IUCAA

INTER-UNIVERSITY CENTRE FOR ASTRONOMY AND ASTROPHYSICS

(An Autonomous Institution of the University Grants Commission)

Annual Report

(April 1, 2000 - March 31, 2001)

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HIGHLIGHTS OF 2000 - 2001

This annual report covers the activities of IUCAA during its twelfth year, April 2000 -March 2001. The endeavours of IUCAA span different fronts, as outlined in the pages of this Report. Here is a quick summary and highlights.

IUCAA has an academic strength of 14 Core Faculty Members, 9 Post-doctoral Fellows and 13 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 gravity, brane models, classical general relativity, gravitational waves, cosmological structure formation, cosmic microwave background radiation, physics of the cosmological constant, quasi-steady state cosmology, investigations of the QSO absorption systems, IGM, bulges and centres of galaxies, observations of infrared galaxies, properties of interstellar dust, relativistic astrophysics, different aspects of neutron star physics, neural networks and development of the instrumentation for the IUCAA Telescope. These research activities are summarised in pages 16-43.

The publications of the IUCAA members, numbering to about 148 in the current year are listed in pages 64-69. IUCAA members also take part in pedagogical activities like lectures, seminars, popularisation of science, etc., the details of which are given in pages 74-84 of this Report.

The extended academic family of IUCAA consists of 80 Visiting Associates, who have been active in several different fields of research. Pages 44-59 of this report highlights their research contributions, spanning theoretical physics, nonlinear dynamics, quantum gravity, quantum cosmology, quantum field theory in curved spacetime, gravity in higher dimensions, exact solutions, alternative theories of gravity, early universe, cosmology, quasars, gravitational lensing, galactic dynamics, inter-stellar matter, star formation, neutron stars, strange stars, convection, solar coronal heating, solar system studies, plasma physics, atmospheric physics and chemistry, atomic and molecular physics, observational astronomy, X-ray astronomy and instrumentation. The resulting publications, numbering to about 99 are listed in pages 70-73 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 440 visitors throughout the year.

IUCAA conducts its graduate school jointly with the National Centre for Radio Astrophysics, Pune. Among the research scholars, one student has successfully defended his thesis and obtained Ph.D. degree from the University of Pune during the year 1999-2000. Summary of his thesis appears in pages 60-63.

Apart from these activities, IUCAA conducts several workshops, schools and conferences each year, both at IUCAA and at different university/college campuses. During this year, there were 13 such events in IUCAA and 5 were held at other universities/colleges under IUCAA sponsorship.

Another main component of IUCAA's activities is its programme for Science Popularisation. On the National Science Day this year, several special events were organised including an inter-school science festival with over 550 students from 90 schools in the region participating in it. IUCAA also organised a special event in March to celebrate the 150th anniversary of the Foucault Pendulum, which attracted nearly 800 visitors from the public.

These activities were ably supported by the scientific and technical, and administrative staff (21 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 look after the major facilities like Library, Computer Centre and Instrumentation Laboratory. A brief update on these facilities is given on pages 95-98 of this Report.

IUCAA has plans for a 2-metre new technology telescope for observational research. The telescope is being made under contract with the Particle Physics and Astronomy Research Council of the UK Government. It will be located on a hill near Giravali, about two and half hours drive from IUCAA.

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The Council and the Governing Board

The Council

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Hari Gautam,
Chairperson,
University Grants Commission, New Delhi.

Vice-President

A.S. Nigavekar, (from September 2000)
Vice-Chairman,
University Grants Commission, New Delhi.

Members

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

A.K. Banerjee, (till December 2000)
Vice-Chancellor,
Calcutta University, Kolkata.

A. Bhanumathi, (till December 2000)
Solid State Physics Laboratory,
Andhra University, Visakhapatnam.

Arvind Bhatnagar,
Emeritus Scientist,
Udaipur Solar Observatory, Udaipur.

M. Bhattacharyya (from January 2001)
Vice-Chancellor,
West Bengal University of Technology, Kolkata.

P. Bhattacharyya, (till December 2000)
Vice-Chancellor,
Tezpur University, Tezpur.

Suresh Chandra, (till December 2000)
Swami Ramanand Teerth Marathwada University,
Nanded.

L. Chaturvedi, (from January 2001)
Banaras Hindu University, Varanasi.

S.M. Chitre, (from January 2001)
Tata Institute of Fundamental Research, Mumbai.

Ramanath Cowsik, (from January 2001)
Director,
Indian Institute of Astrophysics, Bangalore.

N.K. Dadhich, (till December 2000)
IUCAA, Pune.

G.G. Dandapat, (from October 2000)
Officiating Secretary,
University Grants Commission, New Delhi.

S.H. Devare, (till December 2000)
Honorary Professor,
University of Pune, Pune.

R.P. Gangurde, (till September 2000)
Secretary,
University Grants Commission, New Delhi.

S. Gopal, (from January 2001)
Vice-Chancellor,
Mangalore University, Mangalore.

A.K. Goyal, (till December 2000)
Hans Raj College,
University of Delhi, Delhi.

K. Babu Joseph, (till December 2000)
Vice-Chancellor,
Cochin University of Science and Technology,
Kochi.

A.W. Joshi, (from January 2001)
University of Pune, Pune.

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

S.S. Katiyar, (from January 2001)
Vice-Chancellor,
Chhatrapati Shahu Ji Maharaj University, Kanpur.

C.L. Khetrapal, (from January 2001)
Sanjay Gandhi Post-Graduate Institute of
Medical Sciences, Lucknow.

A.S. Kolaskar, (from March 2001)
Vice-Chancellor,
University of Pune, Pune.

N. Kumar, (till December 2000)
Director,
Raman Research Institute, Bangalore.

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

N. Mukunda, (till December 2000)
Centre for Theoretical Studies and Department of Physics,
Indian Institute of Science, Bangalore.

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

A.S. Nigavekar, (till August 2000)
Vice-Chancellor, University of Pune, Pune.

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

T. Padmanabhan, (from January 2001)
IUCAA, Pune.

K.N. Pathak, (from January 2001)
Vice-Chancellor,
Panjab University, Chandigarh.

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

D.C. Reddy, (till December 2000)
Vice-Chancellor,
Osmania University, Hyderabad.

P. Rama Rao, (from January 2001)
Vice-Chancellor,
University of Hyderabad, Hyderabad.

A. Sankara Reddy, (from January 2001)
Sri Venkateswara College, New Delhi.

K. Siddappa, (from January 2001)
Vice-Chancellor,
Bangalore University, Bangalore.

D.K. Sinha, (till December 2000)
Vice-Chancellor,
Visva Bharati, Santiniketan.

R.S. Shastri, (till December 2000)
Vice-Chancellor,
Pandit Ravishankar Shukla University, Raipur.

N.J. Sonawane, (from September 2000)
Officiating Vice-Chancellor,
University of Pune, Pune.

Member Secretary

J.V. Narlikar,
Director, IUCAA.

The Governing Board

Chairperson

R.P. Bambah

Members

A.K. Banerjee (till December 2000)
Arvind Bhatnagar
A. Bhanumathi (till December 2000)
L. Chaturvedi (from January 2001)
Ramanath Cowsik (from January 2001)
N.K. Dadhich (till December 2000)
G.G. Dandapat (from October 2000)
R.P. Gangurde (till September 2000)
A.S. Kolaskar (from March 2001)
N. