of the moving matter is converted to thermal energy and heating around the site of reconnection occurs.

Quite recently, Pandey, Narain and Lohani have studied tearing mode instability in tripolar geometry and its role in heating solar atmosphere by using recent data on photosphere and chromosphere. Particular attention has been paid to the wave number of the rapidly growing tearing mode, island scale length, frequency of mhd fluctuations and energy dissipation rate and the minimum magnetic field required to heat chromospheric plasma to coronal temperatures. Small length scales which dissipate energy efficiently are found to form in the upper chromosphere. It is found that for a better understanding of heating problem, the distribution of magnetic field with height is absolutely essential.

Usmani, Anisul Ain

Theoretical understanding of neutron stars still has a long way to go in many areas of nuclear physics. Conventional many-body theories have been successfully used to study such a dense infinite system. One of the most debated problems is, to which extent neutron matter can sustain the presence of strange particles such as Λ-particles, which is of importance to understand the cooling scenario of the star. 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 coexist with nuclear and neutron matter, and to explore to what amount of strange matter a neutron star can sustain, using various state-of-art many body theories.

For a microscopic study, one inevitably requires a basic knowledge of fundamental baryon-baryon and three-baryon forces. These forces may be determined from the studies of wide spectrum of nuclei and hypernuclei. The information obtained so, may be used to study equation of state of nuclear and neutron matter and evolution and cooling scenario of the star. Bearing this in mind, A. A. Usmani has performed a realistic study of $^5_\Lambda He$ hypernucleus using variational Monte Carlo technique. The Hamiltonian for ^4He nuclear core of the hypernucleus is written using Argonne V_{18} NN potential and Urbana NNN potential. For the strange sector, he uses phenomenological ΛN and ΛNN potentials. Similar study will be performed on a wide spectrum of hypernuclei in order to determine the strengths of these potentials. The Λ-binding to nuclear will also be calculated in this regard. The study will be further extended to study the strangeness physics of neutron stars.

X-ray Binaries

Shanthi, K.

X-ray binaries are systems that have a neutron star or a blackhole accreting matter from a regular star. These systems exhibit a wide range of timing phenomena which can be quantified by computing their power density spectra (PDS). Gaussian like features at certain frequencies have been detected in the PDS of several sources and are called Quasi Periodic Oscillations (QPO). Understanding the origin and nature of these QPO especially, the high frequency kHz QPO) is important since they are potentially valuable probes of strong gravity and may shed light on the behaviour of matter in such environments. K. Shanthi and R. Misra analyzed the archival *Rossi X-ray Timing Experiment* (RXTE) data of the neutron star binary source 4U1636 - 53, which is known to exhibit strong kHz QPO. The 1.32×10^6 sec of non-zero count rate data was divided into 10309 segments of 128 sec each and for each segment an automated search for kHz QPO was undertaken. The histograms of the maximum Leahy normalized power for each segment for different flux levels were obtained and it was shown that they can be fitted by theoretical probability functions. The fraction f of the segments for which there was a QPO was found to decrease from near unity at low flux states (≈ 1000 c/s) to zero at high states (> 2500 c/s). The average QPO power as a function of frequency was found to be Gaussian, with no obvious high or low frequency cut-off.

Singh, Y.K.

Most of the X-ray binaries that we know today belong to distinct categories viz., the blackholes and the neutron star systems. Study of the periodic and periodic variability and spectral characteristics of these binaries throw light about their nature and the physical processes responsible for X-ray emission in them. Most rapid intensity variations are found in accretion powered X-ray binaries. However, in the case of the bright X-ray binary Cygnus X-3, in spite of its being one of the most frequently observed X-ray sources, the nature of the compact companion object is not yet ascertained. There is also uncertainty about the mass and the type of the companion star. An interesting way to probe this system is to investigate the arrival time history of the orbital period modulation in the X-ray light curve.

Y. K. Singh, with his collaborators has carried out extensive analysis of the X-ray data of Cygnus X-3 obtained from the Indian X-ray Astronomy Experiment (IXAE) and the Rossi X-ray Timing Explorer (RXTE) for determining the X-ray variability and for determining the rate of change of the orbital period with great accuracy.

Interstellar Matter and Star Formation

Chandra, Suresh

Suresh Chandra is working on asymmetric top molecules found in cosmic objects. Recently, he has investigated transfer of radiation through cyclopropenylidene and ethylene oxide. These molecules have a number of line-pairs having nearly equal frequencies, but different excitation energies, and/or belonging to two different (ortho and para) species. These pairs of lines may be used for diagnostic purposes. The advantage of using such pairs is that two lines of the pair may be observed almost simultaneously with a common telescope, and thus, in forming ratio of the line intensities, systematic errors involving source coupling efficiency, calibration uncertainty, and atmospheric absorption, are cancelled out.

He has calculated Einstein A-coefficients for rotational transitions in the ground vibrational state of Si_2C molecule. These data are being used in further investigation.

Indulekha, K.

The study of the formation of bound open clusters in the galaxy has been continued. Energy equipartition of normal stars with low mass stars, including brown dwarfs, has been investigated and found to be an energetically feasible mechanism for reducing sufficiently the kinetic energy of the stars, for bound clusters to form. The low mass star fraction necessary are consistent with the observed values for the low mass stellar spectral index.

The response of a gas cloud to the collapse and revirilisation of a stellar cluster embedded in the gas was also studied. It was found that the shrinking of the gas cloud is not significant enough to affect the final apparent star formation efficiency of the cloud.

She has also evolved a code for solving partial differential equations of the flux conservative type (1+1 dimensions) when boundary conditions are given only at one end.

Kumbharkhane, A. C.

The space between stars in the Galaxy is filled with gas containing hydrogen, helium, carbon, calcium and many other elements and dust grains. This constitutes the Interstellar Medium (ISM). Radio Recombination Lines (RRL) are useful for studying different types of ionized regions in the Galaxy, which give rise to detectable recombination lines of various atomic species such as hydrogen, helium and carbon. In general, recombination lines of hydrogen and helium are detected from hot fully ionized clouds, known as H II region. One of the main interests of A. C. Kumbharkhane in collaboration with Nimisha Kantharia, is to study and analyzing the Radio Interferometric data using AIP software developed by NRAO. Their interest is to study the partial ionized medium surrounding the H II region with Giant Metre wave Radio Telescope (GMRT) in the L-band and determine the physical properties of the line forming medium. We are analyzing the data of object "3C147" using AIPS software and studying the RRL.

Rastogi, Shantanu

Astronomical spectroscopic observations have established the presence of a variety of polyatomic molecules, ions and radicals in the interstellar space. Majority of such polyatomics are carbonaceous organic molecules. Among them, polycyclic aromatic hydrocarbon (PAH) molecules belong to the most stable and probably the most abundant species. Their presence is indicated by the distinctive set of infrared emission features at 3050, 1610, 1310, 1165 and 885 cm^{-1} (3.28, 6.2, 7.7, 8.6 and 11.2 μm), earlier known as the unidentified IR (UIR) bands. These UIR lines correspond to vibrational modes of molecules having aromatic moieties and are found to be ubiquitous in a variety of interstellar 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) (a number of absorption features superposed on the interstellar extinction curve) observed in the visible and near infrared spectral ranges. The general features of the interstellar IR spectra are attributed to aromatic species yet identification of individual molecules is complex and no specific PAH molecule has yet been identified. Shantanu Rastogi has performed vibrational analysis on infinite polymeric graphene sheet models to understand the composite spectra. 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 calculations on models show that 7.7 μm (1300 cm^{-1}) feature assigned to (C-C) stretching mode couples very strongly with the ring deformation modes and show large dispersion giving high density of state regions at 1254 and 1343 cm^{-1}. This band appears at very different positions ranging from 1260 to 1330 cm^{-1} in different molecular forms and in some circumstellar ISO spectra, this broad feature is resolved at 1280 and 1320 cm^{-1}. The density of state lead to heat capacity which is useful in obtaining the PAH cooling times by IR fluorescence.

Sun and the Solar System

Sahijpal, Sandeep

Earliest formed solar system grains that are found in primitive meteorites are host to isotopic anomalies resulting from the decay of several short-lived nuclides, e.g., $^{41}Ca,^{26}Al,^{10}Be,^{60}Fe,^{53}$Mn (mean-life; $\tau \leq 5$ million years). The presence of these short-lived nuclides in the early solar system is generally attributed either to a late stage stellar nucleosynthetic contribution to the proto-solar molecular cloud from a evolved star in its vicinity, or due to their 'local' production in the early solar system, as a result of irradiation of solar system grains by energetic particles from the active early sun going through T Tauri phase. The former astrophysical scenario has also been hypothesized as the most plausible cause that triggered the formation of the solar system as a result of the interaction of the proto-solar molecular cloud with the shock front associated with the evolved star. In order to understand the various physico-chemical processes that led to the formation and early evolution of the solar system in proper perspectives, it is extremely essential to decipher the origin and the extent of distribution of these short-lived nuclides in the early solar system. S. Sahijpal has been carrying out analytical studies on the possible role of all the proposed stellar nucleosynthetic sources, e.g., Wolf-Rayet stars, supernovae [Type Ia, Ib/c, II], novae, AGB stars, in synthesizing the short-lived nuclides, specifically the most abundant, ^{26}Al, found in early solar system.

Ejected stellar nucleosynthetic yields of various stellar sources, i.e., AGB stars, novae, Wolf-Rayet stars, supernovae Type 1a, Ib/c and Type II corresponding to different metallicities, initial masses, evolutionary details, etc., were considered individually to obtain the required canonical abundance of ^{26}Al in the early solar system, after considering all the dynamical details associated with the interaction of stellar ejecta and the proto-solar molecular cloud. The associated isotopic effects in all the stable nuclides from ^{12}C to ^{58}Fe, along with the abundances of other short-lived nuclides ($^{41}Ca,^{36}Cl,^{60}Fe,^{53}Mn$) were assessed assuming solar abundance for the proto-solar molecular cloud prior to the stellar ejection. In the absence of any detailed nucleosynthetic models dealing with the massive Wolf-Rayet stars (e.g., $60M\odot$ star) evolved to Type 1b/c supernovae, several synthetic nucleosynthetic models were generated corresponding to different mass-loss evolutionary details during the Wolf-Rayet stages.

As the major findings of the work, on the basis of inferred associated stable isotopic anomalies it seems unlikely (expect for a probable case of a Wolf-Rayet star evolved to supernova Type 1b/c) that the short-lived nuclides with $\tau \leq 5$ million years (including ^{26}Al) were produced by stellar nucleosynthesis, even after considering all the associated uncertainties in nucleosynthetic yields. This drastically delimits the chronological use of these short-lived nuclides for understanding the early solar system processes.

Magnetohydrodynamics and Plasma Physics

Khan, Manoranjan

Dissipation mechanism in a collisionless dusty plasma consisting of non-thermal electrons, ions, and dust grains having variable charge is an important area of study. Manoranjan Khan in collaboration with his co-workers M.R. Gupta, S. Sarkar and S. Ghosh has shown that collisionless damping due to dust charge fluctuation causes the nonlinear dust ion acoustic wave propagation, which may be described by the damped K-dV equation. It is also shown that due to presence of non-thermal electrons, the dust ion acoustic wave admits both positive and negative potentials. The effect of ion-dust collisions on small amplitude nonlinear dust ion acoustic wave has also been investigated analytically which shows that propagation of the small amplitude wave is governed by the K-dV Burger equation. The experimental results of Nakamura et al., [Phys. Rev. Lett. 83, 1602 (1999)] has been verified and numerical investigation has revealed that the dust-ion acoustic wave exhibits both oscillatory and monotonic shocks depending on the number density of dust particles. Non-adiabatic dust charge variation on the non-linear dust acoustic wave in a dusty plasma have been studied by Manoranjan Khan and his co-workers by reductive perturbation technique. It has been shown that non-linear dust acoustic wave is governed by a modified K-dV Burger equation. Numerical integration of m K-dV B equation shows that the non-linear dust acoustic wave admits negative potentials with the oscillatory or monotonic shock transition and exhibits compressional shock wave.

In general, the dust grain density is small compared to electron-ion density in naturally occurring plasma. However, high dust density can lead to dust crystals formation of voids, etc.

The non-linear dust electro (DEA) acoustic mode has been studied at high density in collaboration with the group members of the Centre for Plasma Studies and K. Avinash of the Institute for Plasma Research (Gandhinagar). It has been found that the dispersive effect of DEA wave is more pronounced than that of dust acoustic wave for hydrogen plasma at the same electron and ion temperature.

Kumar, Nagendra

Alfven waves have been widely discussed in space plasmas. If we consider solar wind as the part of the corona, we can undoubtfully say that Alfven waves lead to coronal heating. It is well known that viscosity is strongly anisotropic in the solar corona and solar wind. So, N. Kumar along with his student H. Sikka has studied the effect of ion-parallel viscosity on the propagation of Alfven surface waves at a single magnetic interface. The velocity field is assumed as solenoidal. It is found that there are two damped modes of Alfven surface waves, which do not propagate simultaneously, i.e., when one vanishes other propagates after a certain propagation gap. The propagation speed of the latter mode is lesser than that of former. The damping of the modes increases as viscosity increases but decreases after a certain specific value.

The behaviour of the hydromagnetic waves in a fluid which comprises of two components (suprathermal and thermal) propagating with different sound speeds in the presence of steady flow has been studied by them.

The results of this work show that in addition to the usual slow, fast and Alfven modes, there is another mode called suprathermal mode which arises due to the coupling between the two components, thermal and suprathermal plasma. The suprathermal mode propagates with the faster speed than all other modes and attains its maximum along magnetic field lines. Alfven, slow and fast waves too do not propagate in a direction perpendicular to magnetic field and have greatest speed along the direction of the magnetic field.

Mondal, Kalyan Kumar

Theoretical study on the instability of ion-acoustic waves in a multicomponent plasma consisting of positive ions, negative ions and two-temperature electrons has been made. Considering ion-streaming, dispersion relations have been derived for an unbounded and a bounded system. Moreover, a comparative study on the results obtained in the two cases for the plasmas (O^-, Ar^+) and (Cl^-, H^+) has been made.

Propagation of linear and non-linear waves in a multicomponent plasma containing electrons, positive ions and negative ions bounded in a cylindrical waveguide has been theoretically investigaed. Effects of finite geometry and the concentration of negative ions on the stability of the ion-acoustic wave has been investigated through the derivation of Sagdeev potential and various important results on the variation of ion-streaming, and geometry of the bounded plasma have been obtained.

The Sagdeev- potential equation, considering both the ion-dynamics and dust-dynamics has been derived for an unmagnetised collisionless plasma consisting of warm ions, non-isothermal electrons and cold massive charged dust grains. It has been observed that compressive solitary waves are likely to be excited in such plasma and various parameters namely, ion-temperature, non-isothermality of electrons and Mach numbers, etc. have significant impact on both the amplitude and the width of large amplitude as well as small-amplitude ion-acoustic waves. Moreover, incorporating dust-charge fluctuation and non-isothermality of electrons, a non-linear equation relating the grain surface potential to the electrostatic potential has been deduced. It has been solved numerically, and interdependence of the two potentials for various ion-temperatures and orders of non-isothermality have been studied.

For an unmagnetised partially ionized dusty plasma containing electrons, singly charged positive ions, micron-sized massive negatively charged dust grains and a fraction of neutral atoms and incorporating dust charge fluctuation, dispersion relations for both D and DIA waves have been derived and then exhaustively studied under various conditions. Effects of dust-charge variation on the growth rates have also been investigated.

In astrophysical environments, dynamics of large bodies such as planets, stars and satellites is solely governed by gravitational force, whereas, electromagnetic force is the only force effective in controlling the dynamics of electrons and ions. But it is very interesting to note that for the micron and submicron size dust grains, these two forces become comparable, i.e.,$\mathbf{G}m_d^2/q_d^2 \approx O(1)$ and the interplay between the gravitational and the electrostatic forces in the dynamics of such grains leads to various novel phenomena in terrestrial and the solar environment. Instability Jeans type of the dust acoustic wave excited in a dusty plasma composed of electrons, ions and dust grains due to self gravity has been studied. In this case, plasma has been assumed to be infinite and homogeneous. Taking into consideration the ion-dynamics, the dust-dynamics together with the dust-charge flucutation, a dispersion law associated with the analysis of the linear gravitational instability of the wave has been derived and analysed in detail.

Atmospheric and Ionospheric Physics

Iyer, K. N.

Multi-technique observations may considerably improve our understanding about the factors responsible for the generation, growth and dynamics of the estabilized night time equatorial F region plasma irregularities. In order to investigate the dynamics of plasma density irregularities of different scale sizes, a campaign of observations was conducted during November 11 to 20, 2001 at the Brazilian magnetic equatorial station Sao Lus $(2.57^o S, 44.21^o W, dip\ latitude\ 1.73^o S)$. K. N. Iyer has carried out observations using VHF coherent backscatter radar, two spaced GPS based scintillation monitors and one digisonde. Range type spread F on ionograms and radar plumes signatures on Range-Time-Intensity (RIT) maps of the VHF radar started almost the same time. In order to compare GPS L1 (1.575 GHz) scintillations and radar plumes, he used the scintillation S4 index computed for the signal transmitted by the highest elevation satellite. The occurrence time of the maximum S4 values was concurrent to the strongest echoes observed by the radar. Zonal and vertical velocities of 5-metre irregularities measured by the radar were analyzed jointly with the apparent zonal velocity of $\sim$ 400-metre irregularities computed using scintillation spaced receivers method. Larger values of the zonal velocity computed by scintillation technique were found during the explosive growth phase of plumes associated to large values of vertical drifts measured by the radar. Finally, he obtained the Fresnel frequency from the GPS signal power spectrum and he estimated the height of scattering layer causing scintillation. The scattering layer height was compatible with the plume height showed by the RTI radar map.

Data collected during the first two observational campaigns, conducted in August 1998 and December 1999, using the new 50 MH_z coherent back-scatter radar, developed at INPE, that became operational at the magnetic equatorial site at Sau Lus, Brazil, were analysed. The spatial and temporal distribution of 3-m irregularity power in the form of RTI maps and spectral distribution in the form of spectrograms were analyzed for quiet conditions and during geomagnetic storm disturbances. The analysis has brought out some new findings, besides confirming some of the already known storm response features of the EEJ and its plasma instabilities. Among the results, highlights are: the electrical coupling between the equatorial and auroral electrojets is important even on a quiet day, and gets very strong during magnetic storm disturbances; disturbance prompt penetration electric field, and the delayed electric field from disturbance dynamo, control the 3-m plasma wave development and inhibition in different degrees during the storm main phase and recovery phase; the amplitudes of the disturbance are larger during the morning hours than in the afternoon, in agreement with theoretical models; the height dependence of the relative dominance of the type-1 and type-2 waves generated by disturbance electric field is different from that of quiet conditions, the relative power of the type-2 getting enhanced at higher levels in the former case.

Reddy, Ramakrishna R.

R. R. Reddy has been engaged in the study of tropospheric gaseous pollutants. Surface ozone (O_3) and its precursor gases $(NO_X\ and\ CO)$ play a central role in the oxidizing capacity of the atmosphere. Standard meteorological parameters and concentrations of these trace gases at a semi-arid site, Anantapur $(14.62^0 N, 77.65^0 E;$ 331 mts a.m.s.l) in tropical India, were monitored. Continuous measurements of CO, $NO_X(NO + NO2), O_3$

and SO_2 have been carried out during 2002. Seasonal, monthly and diurnal variations are examined. Higher levels of O_3 are observed during daytime i.e., between 12oo and 1700 hrs. Ozone concentration increases after sunrise, attains a maximum and then decreases. The daytime ozone production is basically due to the photooxidation of the precursor gases. At the observational site, the diurnal variations of the average ozone concentrations are about 45-55 ppbv. In autumn months (July-October), O_3 shows low values (8-18 ppbv) and in the winter and summer months (November-May) the O_3 concentration is high (40-50 ppbv). However, high levels of ozone, exceeding 70 ppbv, are rarely observed. High concentrations of CO and NO_X are noticed during rush hours and low levels at noon time in all months at the observational site. Diurnal variations in NO_X and CO are a manifestation of combined effects of local emissions, boundary layer processes, chemistry and local wind pattern. During the course of our observations for this period the day time concentrations of CO varies between 200 and 1200 ppbv and that of NO_X varies between 3 and 20 ppbv. It is observed that CO concentration levels are high during autumn and summer, and low in winter. Whereas NO_X concentration levels are high during autumn and winter, and low in summer. Low concentration levels of $SO_2(\approx 4-6\ ppbv)$ are observed at the observational site. Generally, coal consumption and oil products contribute 64% and 29% of SO_2. Low levels of SO_2 at the observational site may be due to the non-availability of coal burning in this area. By the burning of high-speed diesel and fuel consumption of the transport, rarely we have observed a high concentration ($\approx$ 10 *ppbv*) of SO_2 at this site.

Observational Astronomy and Image Analysis

Kuriakose, V. C.

In collaboration with A.K. Kembhavi and Ravikumar V.C. Kuriakose has studied the photometric analysis of galaxies in the nearby rich clusters observed in the near infrared window. The galaxy parameters are extracted using extensive simulations of images of galaxies and various galaxy formation scenarios are explored by studying different correlations like the photometric and fundamental planes existing between the global parameters of the galaxies.

Pandey, S.K.

Early-type galaxies having dust lanes/patches are suitable objects for studying properties of dust in the extragalactic environment, because the underlying galaxies have fairly smooth distribution of stellar light. The amount and spatial distribution of dust in these galaxies provide important information regarding the structure of the galaxies as well as the history of interactions and mergers that the galaxies might have experienced in the past. Amount of dust in these galaxies can be quantified accurately using IRAS fluxes, however, it leaves the spatial distribution uncertain. Therefore, optical methods are proved to be essential tool for studying the spatial distribution of dust in the extragalactic environment. Good quality multi-colour (optical as well as near-IR) data on a number of early-type galaxies have been collected, using the observing facilities at Nainital, Kavalur and Mt. Abu, with the objective of deriving wavelength dependence of dust extinction in them and to see how different they are from that of our Galaxy. The analysis of the wavelength dependence of the dust extinction shows that the extinction curves run parallel to the galactic curve implying that the extinction properties of dust in the sample galaxies are similar to that of the Milky Way. The ratio of total to selective extinction R_V, however, turns out to be smaller than the canonical galactic value of 3.1, suggesting that the dust grains responsible for the optical extinction are smaller than that in the Milky Way. Further, it was also noticed that, the optical extinction curve and the value of R_V depends on the environment of the host galaxy: in the sense that the lower density regions have smaller R_V compared to denser regions. The work forms a major part of the thesis work of M. K. Patil, S.R.T.M. University, Nanded.

It is now well established that elliptical galaxies contain a complex, multiphase ISM. All forms of ISM present in spiral galaxies have been detected in elliptical galaxies , though in different proportion. High resolution imaging observations in the optical, x-ray as well as in the infrared bands, which make it possible to examine the morphology of various forms of the ISM, have provided some clues for the origin and possible physical connection between the different constitutents. Detailed observations, which can lead to some understanding of the nature, origin and evolution of the ISM in elliptical galaxies are available for only a small number of ellipticals. With the objective of establishing evidence for the multiphase (hot, warm and ionized, cool molecular gas and dust) ISM in elliptical galaxies a well defined sample of 34 elliptical galaxies, was chosen from Brown and Bregman(1998) for carrying out observations in optical, infrared and x-ray bands. A subsample of nine galaxies was observed in near-infrared(NIR)-JHK-bands using 3.5m NTT and near-IR camera SOFI at the European Southern Observatory(ESO) during December 2002. Proposals for observations in optical/NIR of the sample have been submitted at Palomar and other observatories too. These observations will be the first of its kind for a well defined large sample, and will lead to a detailed understanding of the nature, origin and evolution of ISM in elliptical galaxies. People invovled in this joint collaborative programe included A. K. Kembhavi, S. Raychaudhury, Ashish Mahabal and the group at respective observatories.

With a view to look for activity cycles, akin to the familiar 11-year sunspot cycle, long-term photometric variation for a sample of well observed chromospherically active stars was studied using the photometric data for over two decades. The analysis reveals the presence of activity cycles in the most of the stars with the period ranging from few years to few decades. This study was extended to T Tauri stars (pre-main sequences stars) and FK Com type stars (single fast rotating stars) to investigate the existence of activity cycles. Detailed analysis of the data for these stars is in progress. Padmakar Parihar and Sudhanshu Barway are involved in this programme.

Philip, Ninan Sajeeth

Observational astronomy has reached a status where traditional methods such as expert identification and classification of stellar observations is no longer feasible. The quantum of raw data collected by the ongoing space surveys are in terabytes and no human classifier can manually group them in reasonable time and extract the desired science out of it. It is in such a circumstance that machine learning finds its relevance. Artificial Neural Networks are the most popular class of machine learning tools used for automated classification of data. N.S. Philip and K. Babu Joseph have developed a fast and efficient neural network model based on Bayesian principle for probabilistic estimation of likelihoods. This tool has been successfully deployed in many practical problems, such as climate prediction and stock market prediction. The new tool is called a Difference Boosting Neural Network (DBNN). In a collaborative investigation, N.S. Philip, Yogesh Wadadekar, Ajit Kembhavi and K. Babu Joseph have successfully shown that the said tool can be used for automated star-galaxy separation with more accuracy and speed as compared to other popular tools. The software developed for this purpose is in public domain and is a basic tool for filtering out foreground stars from any astronomical observation.

In another study, Stephen Odewahn, S.H. Cohen, R.A. Windhorst and N.S. Philip used DBNN for classifying galaxy types based on their morphology. The thrust in this study was to separate out barred galaxies from a mixed sample of different types. For comparison, a standard neural network was also used. It was found that DBNN accuracy was marginally better than that of existing network tools. In large surveys, even a marginal improvement is significant.

At present, N. S. Philip and Shaukat N. Goderya at Illinois State University are using DBNN for a broader, automated, classification of galaxy types. The objective of this study is to classify galaxies into one of the five Hubble types. The preliminary results showed remarkable improvement in classification accuracy from 68% to 89%, when DBNN was used instead of other popular neural network tools. Possible improvements in classification accuracy by using wavelet based feature identification methods are currently investigated.

Rao, P. Vivekananda

P. Vivekananda Rao has been engaged in the study of RS CVn binary. All the light curves available on the RS CVn binary UV Piscium spread over several years were analysed to determine the long term behaviour of the spot characteristics on this system. From our analysis, it is found that the spots on UV Piscium are relatively stable for long periods compared to other short period RS CVn systems. The spots are confined to two Active Longitudinal Belts (ALB's) of near 90 and 270 degrees. The spots near 90 degrees are found to be in the latitude range 18-25 degrees, while the spots near 270 degrees to be in the range 10-15 degrees. The stability of the spots in these two regions could be due to low X-ray fluxes compared to the ones which show rapid spot changes. No latitude drifts in the spot regions have been noticed. It is found that UV Piscium has secular variations in the mean brightness out of the eclipse that are not explained by spot models and indicate luminosity changes in the primary star.

From the analysis of several main sequence eclipsing binaries, he has found that the derived parameters of the components are in agreement with the ones obtained for the stars observed with the intensity interferometer in defining the radiative flux-temperature relation in the spectral range B6-F2. Since, the sensitivity of the intensity interferometer may not be great enough to encompass main-sequence stars in the late K-M region, the eclipsing binary with late type components properly removed for the starspots would be very promising in solidifying the radiative surface flux and temperature scales in this spectral region.

Analysis on two W UMa systems discovered in the intermediate open cluster Be 33 were made and their parameters determined by Vivekananda Rao. From the analysis, it is found that the components of these binaries have several properties which are in common with the W UMa systems found in the solar neighbourhood.

Instrumentation

Bhatnagar, S. P.

A 14" automated telescope developed at IUCAA was fabricated for Bhavnagar University and installed at the roof-top of the Department of Physics, Bhavnagar University in December 2000 by S. P. Bhatnagar and his collaborators. Software for the telescope control was developed at Bhavnagar University by S. P. Bhatnagar. Some minor improvisations in the electronics, mechanical and optical systems were attempted. A plan to study some brighter variables, declared suspected variables by Hipparcos mission was prepared. During the past two years some of these are being observed photometrically.

The telescope is being used for science popularisation during moonlit nights. Many school students and others are using the telescope for celestial observations.

(III) 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

Chakrabarti, Sandip K. and **Bhattacharyya, Abhijit** (2002) How thick are the Saturn's rings?, Bull. Astr. Soc. India, **30**, 3.

Choudhury, T. Roy and **T. Padmanabhan** (2002) A simple analytical model for the abundance of damped Ly α absorbers, ApJ, **574**, 59.

Choudhury, T. Roy and **R. Srianand** (2002) Probing the dark ages with redshift distribution of gamma ray bursts, MNRAS, **336**, L27.

P. S . Joshi, **N. Dadhich** and R. Maartens (2002) Why do naked singularities form, Phys. Rev. **D, 65**, 101501(R).

Dadhich, N. and Z. Y. Turakulov (2002) The most general axially symmetric stationary electrovac solution and separability of equations of motion, Class. Quan. Grav. **19**, 2765.

Dadhich, N. and Z. Y. Turakulov (2002) Gravitational field of a rotating gravitational dyon, Mod. Phys. Lett,. **A,17**, 1091.

S. G. Ghosh and **N. Dadhich** (2002) Gravitational collapse of Type II fluid in higher dimensional spacetimes, Phys. Rev. **D,65**, 127502.

A. Banerjee, S. Chatterjee and **N. Dadhich** (2002) Spherical collapse with heat flow and without horizon, Mod. Phys. Lett. **A,17**, 2335.

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

Das, Tapas K. (2003), Role of shocked accretion flows in regulating the QPO of galactic blackhole candidates Ap. J. Letts., 588, **L89**.

Das, Tapas K., Pendharkar, Jayant K., and **Mitra, Sanji**t. (2003), Multi-transonic black hole accretion discs with dissipative standing shocks.Ap. J., **592**, 1078.

Das, Tapas K. (2002), Generalized shock solutions for hydrodynamic blackhole accretion. Ap. J., **577**, 880.

Das, Tapas K., A.R. Rao, S.V. Vadawale (2003), QPO frequencies and mass-outflow rate in galactic micro-quasars, MNRAS, **343**, 443.

Das, Tapas K. (2002), Pseudo-Schwarzschild description of accretion-powered spherical outflow Int. Jour. Mod. Phys. D., **11**, 1285.

Dhurandhar, S. V., K. Rajesh Nayak, and J. Y. Vinet (2002) Algebraic approach to time-delay data analysis for LISA, Phys. Rev. **D, 65**, 102002.

Sengupta, A., S. V. Dhurandhar, A. Lazzarini and T. Prince, (2002) Extended hierarchical search (EHS) algorithm for detection of gravitational waves from inspiraling compact binaries, Class. Quan. Grav., **19**, 1507.

Pai, A., S. Bose and **S. V. Dhurandhar** (2002) Computational cost for detecting inspiraling binaries using a network of laser interferometric detectors Class. Quan. Grav., **19**, 1477.

S. R. Valluri, J. J. Drozd, F. A. Chishtie, R. G. Biggs, M. Davison, **S. V. Dhurandhar** and B. S. Sathyaprakash (2002) A study of the gravitational waveform from pulsars Class. Quant. Grav., **19**, 1327.

Dhurandhar, S.V. (2002) Gravitational Wave Astronomy: Recent Advances, Bull. Astr. Soc. India, **30**, 729.

Gupta, Ranjan, M. Burse, H.K. Das, A. Kohok, A.N. Ramaprakash, S. Engineer and **S.N. Tandon** (2002) IUCAA 2 meter telescope and its first light instrument IFOSC, Bull. Astr. Soc. India, **30**, 785.

Bhatnagar, S.P., Umesh V. Dodia, *M.N. Anandaram, B.A. Kagali* and **Ranjan Gupta**, A 14" Schmidt Cassegrain Automated Telescope for Bhavnagar and Bangalore Universities, J. Instrum. Soc. India, **31** (3 & 4), 234 .

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

Philip, N. S., Yogesh Wadadekar, **Ajit Kembhavi**, K. Babu Joseph (2002) A difference boosting neural network for automated classification,A & A **385 (3)**, 1119.

Patil, M. K., Sahu, D. K., Pandey S. K., **A. K. Kembhavi,** Joshi, U. C., Baliyan, K.S. and Singh, M. (2002) Dust properties in early-type galaxies, Bull. Astr. Soc. India, **30**, 759.

Misra, R. and R. E. Taam (2002) The effect of a dissipative corona on the structure and stability of cold optically thick accretion disks at high accretion rates, Ap. J., **573**, 764.

Mukhopadhyay, B. and **R. Misra** (2003) Pseudo-Newtonian potentials to describe the temporal effects on relativistic accretion disks around rotating blackholes and neutron stars, Ap. J., **582,** 347.

Misra, R. and K. Sriram (2003) Flux enhancement in the inner region of a geometrically and optically thick accretion disk, Ap. J, **584**, 981.

Mukhopadhyay, B. (2002) Dynamics of electromagnetic waves in Kerr geometry, Class. Quan. Grav. **19**, 2307.

Mohanty, S., **B. Mukhopadhyay,** and Prasanna, A. R. (2002) Experimental tests of curvature couplings of fermions in general relativity, Phys. Rev. **D, 65**, 122001.

Mukhopadhyay, B. (2002) Hydrodynamical study of advective accretion flow around neutron stars, Int. Jour. Mod. Phys. **D, 11**, 1305.

Mukhopadhyay, B. (2002) Description of pseudo-Newtonian potential for therelativistic accretion disk around Kerr black holes, Ap. J., **581**, 427.

Prasanna, A. R. and **B. Mukhopadhyay** (2003) Effect of Coriolis force on accretion flows around rotating compact object, Int. J. Mod. Phy. **D**, 12, **157**, 2003.

Mukhopadhyay, B., Ray, S., Dey, J. and Dey, M. (2003) Origin and interpretation of kilohertz quasi-periodic-oscillations from strange stars in X-ray binary system:Theoretical hydrodynamical description, Ap. J. letts., **584**, L83.

Mukhopadhyay, B. and A. R. Prasanna (2003) Fluid flow and inertial forces in blackhole spacetimes, Int. Jour. Mod. Phys. **A, 18**, 1091.

Mukhopadhyay, B. (2003) Stability of accretion disk around rotating blackholes: A pseudo-general-relativistic fluid dynamical study, Ap.J., **586**, 1268.

Narlikar, J.V., R.G. Vishwakarma and G. Burbidge (2002) Interpretations of the accelerating universe, Publications of the Astronomical Society of the Pacific, **114**, 1092.

Wainwright, M., N. C. Wickramasinghe, **J.V. Narlikar** and P. Rajaratnam (2003) Microorganisms cultured from stratospheric air samples obtained at 41 km, FEMS Microbiology Letters, **218**, 1, 161.

Wickramasinghe, N.C., M. Wainwright, **J.V. Narlikar,** P. Rajaratnam, M.J. Harris and D. Lloyd (2003) Progress towards the vindication of panspermia, Astrophysics and Space Science, **283**, 403.

Narlikar, J. V., (2003) The quasi-steady-state cosmology, Chaos, Solitons and Fractals, **16**, 469.

Narlikar, J. V., R.G. Vishwakarma, Amir Hajian, Tarun Souradeep, G. Burbidge and F. Hoyle (2003) Inhomogeneities in the microwave background radiation interpreted within the framework of the quasi-steady state cosmology, Ap. J., **585**, 1.

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

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

Shankaranarayanan, S., **T. Padmanabhan** and K. Srinivasan (2002) Hawking radiation in different coordinate settings: Complex paths approach, Class. Quan. Grav., **19,** 2671.

Padmanabhan, T. (2002) Combining general relativity and quantum theory: Points of conflict and contact, Class. Quan. Grav. **19**, 3551.

Padmanabhan, T. (2002) Thermodynamics and/of horizons: A comparison of Schwarzschild, Rindler and de Sitter spacetimes, Mod. Phys. Letts. A, **17**, 923.

Padmanabhan, T. (2002) Is gravity an intrinsically quantum phenomenon? Dynamics of gravity from the entropy of spacetime and the principle of equivalence, Mod. Phys. Letts. A, **17**, 1147.

Padmanabhan, T. (2002) Accelerated expansion of the universe driven by tachyonic matter, Phys. Rev. **D,66**, 021301.

Padmanabhan, T. (2002) Why do we observe a small but non-zero cosmological constant? Class. Quan. Grav., **19** , L167.

Padmanabhan, T. (2002) Classical and quantum thermodynamics of horizons in spherically symmetric spacetimes, Class. Quan. Grav. **19**, 5387.

Padmanabhan, T. and **T. Roy Choudhury** (2002) Can the clustered dark matter and smooth dark energy arise from the same scalar field? Phys. Rev. **D,66**, 081301.

Padmanabhan, T. (2002) Evolution of the correlation function for a class of processes involving non-local self-replication, Ap. J. **579** , 10.

Padmanabhan, T. (2002) The holography of gravity encoded in a relation between entropy, horizon area and the action for gravity, Gen. Rel. Grav., **34,** 2029.

[*Second Prize essay: Gravity Research Foundation Essay Contest, 2002.*]

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,

Srivastava D. C. and **S.K. Sahay** (2002) Data analysis of continuous gravitational wave: All sky search and study of templates, MNRAS, **337**, 322.

Srivastava, D.C. and **S.K. Sahay** (2002) Data analysis of continuous gravitational wave: Fourier transform-I, MNRAS, **337**, 305.

Srivastava, D. C. and **S. K. Sahay** (2002) Data analysis of continuous gravitational wave: Fourier transform-II., MNRAS, **337**, 315.

Shtanov, Yuri and **Varun Sahni** (2002), New cosmological singularities in braneworld models, Class. Quan. Grav., **19**, L101.

Sahni, Varun (2002), The cosmological constant problem and quintessence, Class. Quan. Grav., **19**, 3435 (2002).

Sahni, Varun and Yuri Shtanov (2002), New vistas in brane world cosmology, Int. J. Mod. Phys. **D, 11**, 1-7 .

Sahni, Varun (2003) Theoretical models of dark energy, Chaos, Solitons and Fractals, **16**, 527.

K. Coble, S. Dodelson, M. Dragovan, K. Ganga, L. Knox, J. Kovac, B. Ratra and **Tarun Souradeep** (2003) Cosmic microwave background anisotropy measurement from Python V, Ap. J., **584**, 585.

Ledoux, C., **Srianand, R.** and Petitjean, P. (2002) Detection of H_2 molecule in near solar metallicity damped Lyman-α system at z_{abs} = 1.962 toward Q 0551-366, A & A, **392**,781.

Srianand, R., Petitjean, P., Ledoux, C., and Hazard, C. (2002) A collimated flow driven by radiative pressure from the nucleus of quasar Q~1511+091, MNRAS, **336**,753.

Peroux, C., Petitjean, P., Aracil, B. and **Srianand, R.**, (2002) A new measurement of zinc metallicity in a DLA at z ~ 3.35, New Astronomy, **7**, 577.

Ledoux, C. **Srianand, R**. and Petitjean, P. (2002) Detection of molecular hydrogen in a near solar-metallicity damped Lyman- α system at z_{abs} ~2 toward Q 0551-366, A&A, **392**, 781.

Lewis, Geraint F., Ibata, Rodrigo A., Ellison, Sara L., Aracil, Bastien, Petitjean, Patrick, Pettini, Max and **Srianand, R.** (2002) Spatially resolved STIS spectra of the gravitationally lensed broad absorption line quasar APM08279+5255: The nature of component C and evidence for microlensing, MNRAS, **334,** 7.

Brandenburg, A., A. Bigazzi and **K. Subramanian** (2001) The helicity constraint in turbulent dynamos with shear, MNRAS, **325**, 685.

Seshadri, T.R. and **K. Subramanian** (2001) CMBR polarization signals from tangled magnetic fields, Phys. Rev. Lettes., **87**, 101301.

Brandenburg, A., W. Dobler and **K. Subramanian** (2002) Magnetic helicity in stellar dynamos: New numerical experiments, Astronomische Nachrichten, **323,** 99-122.

Subramanian, K. and J. D. Barrow (2002) Small-scale microwave background anisotropies due to tangled primordial magnetic fields, MNRAS, **335**, L57.

Vishwakarma, R.G. (2002) A Machian model of dark energy, Class. Quan. Grav., **19** 4747.

Vishwakarma, R.G. and **Parampreet Singh** (2003) Can brane cosmology with a vanishing Lambda explain the observations? Class. Quan. Grav., **20,** 2033.

(b) Proceedings

Das, Tapas K. (2002) Simultaneous solution scheme for coupled transonic accretion-wind systems, in Proceedings of the ninth Marcel Grossman Meeting on Recent developments in theoretical and experimental general relativity, gravitation and relativisitc field theories. ed. Vahe G. Gurzadyan, Robert T. Jantzen and Remo Ruffini, p. 2255.

A. Deep, et. al. (2002) Near Infrared PICNIC Imager (NIPI) for IUCAA telescope, in Proceedings of the XXI Meeting of the ASI, Bull. Astr. Soc. India, **30**, 791.

A. K. Sen, **Ranjan Gupta, A. N. Ramaprakash** and **S. N. Tandon** (2002) Reduction of imaging polarimetry images in automated data analaysis in astronomy, ed. Ranjan Gupta, H. P. Singh and C. Bailer-Jones, Narosa Publication, p. 335.

Ambika G., M Takeuti and **A. K. Kembhavi** (2003) in "Mass losing pulsating stars and their circumstellar matter" eds. Y Nakada, M Honma and M Seki -Kluver Academic Publications-Dordrecht, 95.

Narlikar, J.V. (2002) Creation of matter and anomalous redshifts, Gravitation and Cosmology: From the Hubble Radius to the Planck Scale, Eds. R.L. Amoroso, G. Hunter, M. Kafatos and J-P Vigier (Kluwer: Dordrecht), 11.

Narlikar, J.V. (2002) Absorber theory of radiation in expanding universe, Gravitation and Cosmology: From the Hubble Radius to the Planck Scale, Eds. R.L. Amoroso, G. Hunter, M. Kafatos and J-P Vigier (Kluwer: Dordrecht), 81.

Narlikar, J.V. (2002) The lighter side of gravity, Proceedings of the 16th International Conference on General Relativity and Gravitation, Eds. N.G. Bishop and S.D. Maharaj (World Scientific), 315.

David Lloyd, N.C. Wickramasinghe, Melanie J. Harris, **J.V. Narlikar,** P. Rajaratnam, Pushpa Bhargava, S. Shivaji, G.S.N. Reddy, Michael P. Turner, S. Al-Mufti, Max K. Wallis, S. Ramadurai and F. Hoyle (2002) Detection of extraterrestrial life in stratospheric samples, Proceedings of the International Conference entitled "Multicolour Universe", Eds. R. K. Manchanda and B. Paul, (Tata Institute of Fundamental Research, Mumbai), 367.

Ramaprakash, A. N. (2002) Multi-band monitoring and polarimetry of GRB afterglows with the IUCAA telescope, Proc. of Gamma-ray Astrophysics through multi-wavelength experiments: GAME 2001, Bull. Astr. Soc. India, **30**, 294.

R. Srianand, et. al. (2002) Science with IUCAA Telescope, in Proceedings of the XXI Meeting of the ASI, Bull. Astr. Soc. India, **30**, 797.

A. Brandenburg, A. Bigazzi and **K. Subramanian** (2001) Sheared helical turbulence and the helicity constraint in large-scale dyanamos, in Dynamos and Dynamics: A Mathematical challenge, P. Chossat, et al. (eds.), Kluwer Academic Publishers, 117.

Pathak, Sandeep Kumar (2002) Role of electronic journals in Astronomy and Astrophysics Libraries in India : An overview of IUCAA Library. XX IASLIC Seminar Proceeding, Punjabi University, Patiala on the theme "Digital Information System and Services". 187.

Pathak, Sandeep Kumar (2003) Importance of library webpage in special libraries :A case study of IUCAA Library, 48th ILA Conference Proceeding, NIMHANS, Banglore on the Theme "Electronics Information Environment and Library Services : A Contempo paradigm". 482.

Subramanian, P., Ananthakrishnan, S., Rao, A. P. (2003), Observations of the Sun with the GMRT, in 'Probing the Sun with High Resolution', eds. S. C. Tripathy and P. Venkatakrishnan, Narosa Publishing House, 167.

c) Books Authored

Narlikar, J.V. (2002) [in Marathi] Abhayaranya, Mouj Prakashan Griha, Mumbai.

Padmanabhan, T. (2002) Course of Theoretical Astrophysics - Vol III: Galaxies and Cosmology, (Cambridge University Press, Cambridge)

d) Book Reviews

Narlikar J.V. (2002) Distant wanderers: The search for planets beyond the solar system : A review of the book by Bruce Dorminey, Current Science, **82**, 10, 1289.

Padmanabhan, T. (2002) Universal values: A review of the book: The Constants of Nature by John Barrow, Nature, **419**, 6909.

e) Popular Articles

Narlikar, J.V. (2002) Science journalism in India and abroad, (Indian Journal of Science Communication, 1, 1, 23).

- (2002) Astronomy at the millennium, (Proceedings of Andhra Pradesh Akademi of Sciences, 6, 2, 87).

- (2002) QSSC : Requiem for big bang?, (ECHO, 13).

- (2002) Virtual database: Future of scientific information, (Times of India, June 21)

- (2002) Current speculations about the origin of the universe, (India International Centre Quarterly, 29, 1, 115).

- (2002) Challenges and benefits of studying astronomy (Jawaharlal Nehru Birth Centenary Award Lecture delivered to the Indian Science Congress Association, Kolkata, March 21) (Everyman's Science, XXXVII, 1,8).

- (2002) Looking at the future, learning from the past, (Mantram, July).

- (2002) Original sins: Lack of integrity in R & D, (Times of India, November 22).

- (2003) Monumental marvels : Science through the looking glass, (Times of India, January 28).

- (2003) Search for micro-organisms in outer space, (Surya, 1,6, 11)

- (2002) Do Shabdh (in Hindi) [Two words] (Bal Vidnyanik, Preface for Standard 7 textbook).

- (2002) Jyotish vidnyan nahi hai (in Hindi) [Astrology is not a science], (Srot, August).

- (2002) Ekeesavi shati me vidnyan (in Hindi)[Science in the twentyfirst century], (Ekeesavi Shati Ka Bhavishya, 20).

- (2002) Naummidi mein vidnyan ki khoj : Uchit samikaran (in Hindi)[The right equations: Desperately seeking science], (Harkara, August-October, 2).

- (2003) Ekeesavi sadi me vidnyan (in Hindi)[Science in the twentyfirst century], (Vidnyan Prakash, January, 3).

- (2002) Hype Hype Hurray! Bazarpetheat vidnyanik (in Marathi) [Hype Hype Hurray - The scientist in the market place], (Vishwa Vidnyan, April).

- (2002) Ekvishavya shatakat (in Marathi)[In the twenty-first century], (Vidnyanyug, May).

- (2002) Tari mi alp-patith (in Marathi) [Still I am ill-read], (Balvikas, June).

- (2002) Abhayaranya (in Marathi)[Sanctuary : A science fiction story], (Anubhav, 24).

- (2002) Bhutkalacha magova.. Mahakavyatil vidnyan va tandradnyan (in Marathi)[Going back in time - Science and technology in epics], (Vishwa Vidnyan, August).

- (2002) Yogya samikarane! Vidnyanachi neetanth nikad!! (in Marathi)[The right equations - Desperately seeking science], (Vishwa Vidnyan, September).

- (2002) Mazya chhatra jeevanatale sansmarniya prasang (in Marathi)[Memorable incidents from my student days], (Aayushyateel Wadal-lata, 6).

- (2002) Aathavaninchya durbinitun (in Marathi)[From the telescope of memories], (Chhatra Prabodhan, Diwali Issue, 71).

- (2002) Chandrachi safar (in Marathi)[A journey to the moon], (Vachu Anande. 47).

- (2002) Prof. Visarbhole (in Marathi)[Prof. Visarbhole], (Tonic, 34).

- (2002) Ganitatil gamati-jamati (in Marathi)[Recreations in mathematics], (Gammat Jammat, Diwali Issue, 9).

- (2002) Bharatiya shastradnyanche sumar bhavitavya! Bharatiya shastradnya vyathith ka?? (in Marathi)[Mediocrity to the fore - Why scientists suffer in India], (Vishwa Vidnyan, December).

- (2002) Vidnyan, tantradnyan aani Marathi bhasha (in Marathi) [Science, technology and Marathi language], (Marathi Pathyapustak, IInd year Science, Pune University, 143).

-(2003) Yetya dashakatil khagolvidnyan aani vishwarachanashastra (in Marathi).[Astronomy and the structure of the universe in the coming years], (Akashdarpan, January-February, 3).

- (2003) Kai. Shri Varadananda Bharati: Kahi Aathavani (in Marathi)[Late Shri Varadananda Bharati : Some memories], (Sanskruti Vandana, 28).

- (2003) Gelya sahasrakatil vishwasankalpanecha vikas (in Marathi)[The development of cosmology in the past millennium], (Sahasrakatil Vidnyan, 1).

- (2003) Manogat (in Marathi)[Introspection], (Lokmudra, March 9).

- (2003) Ek aashavadi shastradnya (in Marathi) [One optimistic scientist], (Maharashtra Times, March 9).

Arvind Paranjpye (2002) Jidnyasa in Marathi for Loksatta Newspaper, Chanda ani Abhyas Akashnirikshanacha in Marathi for Tarun Bharat, Belgaum Star Trek in English for the Times of Indian Pune Plus edition.

(f) Resource Summaries in Khagol

Ranjan Gupta and D.B. Vaidya (2003) Interstellar Dust and Extinction (Issue No. 54 April).

Prasad Subramanian (2003) Coronal Mass Ejections from the Sun: Energetics (Issue No. 53, January).

Ranjeev Misra (2002) Rapid Temporal Behaviour of Blackholes and Neutron Star Systems (Issue No. 52, October).

T. Padmanabhan (2002) Gravitational Clustering in Static and Expanding Backgrounds (Issue No. 51, July).

Publications

by Visiting Associates

(a) Journals

Ahsan, Z. and **N. Ahsan** (2002) A Maxwell inheritance - a symmetry of the electromagnetic fields, Bull. Calcutta Math. Soc. 94 No.5 , 385.

Ahmad, F., Saslaw W. C. and Bhat, N.I. (2002) Statistical mechanics of the cosmological many-body problem, Ap.J. **571**,576.

Ambika, G. and Sujatha N. V. (2002) Critical exponents in the transition to chaos in one dimensional discrete systems, (2002) Pramana (J. Phys.) **59**, 9.

Ambika, G. and Thomas K I. (2002) Occurrence of stable periodic modes in a pendulum with cubic damping and 8211: an analytic study, Pramana (J.Phys.)59,445.

Ambika, G., Sujatha N.V. and **Harikrishnan K. P.** (2002) Stochastic resonance and Chaotic resonance in bimodal maps- a case study, Pramana (J. Phys.), **59**,539.

Ambika, G. and Kamala Menon (2002) Fractal patterns in the onset of coherent structures in a coupled map lattice, Pramana (J. Phys.) **59,** L155.

Sutapa Ghosh and **Chakrabarty, S.** (2002), Magnetically induced "dry" water like structure of electron gas in dense stellar matter in presence of an ultra strong magnetic field, Mod. Phys. Lett. **A17**, 2147.

Sutapa Ghosh and **Chakrabarty, S.** (2002), Can there b-equlibrated quark m atter at the core of a compact newborn neutron star with moderately strong magnetic field?, Spacetime and Substance Journal, **3,** 88.

Sutapa Ghosh, Soma Mandal and **Chakrabarty, S.** (2003) , Impossibility of spin polarized states for neutron sar/ proto-neutron star matter in β -equilibrium condition, Mod. Phys. Lett. **A18,** 1297.

Sutapa Ghosh and **Chakrabarty, S.** (2003) Instability of quark matter core in a compact newborn neutron star with moderately strong magnetic field, Pramana **60**, 901.

Chakraborty, S. (2002) Inflation, quintessence problem and varying speed of light, .Mod.Phys.Lett.A **17**,295.

Chakraborty, S. and Sulagna Chakraborty (2002), Cosmic no-hair theorem with a varying cosmological constant on brane scenario, Classical and Quantum Gravity **19**,3775.

De A.K., S. Bhanja and **Chakraborty, S.** (2003), Cosmic no-hair theorem for Bianchi models in brane world Scenarios.Gen.Relt.Grav,.**35**.

Chakraborty, N.C. and **Chakraborty, S.** (2002), Brans-Dicke theory in Bianchi III model and inflationary scenario, Int. J. Mod. Phys. D **11**,391.

Chakraborty, N.C. and **Chakraborty, S.** (2002), Brans-Dicke cosmology— A Generalization in anisotropic spacetime models, Gen.Relt.Grav, **34**,453.

Chakraborty, S., N. C. Chakraborty and Debnath (2002), Brans-Dicke cosmology in an anisotropic model when velocity of light varies, Int. J. Mod. Phys. D**11**,921.

Chakraborty, S., N. C. Chakraborty and U. Debnath (2003), Aquintessence problem in Brnas-Dicke theory with varying speed of light, Int. J. Mod. Phys, D **12**, 3.

Chandra, Suresh (2002) Search for molecules in cool cosmic objects, Bull. Astron. Soc. India **30**, 741 (2002).

Chandra Suresh .(2002) Einstein A-coefficients for rotational transitions in the ground vibrational state of Si_2C molecule, Ind. J. Phys. **76B**, 649.

Dwivedi, B.N. (2002) Probing the Sun's hot aatmosphere : Views from Yohkoh, SOHO and TRACE, Bull. Astron. Soc. India **30**, 549-555.

A. Mohan and **Dwivedi, B.N.** (2002) EUV diagnostics for Boron-like ions from spectra obtained by SUMER/ *SOHO* Bull. Astron. Soc. India **30**, 589.

A. Mohan and **Dwivedi, B.N.** (2003) On the EUV/UV plasma diagnostics for nitrogen-like ions from spectra obtained by SOHO/SUMER, Ap. J. **582**, 1162.

Gangal, A. D., Gauri Pradhan, Sagar Pandit and V. Sitaramam (2003) J.Theoretical Biology **220** ,189.

Ghosh S. G., S.B. Sarwe and R.V. Saryakar (2002) Collapsing perfect fluid in self-similar five dimensional spacetime and cosmic censorship., Phys. Rev. D **66,** 084006

Ghosh S.G and D.W. Deshkar (2003): Non-spherical collapse of a radiating star, Int. J Mod. Phys. D. **12** 317.

Goyal, Ashok, Mehta,Poonam and Dutta, Sukanta (2002) Lepto-quark signals via neutrino interactions at a neutrino factory, Phys.Lett. B**535**, 219.

Goyal, Ashok, Deepak, Chandra and Kanupriya, Goswami (2002) Neutrino opacity in magnetised hot and dense nuclear matter, Phys. Rev. **D65**, 053003.

Goyal, Ashok, Gupta,V.K. and Tuli, Vinita (2002) Radial oscillations of hybrid stars, Ap.J. **579**, 374.

Goyal, Ashok, Gupta,V.K., Anand,J.D., Tuli,Vinita and Singh, S. (2002), Radial oscillations of neutron stars in strong magnetic field, Pramana, **59**,433.

G. Ambika, N. V. Sujatha and **Harikrishnan, K. P.** (2002) Scaling indices and dynamical states of 1" –d discrete systems, nonlinear systems (Ed. R. Sahadevan and M. Lakshmanan), Narosa, New Delhi, 343.

Ibhol, Ng (2002) On the variably-charged blackholes in general relativity:Hawking's radiation and naked singularities, Class Quantum Grav., **19,** 4327

Narayan, C.A., and **Jog, C.J.** (2002. Vertical scaleheights in a gravitationally coupled, three-component galactic disk, Astron. & Astrophys, **394**, 89

Jog, C.J., and Chitre, A. (2002).`Spiral-like light profiles but elliptical-like kinematics in mergers of galaxies, Astron. & Astrophys. Letters, **393**, L89.

Narayan, C.A., and **Jog, C.J.** (2002).`Origin of radially increasing stellar scaleheight in a galactic Disk, Astron. & Astrophys. Letters, **390**, L35.

Jog, C.J. (2002).`Large-Scale Asymmetry of Rotation Curves in Lopsided Spiral Galaxies', Astron.& Astrophys, **391**, 471

Chitre, A., and **Jog, C.J.** (2002) Luminosity profiles of advanced mergers of galaxies using 2MASS data, Astron. & Astrophys., **388**, 407.

Narayan, C.A., and **Jog, C.J.** (2002) Vertical scaleheights of stars and gas in the galaxy, Bull. Astron. Soc. India, **30**, 703.

John, Moncy V.,(2002) Modified de Broglie-Bohm approach to quantum mechanics, Found. Phys. Lett. **15**, 329.

John, Moncy V. , C. Sivakumar and K. Babu Joseph (2003) Classical stochastic approach to cosmology revisited, Pramana J.Phys. **60**, 1.

Samiran Ghosh, T.K. Chaudhury, Susmita Sarkar, **Manoranjan Khan** and M.R. Gupta (2002) Collisionless damping of non-linear dust ion acoustic wave due to dust charge fluctuation, Phys. Rev E, **65**, 037401.

Samiran Ghosh, Susmita Sarkar, **Manoranjan Khan** and M.R. Gupta, (2002 .Effect of non-adiabatic dust charge variation on non-linear dust acoustic waves in presence of non-isothermal ions in a dusty plasma, S Phys. Plasma **9 (4)**, 1150.

Samiran Ghosh, Susmita Sarkar, **Manoranjan Khan** and M.R. Gupta (2002) Ion acoustic shock waves in a collisional dusty plasma, Physics Plasmas **9 (1)**, 378.

Samiran Ghosh, S. Sarkar, **Manoranjan Khan**, M.R. Gupta and K. Avinash (2002) Non-linear acoustic mode at high dust density, Physics Letters A **298**, 49.

Kaushal, R. S. and Parthasarathi (2002) Quantum mechanics of complex Hamiltonian systems in one dimension, Journal of Physics **A**:Math & Gen.**35**, 8743.

Singh, Shweta and **Kaushal, R. S.** (2003) Complex dynamical invariants for one-dimensional classical systems, Physica Scripta **67**, 181.

Kaushal, R. S. (2003) Stability of extended scalar diquark stars vis-à-vis soliton stars, Pramana- Journal of Physics **60**, 1.

R.Ganapathy and **V. C. Kuriakose** (2002) Cross-phase modulational instability in an elliptical birefringent fiber with higher order non-linearity and dispersion, Pramana - J. Phys. **58**, 669.

P. D.Shaju and **V. C. Kuriakose** (2002) Magnetic field driven fluxons in semicircular Josephson junctions, Physica Scripta. **65**, 545.

P. D. Shaju and **V. C. Kuriakose** (2002) Semicircular Josephson Junctions embedded in a magnetic field, Phys. Rev.B. **65**, 214508

Minu Joy and **Kuriakose V. C.** (2002) Role of scalar field in the formation of structure in the universe, Phys. Rev. D. **66**, 024038.

P.D. Shaju and **V. C. Kuriakose** (2002) Fluxon diode using semicircular Josephson junctions, Phys. Lett. A. **299**, 628.

R.Ganapathy and **V. C. Kuriakose** (2002) Soliton pulse compression in a dispersion decreasing ellpitic birefringent fibre with effective gain and effective phase modulation, J. Nonlinear Optical Physics & Materials **11**,185.

P. D. Shaju and **V. C. Kuriakose** (2002) Magnetic field rectifiers using semicircular Josephson junctions, JETP Letters **76**, 11

R.Ganapathy and **V. C. Kuriakose** (2003), Soliton interaction in a dispersion decreasing fiber with effective gain and effective phase modulation, , Chaos, Solitons and Fractals **15**, 99.

P.D.Shaju and **V. C. Kuriakose** (2003) Rectification of harmonically oscillating magnetic fields in quarter circular Josephson junctions, Physica C 383/4, 395.

Lohiya, Daksh (2002) Cosmological tests for a linear coasting cosmology Phys. Lett. B **548**, 12.

Lohiya, Daksh (2002) Fractal dust model of the universe based on Mandelbrot's conditional cosmological principle, J. Fractals, **11**, 1.

Lohiya, Daksh (2002) A freely coasting universe, Spacetime & Substance **4(14)** 152 .

Lohiya, Daksh (2002), From fractal cosmography to fractal cosmology, Spacetime & Substance, **3(8)** 104.

Bhattacharya, S. K., **Paul S. N**. and **Mondal, K. K**.(2002) On the study of instability of ion-acoustic waves in relativistic plasma: Unbounded and bounded, Phys. Plasmas, **9**(11) 4439.

Mittal, A. K. and **T. R. Seshadri** (2002) Fractals and the large-scale structure in the universe: Is the cosmological principle valid?, Resonance, **7**, 39.

Mukherjee, S. and R. Tavakol (2002) Singular instantons in higher derivative theories, Phys. Rev. **D65**, 064, 064020.

Sharma, R**., S. Mukherjee**, **M. Dey** and **J. Dey** (2002) A general relativistic model for SAX J 1808.4 - 3658, Mod. Phys. Letter **A17**, 827.

Sharma, R., and **S. Mukherjee** (2002) Compact stars: A core-envelop , Mod. Phys. Letters **A17**, 2535**S.**

Mukherjee, S. and **B. C. Paul**, Gravitational instantons: Recent developments, Mod.Phys.Lett **A17**, 1123.

Govinder, M., K. S. Govinder, S. D. Maharaj, R. Sharma, **S. Mukherjee** and T. K. Dey, (2003) Radiating spherical collapse with heat flow, Int.Journal of Mod. Phys, **D12**, 667.

Nandi, K.K. and Y. Z. Zhang, (2002) General relativistic effects on quantum interference and the principle of equivalence, Phys.Rev. **D66**, 063005.

Nandi, K.K, Y.Z. Zhang, P.M.Alsing, J.C.Evans and A.Bhadra (2003) Analogue of the Fizeau effect in an effective optical medium, Phys. Rev. **D67**, 025002.

Philip, N.S. and K. Babu Joseph (2002) Adaptive basis function for artificial neural networks, Neurocomputing, **47**, 1-4,.21-34.

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

Philip, N. S., Yogesh Wadadekar, Ajit Kembhavi and K. Babu Joseph (2002) A difference boosting neural network for automated classification, Astronomy and Astrophysics **385 (3)**, 1119.

S. C. Odewahn, S. H. Coher, R. A. Windhorst and **Philip, N. S.** (2002), Automated galaxy morphology: A Fourier approach, Astronomical Journal , **568,** 539.

Ajith Abraham, **Philip N. S.** and P. Saratchandran (2003) Modeling chaotic behavior of stock indices using intelligent paradigms, International Journal of Neural, Parallel & Scientific Computations, **11**, issues 1 & 2, 143.

Mishra K. N. and **Chakraborty** D. K. (2002) A study of stability of rotating fluid disks using a variational principle, Astrophys and Sp. Sc., **282,** 527.

Huitu, K., Laamanen, J. and **Pandita, P. N.** (2002) Particle spectrum and constraints in anomaly mediated supersymmetry breaking models, Phys. Rev. **D65**, 115003.

Paul, B. C. and Arindam Saha (2002) Probability for primordial black holes in a higher derivative theories Int. J. Mod. Phys. **D 11**, 493.

Paul, B. C. and **S. Chakraborty** (2002) Inflation field and Primordial black hole, Int. J. Mod. Phys. D **11**,1435.

Paul, B.C., **S. Mukherjee** and R. Tavakol (2002) Singular Instantons in higher derivative theories Phys. Rev. D **65** 064020.

Paul, B. C. (2002) Inflation in Bianchi models and the cosmic no-hair theorem in brane-world, Phys. Rev. D **66** 124019.

Paul, B. C. and **S. Mukherjee** (2002) Gravitational Instantons-Recent developments Mod. Phys. Lett. A **17** 1123.

Patil, K.D. (2003) Structure of radial null geodesics in higher dimensional dust collapse , Phys. Rev. **D67,** 04017.

Patil, K.D. (2003) Gravitational collapse in higher dimensional charged – Vaidya spacetime, PRAMANA, **60**,.3,1.

Pradhan, A. and Vishwakarma, A. K. (2002) A new class of LRS Bianchi type-I cosmological models with perfect fluid, Indian J. Pure Appl. Math., **33** (8), 1239.

Pradhan, A., Yadav, V. K. and Saste, N. N. (2002) Plane-symmetric inhomogeneous viscous fluid cosmological models with electromagnetic field, Int. J. Mod. Phys. D, **11** (6), 857.

Pradhan, A. and Yadav, V. K. (2002) Bulk viscous anisotropic cosmological models with variable G and Lambda, Int. J. Mod. Phys. D, **11** (6), 893.

Pradhan, A. and Pandey, H. R. (2002) Plane symmetric cosmological models in the presence of zero-mass scalar fields, Spacetime & Substance, **3** (12), 76.

Pradhan, A. and Vishwakarma, A. K. (2002) LRS Bianchi type-I cosmological models in Barber's second self creation theory, Int. J. Mod. Phys. D, **11** (8), 1195.

Pradhan, A. and Aotemshi, I. (2002) Bulk viscous solutions to the field equations and the deceleration parameter revisited, Int. J. Mod. Phys. D, **11** (9), 1419.

Pradhan, A. and Pandey, O. P. (2002) Conformally flat spherically symmetric cosmological models revisited, Spacetime & Substance, **4** (14), 169.

Rao, P. Vivekananda and P. Radhika (2002) Long-term study of the starspot a ctivity on the eclipsing short-period RS Canum Venaticorum star UV Piscium, Astrophysics & Space Science, **282**, 103.

Rao, P. Vivekananda and P. Radhika, (2003), UV Piscium and the radiative flux scale, Astrophysics & Space Science, **283**, 225.

Rao, P. Vivekananda and J. Rukmini (2002) Photometric study of two W UMA-type systems in the intermediate age open cluster Be 33, Bull. Astron. Soc. India, **30**, 665

Rahaman, Farook., S.Chakraborty and J.Bera (2002) Inhomogeneous cosmological model in Lyra geometry, Int. J. Mod. Phys. D **11**,1501.

Rahaman, Farook., S.Chakraborty, M.Kalam and Nuovo Cimento (2002) Global monopole in higher dimensional space time, **F 116B**, 1213.

Rahaman, Farook, S .Chakraborty and M.Kalam (2002) A study of thin domain wall with spherical symmetry, Ast. Sp. Sc. **282**,391.

Rahaman, Farook (2002) Higher dimensional domain wall in Lyra geometry, Ast. Sp. Sc. **282**, 625.

Rahaman, Farook, **S. Chakraborty**, N.Begum, M.Hossein and M.Kalam **(2002)** A study of four and higher dimensional cosmological models in Lyra geometry, Fizika B **11**, 57.

Rahaman, Farook., S. Das, K. Maity, and M. Kalam (2002) Gravitational field of global monopole in Einstein-Cartan theory, Nuovo Cimento, **117B**, 633.

Rahaman, Farook and S.Mal (2002) Global monopole in Einstein-Cartan theory based on Lyra geometry, Fizika, B **11**,149.

Rahaman, Farook (2002) Higher dimensional global monopole in Lyra geometry, Fizika, B **11**, 223.

Rahaman, Farook (2003) A study of global monopoles in higher dimensional spacetime. Ast. Sp. Sc. **283**,33.

Rahaman, Farook (2003) Super conducting cosmic string in Lyra geometry. Mod.Phys.Lett A 18,41.

Rahaman Farook., N.Chakraborty, S.B.D.Choudhury, R.Mukherji and S.Das (2003) Dilatonic black holes and test particles. Czech J. Phys. 53, 115.

Rahaman, Farook. (2003) Semi classical gravitational effects around global monopole in Lyra geometry, Ast. Sp. Sc. **283**, 151.

Reddy, R.R., Nazeer Ahammed, Y, Sasikala Devi, B, Rama Gopal, K, Abdul Azeem, P and Rao T.V.R.(2002) Spectroscopic studies and Astrophysically interesting TaO, TaS, ZrS and SiO^+ molecules, Astrophysics and Space Science, **281**, 729.

Reddy, R.R., Nazeer Ahammed, Rama Gopal, K, Abdul Azeem, P, Rao T.V.R , Buddhudu, S and Sooraj Hussain, N. (2002) Spectral properties of Eu^{3+}: B_2O_3-AlF_3-RF glasses, JQSRT **75**, 507.

Reddy, R.R., Nazeer Ahammed, Rama Gopal, K, Abdul Azeem, P, Rao T.V.R. (2002) Opto-electronic properties of semiconductors and alkali halides, Indian Journal of Pure & Applied Physics **40**, 471.

Reddy, R.R., Nazeer Ahammed, Rama Gopal, K, Abdul Azeem, P, Rao T.V.R., Sreenivasulu, R, Peeran, S.G., Murthy, K.N.V., Badarinath, K.V.S. (2002) Seasonal and diurnal variation in the levels of NOx and CO trace gases at Anantapur in Andhra Pradesh, J. Ind. Geophys. Union, **6**, 163.

Reddy, R.R., Nazeer Ahammed, Rama Gopal, K, Abdul Azeem, P, Rao T.V.R., Sreenivasulu, R, Peeran, S.G., Murthy, K.N.V., Sunitha, K. and Sreedhar B. (2002) Air space polltants CO and NOx levels at Anantpur (semi-arid zone), Andhra Pradesh, J. Ind. Geophys. Union, **6**, 151.

Reddy, R.R., Nazeer Ahammed, Rama Gopal, K, Abdul Azeem, P, Rao T.V.R., Sasikala Devi, B, Behere, S.H., (2003) On the equivalence between Clausisus-Mossotti and optical electronegativity, Optical Materials, **22**, 7.

Reddy, R.R., Nazeer Ahammed, Rama Gopal, K, Abdul Azeem, P, Rao T.V.R. (2003) Absorption and Emission spectral studies of Sm^{3+} and Dy^{3+} doped alkali

fluoroborate glasses, JQSRT, **77**, 149.

Sami, M., Pravabati Chingangbam and Tabish Qureshi (2002) Aspects of tachyonic inflation with exponential potential, Phys. Rev. **D, 66** 043530.

Sami, M. (2003) Implementing power law inflation with tachyon rolling on the brane: Mod. Phys. Lett. A, **18** 691.

Sami, M. (2003) A Note on the cosmological dynamics in finite-range gravity, Int. Jour. Mod. Phys. D, **12** 689

Singh, G. P., R.V. Deshpande and T. Singh (2002) Viscous cosmological models with particle creation in Brans-Dicke theory, Astrophysics and Space Science, **282**, 489.

Srivastava, S. K. (2003) Riccion from higher-dimensional space-time with D-dimensional sphere as a compact manifold and one-loop renormalization, Pramana, **60(1)**,29.

Singh N. S., S. Naik, B. Paul, P.C. Agrawal, A.R. Rao and. **Singh, K.Y.** (2002) New measurements of orbital period change in Cygnus X-3, Astron. Astrophys. **392**, 161.

P. K. Suresh (2002) Oscillatory phase of inflation and power-law expansion in Bianchi type –I universe. Int. J. Theor. Phys. **41**,1347.

R.C. Verma and A.C.Sharma (2002) Quark Diagram Analysis of Weak Hadronic Decays of Bc Meson, Phys. Rev. D 65 114007.

B.S. Bains and **R.C. Verma**, (2002) Reanalysis of baryon magnetic moments using the effective mass and screened charge of quarks, Phys. Rev. D **66,** 114008

(b) Proceedings:

Dwivedi B. N., A. Mohan and E. Landi (2002) EUV plasma diagnostics for nitrogen-like ions from spectra obtained by SUMER/*SOHO* European Space Agency (ESA), **SP-505**, 397

Paul, B.C. S.Mukherjee and R. Tavakol (2002) Instantons in higher derivative theories in IAU 8th Asian-Pacific Regional Meeting (Astronomical Soc., Japan) Vol. II, eds. : S. Ikeuchi, J. Hearnshu and T. Hanwa, 313.

R. C. Verma (2002), Pascual Jordan: Unsung hero of quantum mechanics, Bull. Indian Association of Physics Teachers (IAPT), **19,** 260.

(c) Books Edited:

A. Zafar (2003) Vector Analysis, : Pragati Prakashan, Meerut (with M. A. Pathan)

V. C. Kuriakose (2003) Optcal solitons: Theoretical and Experimental Challenges, with. K.Porsezian Springer – Verlag, Berlin.

Kaushal, R. S. (2003) Structural Analogies in Understanding Nature, Anamaya Publishers, New Delhi pp 194.

(c) Supervision of thesis

Goyal Ashok K., Applications of QFT to astro-particle physics and cosmology, November 2002, University of Delhi, Ph. D. thesis of Meenu Dahiya.

Goyak Ashok K. and J. D. Anand, Effect of strong magnetic field and applications to astrophysics, December 2002, University of Delhi, Ph. D. thesis of Kanupriya Goswami.

(IV) PEDAGOGICAL ACTIVITIES

(a) IUCAA-NCRA Graduate School

S. V. Dhurandhar: Mathematical Methods of Physics I

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

Ranjeev Misra: Electrodynamics and Radiative Processes II

Sami Mohemmad: Quantum and Statistical Mechanics II

Tarun Souradeep: Methods of Mathematical Physics -II

Varun Sahni: Cosmology

R. Srianand: Extragalactic Astronomy

K. Subramanian: Galaxies: Structure, Dynamics and Evolution

K. Subramanian: Quantum and Statistical Mechanics I

S. N. Tandon: Introduction to Astronomy and Astrophysics I

Tutorial Assistanceship

Harvinder K. Jassal: Quantum Mechanics

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

Naresh Dadhich: Astronomy and Astrophysics II

Ranjan Gupta: Astronomy and Astrophysics I, Theory and Laboratory Course for the Pune University (for Physics Department and Space Science Department). (40 theory lectures and a set of 10 laboratory and night experiments.)

J. V. Narlikar: Astronomy and Astrophysics II

c) Supervision of Projects

Tapas K. Das

Jayant K. Pendharkar (M.Sc. Astronomy, Osmania University).
Multi-transonic shocked isothermal blackhole accretion discs

Ashis K. Lal. (M.Sc. Mathematics, Lucknow University).
Bondi accretion on to compact objects.

Sanjeev Dhurandhar

M.Sc. Projects

Ajith Parameswaran (Mahatma Gandhi University, Kottayam)
General relativity and gravitational waves.

Anirban Saha (Physics Department, Pune University)
General relativity and gravitational waves.

A. K. Kembhavi

Nicolas Druguet, ESPEO, France
Image Processing

Julie Magri, ENSPG, France
Blackholes in galaxies

Julian Grain, ENSPG, France
Knots in X-ray jets

Sameer Pillai, VJTI, Mumbai
Husefa Rangwala, VJTI, Mumbai
Devang Thakkar, VJTI, Mumbai
Mihir Shah, VJTI, Mumbai
Jayant Gupchup, VJTI, Mumbai
Application of data mining techniques to the Tycho catalogue

B. Mukhopadhyay

Shubhrangshu Ghosh, (M.Sc., IIT Kharagpur)

Pseudo-general relativistic solution of accretion disk around rotating compact objects

Ranjeev Misra

K. Sriram (VSP)
Flux enhancement in the inner region of a geometrically and optically thick accretion disk.

(jointly with H. K. Jassal)

Madhura A. Gokhale (Pune University, M. Sc.)
Computation of observed emission from regions near a blackhole

T. Padmanabhan

Yann Michel (Ecole Normale Superieure, Paris, France)
Structure formation and early universe

A. Paranjpye

Nidhi Mehta (FinalYear BSc, Fergusson College)
Observations of Transient Phenomenon in Astronomy

Swati Shinde (Final Year B.Sc, Garware College)
Observations of Transient Phenomenon in Astronomy

A.N. Ramaprakash

Koshy George (Mahatma Gandhi University, Kerala)
Missing GRB optical afterglows

Tarun Souradeep

Amir Hajian, IUCAA graduate student.

Statistical isotropy of cosmic microwave background anisotropy

Jeremie Lasue (M. Sc. Project for Ecole Polytechnique)
Reconstructing the inflaton potential of the early Universe

Amir Reza Aghamousa (M.Sc., University of Pune)
'Rapid Computation of CMB correlations

R. Srianand

Hum Chand Verma, (IUCAA graduate student)
Probing the evolution of fine-structure constant using QSO absorption lines

Neeraj Gupta (NCRA) Reading project,
Chemical enrichment at very high redshift,

P. Subramanian

Vivek Rane, (Garware College: M.Sc.)
Measurements on flux tope coronal mass ejections from the Sun

Ranjit Chavan, (Garware College : M.Sc.)
Measurements on flux tope coronal mass ejections from the Sun

Chaitanya Sakhare, (S. P. College: B.Sc.)
Energetics of coronal mass ejections from the Sun

Kalyani Date and Sayali, (Fergusson College: B.Sc.)
Sunspot observations and correlation with solar activity indices

K. Subramanian

Saurav Chatterjee (VSP)
Galaxy Formation.

S. N. Tandon

Moinakhtar Shaikh, Amish Shaha and Gautam Aggrawal
(Bharati Vidyapeeth's College of Engineering, Pune, B.E.)
Auto guider for telescope

J. V. Narlikar

Akshay Kulkarni (VSP)
Newtonian gravitation and special relativity (I)

Shuchita Srivastava (VSP)
Newtonian gravitation and special relativity (II)

Garima Saxena (VSRP)
Spectral shifts in astronomy

D.V. Brahmanathakar (VSRP)
Redshifts and luminosity distance

J.R. Senthil M. Ram (VSRP)
Models in newtonian cosmology

(V) IUCAA COLLOQUIA, SEMINARS, ETC.

(a) Colloquia

Ravi Kulkarni: *Ideal boundary of Lorentz Surfaces*, April 29.

K. P. Singh: *Telescopes for X-ray astronomy*, June 10.

Varun Sahni: *The riddle of dark energy*, December 17.

Mark Whittle: *Blakholes in galaxy nuclei: Recent developments*, January 6.

J. V. Narlikar: *Facts and speculations in cosmology*, January 30.

(b) Seminars

Sukratu Barve: *Quantum stress tensor on Cauchy horizons*, April 4.

B. J. Ahmedov: *Electromagnetic fields of magentized neutron stars in general relativity*, May 13.

Ninan Sajeeth Philip: *An introduction to machine learning tools*, May 16.

K. Indulekha: *Formation of bound open clusters in galaxies*, May 30.

Subenoy Chakraborty: *Asymptotic behaviour of homogeneous cosmological models*, May 31.

Sandeep Sahijpal: *Our Solar system: The origin and the last nucleosynthesis(?)*, June 6.

V. K. Gupta: *Radial oscillations of hybrid stars*, June 13.

Pushpa Khare : *Gravitational lensing and the CDM model of the universe*, June 17.

A. Banerjee: *Fluid spheres with heat flux and the junction conditions*, June 18.

T. R. Seshadri: *Nature of galaxy clustering and the transition to homogeneous distribution*, June 19.

Pavan Chakraborty: *Spectropolarimetry at VBT*, July 16.

N. D. Hari Dass: *Emergence of the microcanonical distribution from a pure quantum state*, July 18.

Hum Chand: *Probing the time variation of fine structure constant using QSOs absorption lines*, August 2.

Amir Hajian: *Statistical isotropy of the cosmic microwave background anisotropy*, August 2.

A. A. Zdziarski: *Spectral correlation in accreting black holes*, September 23.

Sanjit Mitra: *Quantum gravity at small distances*, October 3.

T. R. Govindarajan: *Non-commutative spacetime and quantum gravity*, October 16.

T.P. Singh: *Classical and quantum aspects of gravitational collapse*, October 17.

W. C. Saslaw: *Galaxy clustering and statistical mechanics*, November 15.

Sergei Shandarin : *Quantitative morphology for large scale structure and the cosmic microwave background*, November 19.

Tulsi Dass: *Probability-dynamics unification, noncommutative geometry and autonomous formalism for quantum mechanics*, December 5.

Uriel Frisch: *Reconstructing the initial conditions of our universe by optimal mass transportation*, December 23.

Anvar Shukurov: *Simulations of the multi-phase interstellar medium*, December 26.

David John Vikas Rosario: *The interaction between radio jets and the ISM in Seyfert galaxies*, January 7.

Jogesh Babu: *Statistical and computational challenges for the virtual obsevatory*, January 8.

J. Maharana: *Symmetries of axion-dilaton string cosmology*, January 9.

Gargi Shaw: *Molecular hydrogen in photo-dissociation region*, January 10.

Bruno Guiderdoni: *Modelling hierarchical galaxy formation with the hybrid approach: The GalICS project*, January 16.

Hasi Ray: *Positron and positronium physics*, January 23.

A. N. Ramaprakash: *Cambridge infrared panoramic survey spectrograph*, March 20.

(c) IDG Talks

Joydeep Bagchi: *A star in a 15.2-year orbit around the supermassive black hole at the centre of the milky Way,* April 4.

Ranjeev Misra: *Ultra-luminous x-ray sources: A new kind of blackhole system*, April 12.

Prasad Subramanian: *X-ray/Gamma ray flares from hardonic jets in AGN*, April 26.

S. Sridhar: *Stars and singularities: Stellar phenomena near a massive blackhole*, May 10.

A.K.Kembhavi: *Chandra observations of x-ray jets*, July 12.

R. Srianand: *Oxygen Abundance in the low density IGM*, July 26.

T.R. Choudhury: *Constraints on reionization from thermal history of the IGM*, August 23.

Jatush Sheth: *Hot bubbles from active galactic nuclei as a heat source in cooling-flow clusters*, September 13.

Rajesh Nayak: *Sensitivity of the Laser Interferometer Gravitational Wave Observatory to a stochastic background, and its dependence on the detector orientations*, September 27.

D. V. Ahluwalia: *Quantum tower of Pisa*, October 25.

Varun Sahni: *Braneworld Cosmology*, October 25.

Jayant Narlikar: *The case for non-velocity redshifts in normal galaxies*, November 22.

Prasad Subramanian: *Coronal Mass Ejections (CMEs) from the Sun: Energy budgets*, January 17.

Parampreet Singh: *The Pre Big Bang Scenario in String Cosmology*, February 21.

M. Sami: *Cosmological aspects of rolling Tachyons*, January 31.

Tarun Souradeep: *Cosmic Microwave Background anisotropy results from WMAP*, March 7.

Sanjeev Dhurandhar: *Time delay Interferometry for LISA*, March 7.

(d) MAHFIL (Mid-Day Astronomy Hour for Interaction and Lunch)

R. Nityananda B. Ahmedov T. Padmanabhan	) April 10
A.K. Mittal K.P. Harikrishnan Banibrata Mukhopadhyay	) May 15
M. Sami Asit Banerjee T.R. Seshadri	) June 19
D.V. Ahluwalia R. Ramakrishna Reddy Mark Whittle	) October 16
S.V. Dhurandhar Farooq Ahmad P. Gopakumar	) November 20
Jishnu Dey Alexei Starobinsky Arun Mangalam	) January 22
Tulsi Dass R.G. Vishwakarma S.N. Tandon	) February 19
Abhijit Bhattacharyya Pavan Chakraborty N.K. Dadhich	) March 26

(VI) TALKS AT IUCAA WORKSHOPS OR AT OTHER INSTITUTIONS

(a) Seminars, Colloquia and Lectures

Tirthankar Roy Choudhury

Probing reionization with redshift distribution of gamma ray bursts, IUCAA-Delhi University Workshop on Large-scale Structures and the CMBR, Department of Physics, University of Delhi, November.

Physics of structure formation in the universe, XXIInd Meeting of the Astronomical Society of India, Thiruvananthapuram, February.

A theoetician's analysis of the supernova data and the limitations in determining the nature of dark energy, IFA-IUCAA workshop, IUCAA, February.

Naresh Dadhich

Relativistic world: A common sense perspective, Shiraz University, Iran, May 15.

Subtle is the gravity - I, Institute of Advanced Study in Basic Sciences (IASBS), Zanjan, May 20.

Field equations from the particle equation of motion, IASBS, May 21.

Subtle is the gravity - II, IASBS, May 22.

From Newton to Einstein: Holding light's finger, IUCAA Summer School, June 6.

Field equations from the relativistic law of motion, University of South Africa, Pretoria, July 29.

Subtle is the gravity, Institute of Nuclear Physics, Tashkent, August 27.

Einsteinian gravity, University of Samarkand, August 28.

Einsteinian gravity, Astronomical Institute, Tashkent, September 2.

Field equations from the particle equation of motion, University of Tashkent, September 2.

Localization of gravity on FRW brane, Invited talk in the Conference of Institute of Cosmology and Gravitation, University of Portsmouth, September 16

Localization of gravity on FRW brane, DAMTP, Cambridge University, September 21.

Gravitation, Fergusson College, Pune, and Panel Discussion, December 28.

Planck length and gravity, FTAG-III, Kochi, January 23-29.

Gravitational field of a gravitational dyon, IMSc, Chennai, March 3.

Relativity for everyone, Physics Department, Utkal University, Bhubaneswar, March 6.

Localization of gravity on the FRW brane, IOP, Bhubaneswar, March 7.

Tapas K. Das

Shock formation in blackhole accretion and related phenomena, Racah Institute of Physics, The Hebrew University of Jerusalem, Israel, May 5.

How massive BHs feed the AGN, Colloquium presented at the Indian Institute of Technology, Kanpur, India, August 9.

Shock formation in BH accretion and related phenomena, Indian Institute of Technology, Kanpur, India. August 11.

Theory of blackhole accretion and related phenomenon, Department of Physics and Astrophysics, University of Delhi, September 5.

S. V. Dhurandhar

Mathematical structures underlying LISA data analysis, Albert Einstein Institute, Max Planck, Potsdam, Germany, June 6.

Gravitational wave astronomy: A new window to the universe, Meeting of the Indian Academy of Sciences, I.I.Sc., Bangalore, July 6.

Extended hierarchical search for compact inspiraling binaries, LSC meeting at Hanford, USA, August 20.

Algebraic methods in LISA data analysis, Physics Department, Caltech, Pasadena, U. S. A. September 3.

A faster implementation of the hierarchical search for compact inspiraling binaries, Gravitational Wave Data Analysis Workshop, Kyoto, Japan, December 19.

LISA data analysis, Physics Department, Osaka University, Osaka, Japan, December 20.

Mathematical structures in LISA data analysis, Physics

Department, Kyoto University, Japan, December 21.

Gravitational waves: A new window to the universe, Workshop on Frontiers in astronomy in the Science Congress 2003 meeting, Bangalore, January 6.

Gravitational wave astronomy, Workshop on Frontiers in Astronomy and Astrophysics, Tech Fest , IIT, Mumbai, February 2.

Ranjan Gupta

Basics of spectroscopy and *spectroscopic applications for Small telescopes* , Workshop on Astronomy with Small Telescopes at IUCAA, Pune, January 6-10.

New results with T-Matrix calculations on interstellar extinction, Kobe University, Japan, March 14.

H.K. Jassal

Study of tachyon cosmology, Workshop on Early Universe, Large Scale Structure and the Cosmic Microwave Background Radiation, University of Delhi, November 20.

Cosmology with tachyon field as dark energy, IX International Symposium on Particles, Strings and Cosmology (PASCOS'03), Tata Institute of Fundamental Research, Mumbai, January 5.

Tachyon field in cosmology: dark energy or dark matter, Workshop in Field Theoretic Aspects of Gravity (FTAG-III), Cochin University of Science and Technology, Kochi, January 25.

Ajit Kembhavi

The fundamental and photometric plane of galaxies, Pontificia Universidad Catolica de Chile, Santiago, April 29.

Virtual Observatory- A new concept, National Technology Day, IUCAA, May 11.

Design of V table manipulation tools, Towards and International Virtual Observatory Conference, European Southern Observatory, Garching, June 12.

Fundamentals and photometric plane of galaxies, Astronomical Observatory, University of Padova, Italy, June 25.

Galaxy hyperplane, The University of Birmingham, School of Physics and Astronomy, U.K., June 27.

Physics and astrophysics in India, Institute of Nuclear Physics, Tashkent, Uzbekistan, August 27.

Supermassive blackholes in galaxies, University of Samarkhand, Uzbekistan, August 30.

.*Supermassive blackholes in galaxies*, Institute of Astronomy, Uzbekistan, September 3.

The UGC Consortium: *User perspectives and new issues,* Indian Institute of Astrophysics, Bangalore, "*Sharing of E-journals through Consortia in Indian Libraries*", November 28.

Stars, Introductory School on Astronomy and Astrophysics, Fergusson College, Pune, November 29.

Elements of photometry, Workshop on Astronomy with Small Telescopes, IUCAA, January 6.

Noise in detection, Workshop on Astronomy with Small Telescopes, IUCAA, January 7.

Virtual Observatory, Humboldt Colloquium, Alibag, January 18.

Virtual Observatory, Tech Fest 2003, IIT, Mumbai, February 1.

Supermassive blackholes astrophysics and contribution of aryabhata, etc., Bhartiya Sanskriti Sangam, Pune, February 17.

Professional literature for Indian universities - A new initiative by the University Grants Commission, Mapping of Technology on Libraries and People, INFLIBNET, Ahmedabad, February 14.

Galaxy surface photometry, IUCAA-IFA (Hawaii) Workshop on Cosmology and the High Redshift Universe, February 10.

Virtual Observatory, Department of Chemistry, University of Pune, March 1.

An office automation model, Executive Development Programme for Senior Administrative Staff, GMRT, Khodad, March 7.

Variation of fundamental constants, S. N. Bose Centre, Kolkata, February 21

Ranjeev Misra

Flux enhancement in the inner region of a geometrically and optically thick accretion disk, Workshop on Light from Blackholes, Kathmandu, Nepal, October 4.

Accretion disks in blackholes systems, at Maharaja College, Kochi, Kerala, October 10.

Observational evidence for blackholes, at Cochin University of r Science and Technology (CUSAT), Kochi, Kerala , October 11.

B. Mukhopadhyay

Pseudo-Newtonian potentials and its application in accretion disk around rotating compact objects, Tata Institute of Fundamental Research, Mumbai, October 1.

Pseudo-Newtonian potentials and its application in accretion disk around rotating compact objects, 22nd Meeting of the IAGRG, IUCAA, Pune, December (11-14)

Neutrino-antineutrino asymmetry around rotating blackhole , 9th International Symposium on Particles, Strings and Cosmology (PASCOS), TIFR, Mumbai, January (3-8)

J. V. Narlikar

Alternative ideas in cosmology, "New Frontiers of Astronomy" held in memory of Professor Sir Fred Hoyle, St. John's College, U.K., April 16.

Facts and speculations in cosmology, Tata Institute of Fundamental Research, Mumbai, June 7.

Work with Fred on action at a distance, Conference held in memory of Professor Sir Fred Hoyle, Cardiff University, U.K., June 25.

A balloon experiment to detect microorganisms in the outer space, Conference held in memory of Professor Sir Fred Hoyle, Cardiff University, U.K., June 26.

Facts and speculations in cosmology, School of Physics and Astronomy, University of Birmingham, U.K., July 3.

Time travel , Department of Physics and Astronomy, University of Kentucky, U.S.A., September 12.

Facts and speculations in cosmology, Department of Physics and Astronomy, University of Kentucky, U.S.A., September 13

Facts and speculations in cosmology, Department of Physics, Syracuse University, U.S.A., September 19

Physics astronomy frontier, Department of Physics, Dibrugarh University, November 8.

Some unsolved problems in astronomy and astrophysics , Third Regional Conference of the Physics Association of the North-East, Physics Department, Dibrugarh University, November 9.

Searches for extra-terrestrial life, Indian Institute of Technology, Kharagpur, November 12.

Standard cosmology and alternatives: A critical review 22nd Meeting of the Indian Association for General Relativity and Gravitation held at IUCAA, Pune, December 11)

Some great teachers who taught me, Conference on "Assessment and Accreditation of Teacher Education Institutions - A Development-oriented Process", organized by National Assessment and Accreditation Council, Bangalore and hosted by University of Pune, December 22.

Quasi steady state cosmology, Workshop on Cosmology and the High Redshift Universe, IUCAA, Pune, February 11.

The energy problem of cosmic sources, Mumbai University, February 21.

Anomalous phenomena in astronomy, AKR 80 Meeting, Jadhavur University, Kolkata, February 22.

Rajesh Nayak

Gravitational wave astronomy with LISA, IIA Bangalore, January 3.

T. Padmanabhan

Gravity from the thermodynamics of spacetime, Conference on Fred Hoyle's Universe, Cardiff, UK, June 25.

Atoms of spacetime, University of Portsmouth, UK, June 28.

Gravity from spacetime thermodynamics, RRI Bangalore, October 10.

Cosmological constant and the dark energy I and II in Large-Scale Structures and the CMBR, IUCAA-Delhi University workshop, Department of Physics, University of Delhi, (2 lectures), November (16 - 20).

Introducing the universe, Introductory School on Astronomy and Astrophysics, Fergusson College, Pune, November (16 - 20).

Special and general relativity, Introductory School on Astronomy and Astrophysics, Fergusson College, Pune, November.

Action functional and dynamics of gravity, XXII Meeting of the Indian Association for General Relativity and Gravitation, IUCAA, Pune, December 12.

Action functional and dynamics of gravity: a new perspective, Workshop on Field Theoretic Aspects of Gravity - III, CUSAT, Cochin, January 27.

Cosmological constant - Why is it the theoretician's nightmare?, Workshop on Cosmology and The High Redshift Universe, IUCAA, Pune, February 8.

Action principle for gravity - A new thermodynamic perspective, IMSc Chennai, February 18.

Action Principle in gravity: A thermodynamic perspective, HRI, Allahabad, March 12.

The darker side of the universe, HRI, Allahabad, March 12.

Issues in statistical mechanics of gravitating systems, HRI, Allahabad, March 13.

A. N. Ramaprakash

Gamma-ray bursts, IUCAA-NCRA VSP/VSRP, June 7.

Near infrared integral field spectroscopy on large telescopes, 22nd Meeting of the Astronomical Society of India, Thiruvananthapuram, Kerala, February (13 -15).

IUCAA telescope project update, 22nd Meeting of the Astronomical Society of India, Thiruvananthapuram, Kerala, February (13 -15).

Varun Sahni

Exploring dark energy using the Statefinder, On the nature of dark energy: Observational and theoretical results on the accelerating universe, Institute d'Astrophysique de Paris, France, July (1-5)

Dark energy.SF02 cosmology, Summer Workshop, Santa Fe, USA, July (8-27).

The cosmological constant problem and dark energy, Institute of Astronomy, Cambridge, UK, August

The Case for dark energy, National Conference on Theoretical PhysicsIndian Association for the Cultivation of Science, Calcutta, India, January (21-24)

Observational cosmology, XV DAE Symposium on High Energy Physics,University of Jammu, November (11-15)

S. K. Sahay

Search for continuous gravitational wave sources, 22nd Meeting of Indian Association of General Relativity and Gravitation, IUCAA, Pune, December (11-14).

Search for continuous gravitational wave sources, Raman Research Institute, Bangalore, March 10.

M. Sami

Rolling tachyon cosmology in IXth International Symposium on Particles, Strings and Cosmology (PASCOS '03) , TIFR, Mumbai, January (3-8).

Tarun Souradeep

First decade of CMB anisotropy measurements, Acceptance talk at N.S. Satyamurthy award at GB meeeting of Indian Physics Association, April 9.

Statistical isotropy of the Cosmic Microwave Background, International meeting on Particle, Strings and Cosmology (PASCOS-03), TIFR, Mumbai, January (3-8).

Cosmic Microwave Background Anisotropy: the first decade, Talk for N.S. Satyamurthy award (Indian Physics Association), February 24

CMB Anisotropy: from COBE to WMAP, Special Colloquium at the Tata Institute for Fundamental Research, Mumbai, February 25

Cosmological parameters from CMB anisotropy, XXII meeting of ASI, Thiruvananthapuram, February 15.

Cosmic Microwave Background Anisotropy, IUCAA-IFA (Hawaii) worksho on Cosmology and the High Redshift Unvierse, February (8-12)

Jatush Sheth

Sheets or Filaments? - A quantitative investigation of the morphology of the cosmic web using SURFGEN, IUCAA-IFA (Hawaii) workshop on Cosmology and the High Redshift Universe, February (8 -12)

Parampreet Singh

Localized gravity on FRW branes, IAGRG XXII, IUCAA, Pune, December 11.

Dynamics of extended objects in GR - from action to phases, FTAG III, Kochi, January 24.

R. Srianand

QSO and absorption lines, Department of Astronomy, Osmania university, Hyderabad, March (5-6), (2 lectures).

Probing the universe with QSO absorption lines, Colloquium given at TIFR, Mumbai, August 7.

Star formation in proto-galaxies, Vainu Bappu Symposium, IIA, Bangalore, August 10.

Galaxies and QSOs, Introductory School on Astronomy and Astrophysics, Fergusson College, Pune, November (16 - 20)

AGN and QSOs, IIT, Mumbai, February.

H_2 molecules at high redshift, IUCAA-IFA (Hawaii) workshop on Cosmology and the High Redshift Universe, February (8 -12).

Milkyway our galaxy, Fergusson College, Pune, February.

K. Subramanian

Magnetic helicity in galactic dynamos, The 21st Meeting of the Astronomical Society of India, IUCAA, Pune, February (5-8)

Galactic and cosmic magnetic fields, MPA/Ringberg workshop on Dark matter, Cosmic structure and the Early Universe, Ringberg Castle, Bavaria, Germany, April 10.

Cosmic magnetic fields and the CMB, Max-Planck-Institute for Astrophysics, Munich, Germany, April 30.

Magnetic helicity in galaxies: What is it and what is it bad for?, Max-Planck-Institute for Radio Astronomy, Bonn, Germany, May 8.

Magnetic fields, IUCAA-NCRA Summer School/VSP, June (10- 11) (2 lectures)

CMBR anisotropy and polarization IUCAA -Delhi University Workshop on Large Scale Structures and the CMBR, 2002, University of Delhi, November (17-18) ,(2 lectures).

Cosmic microwave background anisotropies from primordial magnetic fields, Indian Institute of Science, Bangalore, January 29.

Magnetic helicity: What is it and what is it bad for?, Raman Research Institute, Bangalore, January 31.

Magnetic helicity: What is it and what is it bad for? IUCAA Workshop on Cosmology and the High Redshift Universe, IUCAA, February 9

P. Subramanian

Our Sun (2 lectures) Introductory School in Astronomy and Astrophysics, December 17 - 21.

Coronal mass ejections from the Sun: Energetics', at the Annual Meeting of the Astronomical Society of India, Thiruvananthapuram, February (13 - 15).

S. N. Tandon

Tools of an astronomer, Introductory School on Astronomy and Astrophysics, Fergusson College, Pune, November (26-28).

R. G. Vishwakarma

Is the universe really accelerating?", 22nd Meeting of IAGRG, IUCAA , Pune, December (11-14).

Interpretation of the observations in a decelerating universe", IUCAA-IFA (Hawaii) Workshop on Cosmology and the High Redshift Universe, IUCAA, February (8-12).

b) Lecture Courses

Naresh Dadhich

Gravitation, Introductory Workshop on Gravitation, Astrophysics and Cosmology, Science College, Nagpur, October (26-30) (3 lectures) .

Gravitation, Siliguri Collge, Siliguri, November 16-20 (3 lectures).

Tapas K. Das

Accretion processes in astrophysics, IUCAA, VSP (6 Lectures)

Ranjan Gupta

Observational astronomy, Assam University, Silchar at the UGC Refresher Course, December 16-18 (6 lectures).

H.K. Jassal

Special relativity in astronomy, Introductory School on Astronomy and Astrophysics, NES Science College, Nanded, December (18 -21) (3 lectures).

A. K. Kembhavi

Stellar evolution and compact objects, Introductory Summer School on Astronomy and Astrophysics, IUCAA, May 20-24 (5 lectures).

High energy astrophysics, delivered to M. Sc. II, University of Mumbai at IUCAA, February 3-7 (9 lectures)

Stars to galaxies, National Institute of Opthamology, Pune, September 11- November 20 (10 lectures).

Stellar structure and evolution, Workshop on Gravity and Astrophysics at Mar Thoma College, Tiruvalla, October 7-9 (3 lectures).

Radiative processes in astrophysics, Workshop on Gravitation and Astrophysics, Science College, Nagpur, October 27-30 (3 lectures).

Radiation mechanism, Introductory School on Astronomy and Astrophysics, Siliguri College, Darjeeling, November 16-20 (3 lectures).

Ranjeev Misra

Radiative processes and application to astrophysical systems, Workshop on Gravity and Astrophysics at Mar Thoma College, Tiruvalla, Kerala, October 7-9, (3 lectures)

B. Mukhopadhyay

Introduction to astrophysics and cosmology, Science College, Nagpur, November 27-30 (3 lectures).

Introductory School on Astronomy and Astrophysics, NES Science College, Nanded, December 18-21 (4 lectures).

J. V. Narlikar

Elements of tensor analysis in general relativity ; Workshop on Gravity and Astrophysics at Mar Thoma College, Tiruvalla , October 7-9 (3 lectures).

Cosmology , Workshop on Gravitation and Astrophysics at Science College, Nagpur, October 27-30 (3 lectures).

T. Padmanabhan

Statistical mechanics of gravitating systems in static and cosmological backgrounds, RRI, Bangalore, October, 11- 23, (6 lectures)

Cosmology as a part of the M.Sc. Physics course offered by Mumbai University, IUCAA, Pune, February 5-9 (12 lectures).

A. N. Ramaprakash

Optical astronomical techniques: IUCAA-NCRA VSP/ VSRP, June 3 -5 (3 lectures).

Introduction to astronomy: Introductory School on Astronomy and Astrophysics, Science College, Nanded December 18 - 21 (4 lectures) .

Detection of light and photometry, Charge Coupled Devices, Workshop on Astronomy with Small Telescopes, IUCAA, Pune, January 6-10 (3 lectures).

S. K. Sahay

Gravitational waves and their detection, Introductory School on Astronomy and Astrophysics, NES Science College, Nanded, December 18-21 (3 lectures).

Tarun Souradeep

Introduction to cosmology, in the Vacation Students Programme, IUCAA, Pune May -June (4 lectures).

Observations and Statistics-I SERC School on Astronomy and Astrophysics - Cosmological Structure Formation, CTS, IIT, Kharagpur, June-July 2002 (18 lectures and tutorials).

R. Srianand

Diffuse matter in the universe, VSP/ Introductory Summer School, at IUCAA, May 27-30, (3 l3ctures).

Observational cosmology, SERC School on Astronomy and Astrophysics, - Cosmological Structure Formation, CTS, IIT, Kharagpur, June 9-17 (6 lectures).

K. Subramanian

Relativistic perturbation theory and CMBR anisotropies, SERC School on Astronomy and Astrophysics, - Cosmological Structure Formation, CTS, IIT Kharaghpur, June 3-5 (6 lectures).

From General Relativity to the Cosmic Microwave Background, NORDITA Master class in Physics, NORDITA, Copenhagen, Denmark, July 20-26 (6 lectures).

Turbulent dynamo, Meera Memorial Meeting on Astrophysical, Geophysical and Atmospheric Fluid Dynamics, Bangalore, January 3-4 (3 lectures).

c) Popular lectures

Naresh Dadhich

Mechanics and light, Annual conference of Satara District Maths Teachers, April 25.

Relativity by following light, New horizons in physics, Presidency College, Kolkata, February 21.

S. V. Dhurandhar

The story of gravity, Garware College, IUCAA Science

Day celebrations, February 24.

Ranjan Gupta

Upcoming telescopes in India and Abroad, at Guwahati University, Guwahati, December 20.

Ajit Kembhavi

Supermassive blackholes- Are there billions of them?, Mar Thoma College, Tiruvalla, October 8.

Galaxies, St. Thomas College, Kozhencherri, October 9.

Supermassive blackholes- Are there billions of them? Sicence College, Nagpur, October 28.

Supermassive blackholes, Siliguri College, Darjeeling, November 16

Supermassive black holes, Presidency College, Kolkata, February 22.

H. K. Jassal

Colours around us : Saturday Lecture series for school students, IUCAA, September 14.

Humaari rang birangi duniya : Saturday Lecture series for school students, IUCAA, September 14.

History of timekeeping : Science week public lecture series, SNDT, Pune, February 26.

Kalmaapan ka itihaas: Science day lecture/ demonstration, IUCAA, March 2.

J. V. Narlikar

Current speculations about the origin of the universe (a talk delivered to the Company Secretaries at the TATA Management and Training Centre), Pune, April 5.

The law of gravitation (a lecture organized by the Exploratory at IUCAA) April 25

Gurutavakarshanacha niyam (The law of gravitation) (in Marathi) (a lecture organized by the Exploratory at IUCAA) May 4.

Some puzzles in astronomy (a lecture delivered to the students of the 4th National Astronomy Olympiad organized by the Nehru Planetarium, Mumbai, at IUCAA) May 19.

Recent trends in astronomy (a lecture delivered to the fellows of the Kishore Vaigyanik Protsahan Yojana, Physics Department, University of Pune) June 4.

Search for microorganisms in the outer space (a lecture delivered in the IUCAA-NCRA Summer School at IUCAA) June 6.

Are we alone in the universe? (a lecture delivered at the 4th European Marathi Convention held in Birmingham, U.K.) July 6.

Shastra vishayachi vyapti aani sandhi (Scope and opportunities in science) (in Marathi) (a lecture organized by the Pimpri-Chinchwad Prabodhan Pratisthan at the Pimpri-Chinchwad Auditorium, Pune) July14.

Khagolshastratil suras aani chamatkarik goshti (A fantastic voyage through the universe) (in Marathi) (a lecture delivered under the Saturday lecture demonstration programme for school students at IUCAA) July 20.

A fantastic voyage through the universe (a lecture delivered under the Saturday lecture demonstration programme for school students at IUCAA) July 20.

Some exciting developments on the physics-astronomy frontier (a lecture delivered to the junior college students at IUCAA) July 27.

The use of high technology in astronomy (Late General B.C. Joshi Memorial Lecture, Army Institute of Technology, Dighi, Pune,) August 1.

Cosmic illusions (a popular talk delivered at the Mar Thoma College, Tiruvalla) October 9.

Vidnyankatha aani vastava (Science fiction and reality) (in Marathi) (a lecture delivered at the Parashuram Saikhedkar Auditorium, Nasik,) October 26.

Searches for extra-terrestrial life (a lecture delivered at the Vasantrao Deshpande Hall, Nagpur) October 27.

Searches for extra-terrestrial life (a lecture delivered to the Dibrugarh community, Dibrugarh) November 7.

The role of science and technology in society (an informal talk to the Technocrats at the oil establishments at Oil India Limited, Duliajan) November 9.

Facts and speculations in cosmology (S.N. Bose Memorial Lecture at the Satyendra Nath Bose National Centre for Basic Sciences, Kolkata,) November 11.

Searches for extra-terrestrial life (Y.B. Chavan Memorial Lecture organized by the Yashwantrao Chavan Smriti Samarah, New Delhi) November 23.

The excitement of doing science (a popular lecture delivered at the Physics Deparment, University of

Kalyani,) Kalyani November 25.

The excitement of studying science (a popular lecture delivered at the Merck Development Centre Private Limited, Taloja) December 7.

Khagaol vidnyan mein nayi dishaen (New directions to astronomy) (in Hindi) (a lecture delivered at the Srishti Club being organized by the Everest English Higher Secondary School, Dewas) December 9.

Antaralat jeevashrushticha shodh (Searches for extra-terrestrial life) (in Marathi) (a lecture delivered at the New Arts, Commerce and Science College, Ahmednagar) December 20.

Searches for extra-terrestrial life (a popular science lecture delivered to the members of Assam Science Society, Guwahati, Assam) January 10.

Searches for extra-terrestrial life (a lecture delivered at the Marathi Vidnyan Parishad, Mumbai) January 26.

Prithvipalikade jeevshristicha shodh (Searches for extra-terrestrial life) (in Marathi) (a lecture delivered on the occasion of third Foundation Day of Akashdarpan, Mumbai) January 26.

Khagol vidnyanatil suras va chamatkarik ghosti (Strange and interesting phenomena in astronomy) (in Marathi) (a lecture delivered at the Modern High School, Ganeshkhind, Pune) February 15.

Ganitachi vividharangi rupe (The many facts of Mathematics) (in Marathi) (a lecture delivered at the Modern High School, Shivajinagar, Pune) February 25.

Playing with mathematics (a lecture delivered on the occasion of the National Science Day at IUCAA) February 28.

Exciting developments in astronomy (a lecture delivered to the students of standard 8th, 9th and 10th at the Persistent System auditorium, Pune being organized by Children Science Movement under the Face to Face Programme) March 1.

Prithvi baheril jeevshristicha shodh (The search for extra-terrestrial intelligence) (in Marathi) Professor Narhar Vishnu Karekar Memorial Lecture, Shivaji University, Kolhapur, March 8.

Acceptance Speech (delivered on the occasion of the Yashwantrao Chavan National Award (2002) from the Yashwantrao Chavan Pratisthan, Mumbai) March 12.

Indian science : A historical perspective (Lokamanya Bal Gangadhar Tilak Memoral lecture at the Department of History, University of Pune, Pune) March 14.

Khagol vidnyanatil gamati jamati (Interesting titbits in astronomy) (in Marathi) (a lecture delivered to the students of standard 8th, 9th and 10th at Dnyan Prabodhini, Pune, being organized by Children Science Movement under the Face to Face Programe) March 15.

T. Padmanabhan

Story of the Calendar, IUCAA, Pune, January 14.

Nobel Prize in Physics - 2002, IUCAA Open Day, IUCAA, Pune, March 2

Story of the Calendar, HRI, Allahabad, March 13.

The Excitement of Astronomy, Government High School, Kochi, January 28.

A. Paranjpye

Kendra Vishwache, Nanded, December 20.

Demonstration cum lecture on operating Internet telescope, at IIT, Kanpur, February 2.

Colombia disaster and after, Rotary Club Midtown, February 13.

Is there a Centre of the universe?, Garware College, Pune, February 15.

Colours in the sky, Rotary Club of Khadki, Pune, March 5.

A. N. Ramaprakash

A picture of relativity: Lecture and slide show as part of the Saturday lectures for Junior College Students, IUCAA, Jan uary 25.

Large optical telescopes and instrumentation: Talk given to the participants of Astronomy Workshop conducted during the TECH FEST 2003 at IIT, Mumbai , February 1.

Jets and superluminal motion: Talk given during the Science week celebrations, IUCAA, Pune, March 2.

K. Subramanian

The fabric of spacetime, National Sciene Day, IUCAA, Pune, February 28.

MAP-ping the universe, IUCAA Popular lecture series, March 28.

Tarun Souradeep

Cosmic microwave background in the Astronomy workshop at Tech Fest-03, I.I.T. Mumbai, February 2.

Cosmic saga in the cosmic background radiation, at Science week, Fergusson College, Pune, February 27

(d) Radio/TV Programmes

S. V. Dhurandhar

Gravitational wave detection, Talk in TV, June.

J.V. Narlikar

Hamare Mehmaan, Vividh Bharati, All India Radio, Pune, May 18.

Hamare Mehmaan, Vividh Bharati, All India Radio, Pune, May 25.

Arvind Paranjpye

Live phone in question and answer programme, Colombia Disaster, Akashwani, Pune, February 18.

(VII) SCIENTIFIC MEETINGS

School Students' Summer Programme 2002

This year's School Students' Summer Programme was held from April 15 to May 24, 2002. IUCAA has been conducting this programme for the students of VIII and IX standards since 1993, to give them a brief insight of doing scientific research. The programme is open to the students in Pune only.

Informal learning sessions formed part of this programme - H.K. Jassal with students

Each week , a new batch of 30 students was invited to work in projects at IUCAA from Monday to Friday. Groups of four to six students were attached to each individual guide. (The details of their projects are given in page 100.) The programme has no set syllabus or course guidelines. The students and the guide work out their own schedule for the week. The students were given access to the IUCAA library.

On their very first day at IUCAA, the students were briefed about the programme and soon after that they would go with their guides to work on different projects. During the week, they also participated in various common activities. Vinaya Kulkarni gave them guided tour of the science park and they participated in operating the internet telescope at Mt. Wilson, California, the facility kindly provided by the Gilbert Clark, the Director, Telescope in Education. Arvind Paranjpye carried out a general question answer session. On the last day of the programme, every student submitted his or her 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'.

S.N. Tandon and the students at a practical session

In their report, the students were also asked to give their impressions on the programme. To almost every one 'coming to IUCAA was like a dream come true'. One student wrote that she "was not quite interested in mathematics" but now she enjoys it. A few students strongly suggested that since they never had access to actual sky watching, at least one night programme may be conducted during their winter holidays. IUCAA has taken all these suggestions very positively. The programme was coordinated by Arvind Paranjpye.

S. V. Dhurandhar with the students

Some more details regardintg this programme can be found on page 100.

Introductory Summer School on Astronomy and Astrophysics

A summer school for students of the B.Sc. final year and M.Sc. first year was organized jointly by IUCAA and National Centre for Radio Astrophysics (NCRA) at Pune during May 20 to June 21, 2002. The school was part of an annual series of Summer Schools on Astronomy and Astrophysics, sponsored by the Department of Science and Technology under which, the schools were conducted alternately at Bangalore and Pune. Lectures covering different theoretical, observational and instrumental aspects of astronomy and astrophysics were given by lecturers from IUCAA, NCRA, and TIFR, Mumbai. The students did a reading assignment, under the supervision of a faculty member from IUCAA/NCRA and presented a ten minute talk. Students visited the GMRT site. Altogether 32 students from all over India attended the school. R. Misra from IUCAA and D. J. Saikia from NCRA were the coordinators of this school.

Students asking questions to J. V. Narlikar

Students and J. V. Narlikar engrossed in a discussion

Workshop on Gravity and Astrophysics

Participants of the Workshop on Gravity and Astrophysics at the inaugural function.

A three days workshop on Gravity and Astrophysics, sponsored by IUCAA, was held at Mar Thoma College, Tiruvalla, Kerala, during October 7 - 9, 2002.

The workshop was inaugurated by the Manager of the College and the Metropolitan of Mar Thoma Church, His Grace The Most Rev. Dr. Philipose Mar Chrysostom Metropolitan. The lectures were delivered by G. Date (Einstein's Equations and Solar System tests); A. Kembhavi (Stellar Structure and Evolution); Ranjeev Misra (Radiation and Accretion Disks); and J. V. Narlikar (Elements of Tensor Analysis in General Relativity). About 100 postgraduate students in Physics, 20 B.Sc. students and 30 research students and teachers from different colleges and universities in Kerala participated in the workshop.

In addition, there were popular talks in the college auditorium by K. Indulekha of the Mahatma Gandhi University, Kottayam on "Tensor Analysis" (in Malayalam) and by J. V. Narlikar on "Cosmic Illusions". The popular talks were well received. About 400 people including class XI, XII students from various schools, general public and students from other disciplines attended the talks with great enthusiasm. A number of students participated in the 'question time' and prizes were awarded for the best question of the day. The coordinators of the workshop were Fr. A. Abraham and A. K. Kembhavi.

Workshop on Gravitation and Astrophysics

An IUCAA sponsored workshop on Gravitation and Astrophysics was held at the Science College, Congress Nagar, Nagpur, during October 27-30, 2002. About 65 selected delegates attended the four-days workshop, out of which about 15 were from outside the region.

The main aim of the workshop was to provide an opportunity to students, research scholars and teachers in the region to get an exposure of the exciting field of gravitation, cosmology and astrophysics, and make them aware of the recent developments in the field. Those who are already initiated in research got a good opportunity for interaction with the experts. J. V. Narlikar, and K. Subramanian delivered a series of lectures on cosmology, Banibrata Mukhopadhyay spoke on accretion disks, Sajith Philip discussed neural networks and their applications, N. Dadhich gave a course on basics of general relativity and A. Kembhavi talked about radiative processes in astrophysics, in addition to delivering a public lecture on "Super massive blackholes - Are there billions of them?" The public lecture was at a level appropriate for school students and even laymen.

Besides lectures, there were interactive discussion and presentation sessions as well. This gave a rare chance to participants from the region to interact with these experts. Sushant Ghosh from the Mathematics Department of the college, was the local coordinator of the workshop.

J.V. Narlikar delivering a lecture

Introductory School on Astronomy and Astrophysics

An Introductory School on Astronomy and Astrophysics was held at N. E. S. Science College, Nanded, during December 18-21, 2002. Colleges under Nanded Education Board run undergradute programmes in A & A. The participants were predominantly undergraduate (about 60) and postgradute (about 20) students along with physics teachers from nearby colleges and universities (about 20).

Six topics were covered during the school: Introduction to Astronomy (A. N. Ramaprakash), Our Solar System (A. Paranjpye), Compact Objects, Accretion Disks and Their Properties (B. Mukhopadhyay) Special Theory of Relativity in Astronomy (H. K. Jassal), Our Sun (P. Subramanian) and Gravitational Waves and their Detection (S. K. Sahay). A public lecture given by A. Paranjpye on 'The Centre of the Universe' in Marathi at the Nanded Science College Auditorium and was well attended and appreciated.

In order to encourage follow up activities after the school, the student participants were asked to write an essay on any one of the six topics covered during the lectures. Authors of the best among these essays will be invited to IUCAA and given oppurtunity to interact with the resource personnel. A. N. Ramaprakash and M.J. Nimkar were the coordinators of the workshop.

Participants of the Introductory School on Astronomy and Astrophysics at the opening session

The Introductory Workshop on Astronomy and Astrophysics

The Introductory workshop on Astronomy and Astrophysics for college students was held at Fergusson College, Pune, during November 26 -28, 2002, co-sponsord by Fergusson College and IUCAA. The aim of the workshop was to convey the excitement of modern astronomy and astrophysics to postgraduate and senior graduate students, studying science in different colleges in Pune. There was enthusiastic participation in the workshop with about 100 students participating in the programme. Lectures were given by N.K. Dadhich, A.K. Kembhavi, J.V. Narlikar, T. Padmanabhan, R. Srianand (from IUCAA), R. Nityananda (from NCRA) and Raka Dabhade (from Fergusson College).

On the last day of the workshop, a discussion session on "Careers in Astronomy" was organised at IUCAA. The panel consisting of N. Dadhich, J.V. Narlikar, R. Nityananda and V.K. Wagh answered a wide variety of questions raised by the students regarding the career in astronomy and astrophysics. Once again the response was very enthusiastic with several students actively participating in the discussions and expressing their opinion. After the discussion session, the students visited different scientific exhibits in IUCAA and participated in the Night Sky Watching Programme organised by Arvind Paranjapye. It is hoped that similar activities can be held every year catering to the students in Pune colleges. The coordinators of the workshop were Raka Dabhade from Fergusson College and T. Padmanabhan from IUCAA.

The 22nd Meeting of the Indian Assocaition for General Relativity and Gravitation

Abhay Ashtekar delivering the lecture

IUCAA hosted the 22nd meeting of the Indian Association for General Relativity and Gravitation (IAGRG) during December 11-14, 2002. The IAGRG meetings are held roughly once in 18 months. This meeting, with around 100 participants, was considerably larger than its recent predecessors. Apart from a broad representation from the Indian GR community, the meeting had about a dozen foreign participants.The scientific programme had 7 review talks and 18 invited talks on topics of current interest ranging from classical GR, quantum gravity, gravitational radiation, astrophysics and cosmology. It also featured 18 short oral research presentations and an equal number of poster presentations. There was a conscious effort to provide opportunity to younger researchers to deliver the invited talks. A highlight of the meeting was the Vaidya-Raychoudhury endowment award lecture, delivered by Rajaram Nityananda, Centre Director, NCRA. His lecture titled "Gravity and Light" covered different aspects of propagation of light in general relativity. Besides IUCAA, the meeting was co-sponsored by grants from the Council for Scientific and Industrial Research (CSIR), New Delhi and Institute of Mathematical Sciences, Chennai.

Introductory School on Astronomy and Astrophysics

An Introductory School on Astronomy and Astrophysics was held in Siliguri College, during November 16-20, 2002. The school was sponsored by IUCAA, Siliguri College and IUCAA Reference Centre of North Bengal University. The aim of the school was to present selected introductory courses on astronomy and astrophysics, specially designed for college teachers, research scholars and university students. The topics covered were : (1) Observational Astronomy, (2) Astrophysical Processes, (3) Relativity and Gravitation, (4) Cosmology and (5) Astroparticle Physics. The lecturers were N.K. Dadhich, A. Kembhavi, S. Mukherjee, S. Bharadwaj, D.V. Ahluwalia, S.K. Ghosal, B.C. Paul, K.K. Nandi and S. Karanjai. Although the lectures were mostly on topical issues, the presentation was introductory in nature, keeping in view the general background of the participants. Apart from lectures, there were seminars and discussion sessions, all of which had active and enthusiastic response from the participants. About 25 college teachers and 45 students from the neighbouring universities and colleges participated in the school. The school generated considerable interest among the students and the academic programmes and was coordinated by S. Mukherjee and A. Kembhavi.

Workshop on Cosmology and the High Redshift Universe

As a part of the scientific collaborative programme between IUCAA and Institute for Astronomy (IFA) Hawaii, a four days workshop on "Cosmology and the High Redshift Universe" was held during February 8-11, 2002. This collaborative programme was funded by Watumull Foundation, Honolulu, Hawaii. There were about 40 participants from all over India attending the workshop. The speakers included Brent Tully, Bob Joseph, Harald Ebelling and Iztvan Szapudi (IFA), J. Bagchi, A.K. Kembhavi, J.V. Narlikar, T. Padmanabhan, Tarun Souradeep, R. Srinand, Tirthankar Roy Choudhury, Jatush Sheth and R.G. Vishwakarma (IUCAA), J. Chengalur (NCRA) and U.C. Joshi (PRL). A wide range of topics in modern day cosmology were covered. The coordinators of the workshop were Ajit Kembhavi and R. Srianand from IUCAA.

Participants of the Workshop on Cosmology and the High Redshift Universe

Participants of the Workshop on Cosmology and the High Redshift Universe

Workshop on Telescope Making at Margao

Participants of the Workshop on Telescope Making

A workshop on telescope making was conducted at Godavari Naik Hall, M and N English High School, Margao by Association of Friends of Astronomy (Goa) from October 28 to November 17, 2002, jointly with Marathi Vidnyan Patrishad, Goa and under technical guidance and supervision of IUCAA. There were 23 participants from six colleges. Six 6 inch reflecting telescopes were made at the workshop by six teams of school and college students, each accompanied by one teacher. The workshop was made possible due to the financial support received from the Department of Science and Technology, Government of Goa and the active interest taken in the project by its Director, N. P. S. Varde. Most of the students who participated were from the Higher Secondary Schools and Junior Colleges from towns in Goa. Some students travelled as much as 100 km every day to attend the workshop. Expert guidance in all aspects of telescope making was given by Arvind Paranjpye and Vinaya Kulkarni and they personally supervised making of the telescopes.

Workshop on Field Theoretic Aspects of Gravity (FTAG-III)

Participants of the Workshop on Field Theoretic Aspects of Gravity

The third Workshop on Field Theoretic Aspects of Gravity (FTAG-III) was organized by IUCAA Reference Centre, Department of Physics, Cochin University of Science and Technology, during January 23- 29, 2003. This workshop was cosponsored by IUCAA, IMSc, Chennai and CUSAT, Kochi. There were about 25 active workers including doctoral and post- doctoral fellows and faculty members from all over India. Following the tradition of FTAG, each talk was of 90 minutes duration and the speaker himself/herself chaired the session. The topics included: quantum gravity, quantum cosmology, quantum field theory in curved spacetime, blackholes, noncommutative geometry, string theory, extended objects in general relativity, dark energy, pre-big bang cosmology, etc. The venue of the workshop (Santhigiri Ashram, Edathala, Aluva), where all the participants stayed, was a beautiful place, ideal for such small gathering. This resulted in lively discussions outside the lecture hall. N.K. Dadhich (IUCAA) and V.C.Kuriakose (CUSAT) were the coordinators of the workshop.

Workshop on Early Universe, Large Scale Structure and the CMBR

Participants of the Workshop on Early Universe, Large Scale Structure and the CMBR

The IUCAA-Delhi University Workshop on Early Universe, Large Scale Structure and the CMBR was held during November 16 - 20, 2002 at the IUCAA Reference Centre, Department of Physics and Astrophysics, University of Delhi. The inaugural talk was given by N. Panchapakesan on "Cosmology: Facts and Fiction". There were 11 pedagogical talks on the following topics: T. R. Seshadri (Univ. of Delhi) on FRW Universes (2 talks); Jasjeet Bagla (HRI, Allahabad) on Structure Formation (3 talks); K. Subramanian (IUCAA, Pune) on CMBR Anisotropy and Polarization (2 talks); D. Narasimha (TIFR, Mumbai) on Gravitational Lensing and Large-Scale Structures (2 talks); T. Padmanabhan (IUCAA, Pune) on Cosmological Constant and Dark Energy (2 talks). In addition, there were a number of seminars by participants. T. R. Seshadri and T. Padmanabhan were the coordinators of the workshop.

Workshop on Astronomy with Small Telescopes

Participants of the Workshop on Astronomy with Small Telescopes

A workshop on Astronomy with Small telescopes was conducted at IUCAA during January 6-10, 2003. There were, in all, 40 participants: 16 M.Sc. students, 16 university/college teachers, and 8 Ph.D students/PDFs/ others, mostly from outside Pune. This list also includes two M.Sc. students from the University of Mauritius. The workshop began with a brief welcome address by J. V. Narlikar, Director, IUCAA. A coherent set of lectures, delivered during the workshop include detection of light and detectors (photometer and CCDs) by A. N Ramaprakash (IUCAA), elements of photometry and error analysis by A. K. Kembhavi (IUCAA), elements of spectroscopy with applications for small telescopes by Ranjan Gupta (IUCAA), astronomical image processing by Pawan Chakraborty (IUCAA), observing strategy and photometric data reduction by Sudhanshu Barway (Ravishankar Shukla University), interacting binary stars and role of small telescopes by N. M. Ashok (PRL), stellar activity in late type binaries by P. V. Rao (Osmania University), variable stars and observational projects for M. Sc. students by S. K. Pandey (Ravishankar Shukla University), quantitative teaching projects by Mark Whittle (IUCAA Visiting Faculty), transient phenomena with small telescopes by Arvind Paranjpye (IUCAA), and Automated Photoelectric

Telescope (APT) by Umesh Dodia (Bhavnagar University). These lectures were planned to be supplemented with observations and demonstrations using the small telescopes (with 10"-16" aperture) available at IUCAA, but sky conditions during the period of the workshop turned out be unfavourable. Some demonstrations using SSP3 photometer and CCD were conducted by Arvind Paranjpye and Sudhanshu Barway during the first two nights. The workshop ended with closing remarks by N. K. Dadhich, Chairman, Workshops Committee, IUCAA, with the hope that such workshops will be organized by IUCAA in future too in order that the excitement of Observational Astronomy with small telescopes can be promoted and sustained in the universities and colleges in our country, specially for the M.Sc. students. S. K. Pandey, was the official coordinator of the workshop, but fair share of credit for making it successful goes to Arvind Paranjpye, Sudhanshu Barway, V. Chellathurai and his team at IUCAA.

PUBLIC OUTREACH PROGRAMME

The model of the building of the IUCAA Muktangan Vidnyan Shodhika is being looked at by Shri Pu. Bhagwat, J. V. Narlikar and others

Foundation stone of "IUCAA Muktangan Vidnyan Shodhika" (IMVS), the Science Exploratorium, was unveiled by the well known Marathi literary doyen Shri. Pu. Bhagawat on December 27, 2002. The Exploratorium will be a building with two floors located on the southern part of Chandrasekhar Auditorium, IUCAA. It will house a laboratory, having facilities for doing science experiments (including the facility for making amateur telescopes), a library, an open air amphitheater and sky observing facilities consisting of a large telescope and a few binoculars.The IMVS is being built out of a generous benefaction from Smt. Sunitabai Deshpande, as well as a grant from the Maharashtra Foundation, USA.

Creating aptitude for science and encouraging curiosity about nature have been considered important parts of education. IUCAA is one of the few scientific institutions that actively participate in this exercise. Appreciating IUCAA's contributions in this field, and to encourage this activity further, Smt. Sunitabai Deshpande has made a handsome donation of Rs. 25 lakhs to the Centre for creating 'Muktangan Vidnyan Shodhika'.The intention to make this donation had in fact been expressed by the multifaceted Marathi humourist *late* Shri P. L. Deshpande, known as 'Pu La' and Smt. Sunitabai Deshpande while Pu La was alive. This has now been fulfilled by Smt. Sunitabai.

Public Lecture Series

IUCAA started a Lecture Series Programme for the public of Pune. The following lectures have taken place:

October 25, 2002 *Searches for Extraterrestrial Life,* J. V. Narlikar

November 12, 2002 *Astronomy and Society,* W. C. Saslaw, [Institute of Astronomy, Cambridge, UK]

December 27, 2002 *When the Universe was Young*, Mark Whittle, [University of Virginia, USA]

January 14, 2003 *The Story of Our Calendar,* T. Padmanabhan

March 28, 2003 *(W)MAP - ing the Universe,* Kandaswamy Subramanian

National Science Day Celebrations

During the National Science Day celebrations at IUCAA, in addition to the regular programmes of competitions for the school students and open day for public, IUCAA organized a special series of lectures during February 24 - 27, 2003, in different colleges in Pune as indicated below:

The Story of Gravity - Sanjeev Dhurandhar
[Garware College], February 24.

Ganitachi Vividha Rangi Rupe - J. V. Narlikar
[Modern College], February 25.

Relativity for Everyone - N. K. Dadhich
[Fergusson College], February 26

Akashganga : Our Galaxy - R. Srianand
[Fergusson College], February 26.

History of Time Keeping - H. K. Jassal
[S. N. D. T.], February 26.

Cosmic Saga in the Cosmic Background Radiation - Tarun Souradeep [Fergusson College], February 27.

The programme for the school students consisted of quiz,essay and drawing competitions and lecture demonstrations. Five students each from 80 schools were invited to participate in the various competitions. This programme, conducted on February 28, began with Jayant Narlikar giving a brief introduction on the importance of celebrating the National Science Day. He also reminded the students that the 28th of February was being celebrated as National Science Day all over India because, on this day, in the year

1928, the "Raman Effect" was discovered, for which Professor C. V. Raman was subsequently awarded the Physics Nobel Prize.

Essay and Drawing competitions along with Quiz elimination round were held from 9:30 a.m. to 10:30 a.m. During this period, the teachers accompanying the students took a science quiz, prepared by T. Padmanabhan. This quiz had questions of varying degrees of difficulty. The best entry was from Sujata A. Deshpande of Abhinav Vidyalaya English Medium School.

Jayant Narlikar gave a lecture in English and Marathi on "Playing with Mathematics" covering some mathematical games.

After the lunch break, final quiz competition was conducted to the top 5 teams selected after the elimination round. This competition was held on stage in front of an audience. The programme ended with Jayant Narlikar giving away the prizes to the winners in all the events.

Sky show

On the same evening, a public sky show was organized. About 1000 people visited the science park, which was the venue of the sky show, to look through telescopes. Six telescopes made by amateur astronomers were used for showing Jupiter and Saturn. Images of these planets were projected on a big screen for which a webcam was attached to IUCAA's 14 inch telescope.

The Open Day

IUCAA's gates were thrown open to the public on Sunday, March 1 at 1:30 p.m. In the lobby between Bhaskara 2 and 3, Amit Dhurandhar, Aniruddha Kembhavi, Krishanu Saha and Puneet Shenoy (students of engineering college) demonstrated the Maze Solving Robot, which they had built (This robot won a prize in the Techfest organized by Indian Institute of Technology, Mumbai). Video films on astronomy and physics were screened in Bhaskara 3 lecture hall and thirty minutes talks were given to the general audience in Chandrasekhar Auditorium. Joydeep Bagchi talked on "Cosmic Rays: The Mystery of Most Energetic Particles in the Universe", A. N. Ramaprakash on "Jets and Superluminal Motion" and Harivindar Kaur Jassal gave a talk on "History of Time" in Hindi. Madhav Khare, an amateur aeromodeler gave two talks and demonstrations on aeromodeling.
In the Science Park, teachers and students of the Range Hill School performed a typical folk dance-drama (Gondhal) entitled Khagol Vidnanacha Gondhal.

The Science Day celebrations ended with a public talk by T. Padmanabhan on "Nobel Prize in Physics 2002", which was well attended by the public.

SCIENCE DAY COMPETITIONS

Prize Winners

Drawing Competition

1st
Abhishek K. Patil - Balshikshan Mandir
2nd
Sayalee B. Chaudhary - Renuka Swaroop High School
3rd
Pooja Suresh Laygude - Narayan Rao Sanas Vidyalaya

Essay (Marathi)

1st
Milind Shethe - Saraswati Madyamik Vidyalaya
2nd
Bhagyashree Thakur - Mahilashram High School

Honourable Mention

Sayalee Subhash Jagtap - Renuka Swaroop High School
Sarang Bawiskar - M. S. S. High School
Minakshi Vaishampayan - Ahilyadevi High School
Smita Ramchandra Pol - Narayanrao Sanas Vidyalaya

Essay (English)

1st
No prize was awarded

2nd
Omkar Sathe S.P.M. English School

Honorable Mention

Tanvee Sharad Shevade - Symbiosis Secondary School
Abhisek Dang - Jnana Prabodhini Navanagar, Nigdi
Shristi Shridhar - Army Public School

Quiz
1st
Dr. Kalmadi Shamrao High School
Aditya Kanitkar
Omkar Wagh
Aditya Chandorkar

2nd
D. E. S. Secondary School
Sarang Kulkarni
Pushkar Pandit
Akshya Navgire

3rd
Bhartiya Vidya Bhavan Sulochana Natu Vidya Mandir
Aneesh Hemant Gokhale
Nakul Nitin Gote
Siddharth Laxmidhar Pati

School Students' Summer Programme

The School Students' Summer Programme was held from April 15 to May 24, 2002. IUCAA has been conducting this programme for the students of VIII and IX standards since 1993, to give them a brief insight of doing scientific research. Schools in greater Pune were invited to nominate two scientifically motivated students each, and about 150 students from 75 schools participated in this programme. Every 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. This programme had no set syllabus or course guidelines and the students and the guide worked out their schedule for the week.

The sample of topics that the Summer School Students took up for their projects included: Foucault pendulum, coriolis force and centrifugal force, Solar system, calculating diameters of planets, gravitational acceleration, gravitational force of planets, orbital period, Keplar's law of planetary motion, study of the Sun, the Earth and the Moon, and tides in the ocean. Some of the students made periscopes and studied telescopes and usage of CCD in astronomy.

Some of them studied mathematical topics like modular arithmetic, geometric progression, tricks to remember complex mathematical formulae, mathematical systems, Euler's functions, Fermat theorem, permutations and combinations, Bond percolation on a square lattice, and random walk on square lattice. Some others worked out problem of water distribution for village of certain population. The problem included study of Archimedes principle, how siphon works, consumption of water, design and height of a tank for a colony of certain number of houses and designing a pump to deliver water to the overhead tank. A group of students also studied variation in temperature inside and outside of a brick house model made by them.

A. L. Ahuja , V. Chellathurai, S. V. Dhurandhar, Ranjan Gupta, Amir Hajian, Harvinder Kaur Jassal , Vinaya Kulkarni, Sanjit Mitra, J. V. Narlikar, T. Padmanabhan, Arvind Paranjpye, A. N. Ramaprakash, Arvind Ranade, A. A. Sengupta, Jatush Sheth, Tarun Souradeep, Prasad Subramanian and S. N. Tandon acted as guides for the students.

FACILITIES

(I) Computer Centre

The IUCAA Computer Centre continues to provide the state of the art computing facility to the users from IUCAA as well as visitors from the universities/colleges and institutions within India and abroad.

An important development from the point of view of security has been the setting up of a Virtual Local Area Network (VLAN). This puts essentially all the computing resources behind a firewall, and only a few servers that run internet services such as mail, ftp, web and mirror-sites are made available on the internet. The new email server has a webmail facility which helps users to access their mail from anywhere in the internet.

IUCAA now has a new look webpage, and three mailing lists (namely, iucaa, cluster and vo), which were setup during the last year. These are used by IUCAA members to share knowledge related to the general IUCAA computing facility, Cluster computing and Virtual Observatory.

The IUCAA computer centre gets frequent requests, from visiting associates as well as other people from the university sector, for copies of publicly available software and support in the installation and use of various packages. To be able to provide this support efficiently, IUCAA has set up a help desk at Science College, Nagpur. An exhaustive collection of publicly available software packages is maintained here, and interested users can get copies on CDs at a nominal charge. The help desk also provides instructions and help in the use of the software. The help desk has proved to be very popular, and IUCAA hopes to set up more of these in the near future.

During the period of this report, the computer centre has acquired very large disk arrays with several terabytes of capacity for the computer centre as well as a part of the Virtual Observatory project. Mirrors of large data bases are being set up on these disks.

The IUCAA computer centre continues to extend support to university departments and colleges for configuring networks, obtaining hardware and software, setting up applications and training personell.

(II) Library and Publications

During the period under review, the IUCAA library added 225 books and 500 bound volumes to its collection. The library subscribes to 128 journals and the total collection amounts to 18,328. The library caters to the needs of the inhouse academic community as well as associates and official visitors coming to IUCAA.

The IUCAA library is an active member of the Forum for Resource Sharing banner (FORSA), established by astronomy librarians in India. The consortia effort has resulted in obtaining substantial reduction in the per annum subscription cost for Nature Online. In the case of the Kluwer consortia, the IUCAA library has online access to 16 journal titles apart from 7 titles subscribed by IUCAA published by Kluwer Academic Publishers.

The IUCAA library has been providing the monthly table of contents service to the university academics since 1999. This is currently being given to 11 visiting associates and 10 official visitors. The journals (approximately 40 in number) comprise of core titles in astronomy and astrophysics and physics being subscribed by the IUCAA library. Full-text of articles are sent upon request. This service is in addition to the article requests received by the IUCAA library through email and post.

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, the controller for automatic dome rotation, in synchronisation with azimuth of the telescope, was fabricated and tested in the observatory building. An accessory has been developed for polarimetric work with the imager-spectrograph (IFOSC) to be used with the IUCAA telescope. The CCD controller (developed in the laboratory during the last years) was modified to suit a near infra-red array detector, and optical design of an infra-red array camera was completed. Work on development of a photon counting imaging detector, for UV and visible range, has been initiated.

(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.

Most of the telescope parts have arrived during this year and the first phase of mechanical integration was done during the months of February and March --this involved mounting of the ring-girder (for the hydrostatic azimuth bearing) on the concrete pier in the building, and floating of the base-box (on which the other parts are mounted) on the azimuth bearing. Further work on the integration would continue in the next year, and it is expected that the telescope would be commissioned at the end of 2003.

A brief description of the instruments being developed for the telescope can be found under the head Instrumentation in pages 43 - 45.

(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 have become 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, 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, 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, and (3) development of a visualization engine VOPlot for the large database known as Vizier, with web based and stand alone versions. These packages have been very well received by the international community and are being demonstrated in various international forums. VOPlot have been developed in collaboration with CDs, France, and is being adapted to various data bases. 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.

IUCAA REFERENCE CENTRES (IRCs)

1. Delhi University
Report by T. R. Seshadri (Coordinator)

The IUCAA Reference Center at Delhi University is now fully functional, with the help of a generous grant from Delhi University for setting up the infrastructure. The IRC has been able to support visitors and also organize regular seminars. The facilities consist of two pentium machines and printers, access to internet through a dial-up connectivity, small library of 24 books on long term loan and several other books donated by individuals to the centre. The books have been used especially by M.Sc. students specializing in the General Relativity and Cosmology, as well as the Astrophysics Courses. IUCAA has arranged for a password based access to the electronic version of some journals.

In November 2002, a workshop on Large Scale Structures and the CMBR was organized at Delhi University the details of which can be found on page 97.

2. Pt. Ravishankar Shukla University, Raipur
Report by S.K. Pandey (Coordinator)

The faculty members, and research scholars in the university as well as visitors from other universities/ colleges in this region made use of the facilities/ (Internet, library, etc.) provided by IUCAA at the centre in strengthening their research activities. Some of the important activities of the centre during the year are listed below.

Research activities : D. K. Chakraborty and his research students continued their work on the projected properties of a family of triaxial mass models. They have extended their work on the mass models with central cusp and central core to investigate the effect of the inclusion of high order residuals on intrinsic shapes of elliptical galaxies. These models exhibit disky or boxy isophotes depending on the viewing direction. A paper based on this work has been accepted for publication in A&A. Mousumi Das has also submitted her thesis entitled " A study of photometric and kinematic properties of elliptical galaxies" to Pt. Ravishankar Shukla University for the award of Ph. D. degree. S. K. Pandey along with his collaborators is involved in the study of multiphase ISM in early-type galaxies, with the objective of examining the physical relationship and coexistence of various forms of ISM in a sample of elliptical galaxies. He along with his students is also investigating the possibility of activity cycles, akin to 11-year sunspot cycle, in a sample of chromospherically active stars using the archival photometric data.

Visitors to the centre: School teachers and students from local schools occasionally visit the centre to make use of the IRC facilities for preparation of Science Posters/ models/lectures etc. Other visitors during the year included Subhash Kaushik from Govt. College, Sidhi ; R. S. Singh from Govt. College, Utai (Durg); A. Jadhav from Govt. College, Neemuch; K. N. Mishra from Bhilai Institute of Technology, Bhilai and Pratibha Claudius from Girls College, Bhilai.

Seminars/lectures : M. Sc. students of the department make use of IRC facilities for the preparation/presentation of weekly seminars organized in the department. N. M. Ashok from PRL, Ahmedabad, gave a lecture on "Observing facility at Mt. Abu" on June 6, 2002. S. K. Pandey gave a lecture on " A Glimpse of the Universe" for the school students at a function organized by Chhattisgarh Vigyan Sabha at Raipur on December 11, 2002. He also gave a series of three lectures on "Structure and Evolution of Stars", and "Galaxies and the Universe" at the Refresher Course in Physics for College/University teachers organized in the department during February 3-23, 2002.

Project work in Astronomy : Thirteen students from M.Sc. (final) of the Department used IRC facilities (INTERNET and library) in carrying out their project work, as a part of their course work, in observational astronomy using the observing facility in the department.

Sky gazing programme : From time to time, sky gazing programme was organised during the year 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 their 6" telescope fitted with solar filters. During May 2002, a programme was organized to witness a grand and beautiful lineup of all bright naked-eye planets: mercury, Venus, Mars, Jupiter and Saturn, for the general public.

3. North Bengal University, Siliguri
Report by S. Mukherjee (Coordinator)

General : The facilities at IRC, NBU have been very helpful in sustaining research activities of its users. The e-Library of the centre has been very popular. IRC received some current issues of journals from IUCAA Library. The activities of the centre included organising discussions, seminars and workshop, and also offering a platform for collaborative research work in some selected areas of current interest. A brief outline of the activities is given below :

Seminar, workshop, etc. : Apart from holding weekly discussions and lectures by visiting scientists, the centre helped Siliguri College to organise an IUCAA - sponsored workshop on Introductory Astronomy and Astrophysics during November 16-20, 2002. About 80 participants, including selected undergraduate and post-graduate students, research scholars and university/college teachers benefited from the workshop. A panel discussion by some eminent educationists was also organised on the topic "Crisis in Higher Education?".

Research : The research work pursued by the users of IRC covered the following areas :

(i) Quantum cosmology : Semi-classical quantum Cosmology has been studied by making use of the instanton techniques. Two processes have been considered in detail : (i) Creation of an inflationary universe with a pair of primordial blackholes and (ii) the quantum creation of an open inflationary universe. While the standard non-singular instanton is used for the first process, the singular Hawking-Turok instanton was used for the second problem. The problems were studied in higher derivative theories also. The work has been done by S. Mukherjee, R. Tavakol (UK), B. C. Paul, A. Saha and S. Chakraborty (Jadavpur University).

(ii) Compact stars : A model for a class of compact stars, which makes use of Vaidya-Tikekar geometry of space-time is used to study very compact stars. It is shown that the model can generate realistic equations of state for stellar matter. The compact stars SAX J1808.4-3568 has been studied in detail. The stability of stellar configuration under radial perturbations has also been studied. The model has been generalised for a star, which has a deconfined quark phase at its core, enveloped by less compact baryonic matter. In a separate study, the model has been considered in higher dimensions and the relevant Schwarzschild limit has been obtained. The work has been done by S. Mukherjee, R. Sharma, M. Dey, J. Dey and B. C. Paul.

(iii) Gravitational collapse : A simple model of radiative collapse with radial heat flux, which describes qualitatively the stages close to the eventual formation of a superdense cold star has been studied. The temporal evolution of the star is specified by solving the junction conditions appropriate for radiating gravitational collapse. The work is done by S. Mukherjee, R. Sharma, M. Govender, K. S. Govender, S. D. Maharaj and T. K. Dey.

(iv) General relativity : General relativistic effects on quantum interference of thermal neutrons in an earth bound configuration have been studied. It is proposed that the measurement of general relativistic contribution to the quantum phase shift depends on the validity of the principle of equivalence at the quantum level. Considering an optical model of static spacetime, it is suggested that experimentally verifiable Fizeau like effects might occur in the effective optical medium, which may be relevant for creating optical blackholes in the Bose Einstein Condensate. The work is done by K. K. Nandi, Y. Z. Zhang, P. M. Alsing, J. C. Evans and A. Bhadra.

Different aspects of relativistic Sagnac effect have been studied by S. K. Ghosal, B. Raychaudhuri and M. Sarkar.

4. Cochin University of Science and Technology, Kochi
Report by V.C. Kuriakose (Coordinator)

The facilities available at the centre are used by teachers and research scholars for their research activities. Teachers and students from other universities and neighbouring colleges visit this centre for reference and computational purposes. One M.Phil. and three M.Sc. students did their project studies in topics related to Astronomy and Astrophysics areas using the facilities available at the centre.

Research Activities

(i) Cosmology : Minu Joy and Kuriakose have studied structure formation using a field theoretic approach. They have used FRW metric as well as Bianchi-I metric and obtained the Jeans criteria for structure formation. In the anisotropic case, it is found that the Jeans wave number in radial and transverse directions are different. P.I Kuriakose and V.C.Kuriakose are investigating the thermodynamic properties of charged blackholes. Three M.Sc. students are doing their project studies in blackhole physics.

(ii) Observational astronomy: C.D. Ravikumar and Kuriakose, in collaboration with A. K. Kembhavi are carrying out the photometric analysis of galaxies in the nearby rich clusters observed in the near infra-red window.

(iii) Non-linear Dynamics : This is another area of research work. Ganapathy, Vinoj and V.C. Kuriakose are studying wave propagation through dispersion decreasing fibres and obtained the conditions under which optical solitons can exist in this system and they have found that such fibres can be used to achieve pulse compression. One M.Sc. student has done project work in this area. Shaju and V.C. Kuriakose have proposed new geometries for Josephson junctions and studied fluxon dynamics in these junctions and found that these systems can be used for certain superconducting devices.

(iv) Particle physics phenomenology: Ramesh Babu T. has carried out research studies in relativistic two-body bound state equations and its applications to meson spectroscopy.

(v)Atomic physics: Multiphoton process in atomic systems is another research work being carried out by Ramesh Babu T.

(vi) Chaos : Sandhya K.G. and M.Sabir are doing research studies in this area and their work is associated with the phenomenon of chaos exhibited by some mapping systems and they have investigated a new family of maps showing a different pattern in bifurcation diagrams.

Workshop:

The third workshop on "Field Theoretic Aspects of gravity" (FTAG-III) was organized by IRC during January 23-29, 2003. This workshop was sponsored by IUCAA, IMSc, and CUSAT. (see page 96).

Seminars and Colloquium:

Monthly seminars were conducted and these were attended by M.Sc. and M.Phil. students, research scholars and teachers of various disciplines. Thus, IRC provides a forum for researchers working in different areas for fruitful interactions. This year, seminars were given by

1) R. Renjith : Magneto Optical trap and Bose-Einstein Condensation.
2) S. Saravanan : A reiew on Plasma Polymerization.
3) K.P.Vijayakumar : (1) Alternative Energy Sources - a review, (2) Photovoltaic Devices.
4) Ranjeev Misra : Accretion Disks.
5) P.I.Kuriakose : Blackhole Physics.
6) Minu Joy : Some Aspects of the Early Universe.
7) M.K.Jayaraj : Electroluminescent Flat Panel Display

A one day colloquium on "Blackhole Physics" was held on March 22, 2003. V.C. Kuriakose discussed 'Spacetime structure' while P.I. Kuriakose discussed 'blackhole thermodynamics' and two M.Sc. students who were doing their project works in 'black hole physics' discussed their works.

Visitors:

Ranjeev Misra, Naresh Dadhich , T. Padmanabhan (all from IUCAA), K.Porsezian (Anna University) visited this centre during this year. Ninan Sajeeth Philip of St.Thomas College, Kozhencherry visited this centre twice for computational and reference purposes.

The Fourteenth IUCAA Foundation Day Lecture

A framework for excellence in higher education

N. R. Narayana Murthy
Chairman of the Board and Chief Mentor
Infosys Technologies Limited
Bangalore, India

Thank you for inviting me. It is a privilege to be here with you. Research centers like the IUCAA are at the core of India's efforts to create quality research infrastructure for higher education in the country. Coming from an industry where knowledge is of vital importance, the subject of higher education is indeed very close to my heart. I welcome this opportunity to speak here.

The forces of globalization and technology are continuously reshaping our world. The future will be impacted by the Internet, mapping of the human genome, convergence of technologies and falling of barriers. Thus, the 21st century will be shaped by intellectual capital. Accordingly, today, 'Knowledge' is the most important force of production that drives economic growth. In this regard, it is important for India to prepare itself to be part of the new world order created out of the knowledge revolution. Any failure to do so, will have us marginalized. In the words of Benjamin Franklin: *By failing to prepare, you are preparing to fail.*

Higher education enables human capita – the education of scientists, engineers, managers – that provides technological and managerial competence for our country. In the past, India has produced many scientists of repute. In fact, I have great respect for Prof. Jayant Narlikar who is the director of this center. People like him and Prof. Padmanabhan have done India proud. Our challenge, today, is to build a system that creates more such people of eminence.

Another important role that higher education plays is to drive innovation. Innovation drives progress. In this regard, India needs an efficient innovation system of industry and universities to create new knowledge and technology. In fact, at least 50% of all economic growth in USA since World War II has been due to technological innovation. In addition, higher education is integral to our country's economic competitiveness, since new knowledge drives business. For instance, the scientists at MIT, Harvard and other universities, have created in Massachusetts, one of the largest concentrations of biotech companies. Thus, an efficient higher education system is fundamental for success, in this era of knowledge economy.

In this overall context, let us look at where we stand? India has one of the largest higher education systems in the world. The country has 237 universities, 58 deemed universities and over 12,600 colleges as compared to only 20 universities and 500 colleges at the time of independence. In this regard, the progress has been good.

However, we face many challenges. For instance, total enrolment in higher education is only 6% of the relevant population (17-23 year olds). Further, institutions are unable to attract and retain high-quality faculty and research students. In addition, there is a lack of research focus. For instance, average number of citations per faculty member in the IITs is just three as compared to 45 at MIT. Consequently, India ranks 63 in the Technology Achievement Index of Human Development Report (HDR) 2001. Some statistics will illustrate this better. The number of patents per million residents in India is one as compared to 779 in South Korea and 289 in the US. Further, despite possessing one of the largest pools of technical talent in the world, the number of scientists and engineers employed in R&D per 100,000 people is 158 as compared to 4,103 in the US. Our higher education system has played a key role in the state we find ourselves in. Consequently, there is a pressing need for reforms in higher education. Let me now talk about these reforms.

The role of government needs to be minimized. Higher education must function as an industry in a free-market environment, while ensuring that every young man and every young woman gets financial assistance to pursue his or her chosen field of study. The state domination of higher education has led to narrow regional and caste considerations. Thus, political domination of education must be removed. The only function of the government, if any at all, may be to regulate the quality of education by setting standards.

Licensing must be removed in education. Full autonomy needs to be granted to all institutions of higher learning. Further, they should be able to decide on compensation levels for faculty, intake of students, courses and fees. Market-driven fees will enable universities to provide competitive salaries and scholarships. However, there should be suitable loan schemes so that the poorest of the poor are not denied access to the best education possible.

We must take steps to increase private sector participation in higher education. In the US, prestigious institutions such as MIT and Stanford are funded almost entirely by private money. However, in India, government has been the biggest investor in education with limited private sector participation. Public spending on education in India is about 3.2% of GNP – higher education accounted for 0.5% of GNP in 1999. However, this pales in comparison with government spending in other countries. In the US, public spending on education is 5.4% of GNP – higher education accounted for over 1.3% of GNP in 1999. This, in absolute terms, is over 50 times that of the Indian government's spending. Despite this enormous government spending, private funding plays a key role in higher education in the US. Likewise, it is essential that there is widespread infusion of private money into our higher education system.

Our universities have to benchmark their performance on a global scale. This is the only way we can hope to create a globally-competitive higher education sector. In this regard, each university should identify a set of parameters and measure how it fares in each of these with respect to the best universities in the world. For instance, at Harvard, before selecting a new faculty, the traditional question asked is: *Who is the most qualified person in the world to fill this vacancy?* Consequently, they try to convince that scholar to join. They may not always be successful in this. However, their goal is elevated by this exercise. Similarly, global benchmarking will elevate our goals and expectations.

Our universities should strive to attract the best faculty. Institutions benefit from high-quality faculty in terms of high-quality research papers and more projects. In this regard, it is important to remember that research is an integral part of any higher education system. In the words of John Slaughter, former president of Occidental College: *Research is to teaching as sin is to confession. If you don't participate in the former, you have very little to say in the latter.* Consequently, research results in more grants from industry and government.

In addition, competent faculty attracts the best students and enables the university to charge higher fees. These high-quality students lead to a strong alumni network which, in turn, forms a source of funds as well as provides mentoring to students. In the words of Henry Rosovsky of Harvard University, one of the reasons why Harvard is so special is its *faculty that continually seeks to create new ideas and knowledge.*

In addition, meritocracy must be introduced among faculty by implementing pay-per-performance system. A system of accountability must be enforced and non-performers must be discouraged. Further, reservation of seats for students, where justifiable, must be on economic factors rather than on caste considerations.

In effect, educational institutions must be allowed to function as corporations making their own decisions. In fact, well-known universities such as Harvard and MIT operate as corporations. Revenues from consultancy projects, research papers, student fees and training programs must go to the universities involved. University research in the US has been commercialized. The 1980 Bayh-Dole Act allowed universities to patent and license their federally funded research results, thereby earning royalties.

A national research facility must be setup to allocate grants for R&D. The basis for allocation must be competency and productivity of these institutions. Our universities must compete for grants for research and projects, both from the government and the industry. In this regard, the Government of India's recent steps to encourage research in the IITs are a welcome step. For instance, Dr. Murli Manohar Joshi announced that the IITs would receive funds only if 50% of these are spent on research projects.

To build a world-class higher education system, we have to enhance our interaction with professors, researchers and students from around the world. This will enable sharing of knowledge and best practices. Thus, our universities should be given the authority to invite scholars from abroad and also to visit universities outside the country.

I believe that subsidies should only exist in basic education and not in higher education. It is unjustifiable that we continue to subsidize higher education, when only about 60% of our children study up to class 5 and when our national literacy rate is only about 65%. Students pursuing higher education do not pay market-determined fees. As a result, millions are at a disadvantage while a few thousand prosper. At the same time, we need a convenient loan scheme for students. It is extremely important to ensure that lack of ability-to-pay does not restrict students from pursuing studies of their choice. Interestingly, in the US, over time, there is a decrease in grants and an increase in loans as a means of funding higher education.

An Educational Development Finance Corporation can be setup to fund higher education through a national student loan program. Suitable regulations must be formulated to strengthen the recovery mechanism in the event of education loan defaults. In stipulating the recovery mechanism, securitization of student's future earnings can be explored. Further, a lien on the provident fund can also be considered.

We must have institutions such as Sallie Mae to provide affordable funding to students. Sallie Mae was started as a US government-sponsored enterprise and offers both federal and private loans. Federal loans are guaranteed by the US government and are cheaper than private loans that are privately insured. Presently, the company has more than seven million borrowers aggregating more than $52.9 billion in assets.

It is estimated that India will face a shortage in technical talent of about 500,000 professionals by 2005. Consequently, we have to increase the intake in institutions of higher education. Therefore, capacity in the IITs, RECs and other engineering colleges must be tripled along with improvements in infrastructure. In this regard, funding from supranational institutions such as the ADB and the World Bank may be sought.

We have seen several instances of reforms in higher education in other countries. For instance, the British government, recently, outlined a funding plan to better nurture its technologists / scientists. An annual boost of $1.97 billion in government science spending will go towards improvements such as higher pay for researchers and better-equipped laboratories. Britain plans to establish a 'National Center for Excellence in Science.' Further, China, through its trans-century education project, has made higher education a national priority. Each university involved in the project has been made autonomous. The Chinese ministry of education has granted more than $200 million to each university. These universities have formed alliances with top international companies for funding and research facilities.

Our universities have to take active interest to establish new partnerships with the industry. An example of such a partnership is MIT's *Leaders for Manufacturing* program. In this program, a group of American industries have joined with MIT to conduct research and educational courses that create new approaches to manufacturing. At the same time, this program will also prepare students who have both the technical and managerial expertise to lead tomorrow's manufacturing companies.

Businesses must be consulted by academic institutions in curriculum design and conducting of courses. For instance, in developed countries, the curriculum is continually updated in tune with the demands of business. In fact, considering the trend of increased outsourcing by US businesses, the Wharton School has recently introduced a course on managing outsourced work.

Further, we need to reform our method of teaching. Unfortunately, teaching in India has followed method-of-rote rather than learning-by-doing. In this regard, courses must contain a real-life project component.

New models of higher education are emerging. Technological and economic changes require individuals to constantly upgrade their skills and knowledge base. For instance, estimates of the size of the market in the United States for higher education services that meet this need for ongoing learning are between 75 million and 100 million, much higher than 15 million currently enrolled at higher education institutions. Thus, existing institutions, using present methods, cannot meet this demand. Hence, we need new models of higher education like the E-learning programs. E-learning enables resource-scarce countries like India to disseminate education. Further, the Internet can enable collaborative teaching and learning across institutional boundaries. For instance, with suitable technology, a class in an engineering college in Satara can now attend lectures of a professor from IIT, Mumbai. Thus, we have to leverage the Internet and other modern technologies to enhance efficiency in higher education.

In addition, access to updated and quality information is critical for research and development. In this regard, colleges must be provided with the latest teaching tools, PCs and Internet connectivity. High-speed Internet connectivity will enable faculty and research students to access and to share information from research databases around the world.

Today, according to some estimates, over 500 technology companies in Silicon Valley are headed by Indians. Further, India is the second largest contributor of 'Expat' managers to Coke after the US. In addition, around 20 percent of software developers in Microsoft are Indians. In the words of Bill Gates: *India is well on its way to becoming a global economic power.* To accelerate this, an effective higher education system is a necessary condition.

I remain optimistic that academia, industry and the government will come together to create a system, where access to high-quality higher education is available to the poorest of the poor; where faculty and students compete to gain entry into world-class universities; and where research flourishes. That, my friends, is what India is all about. Let us make it happen.

Thank you.

IUCAA

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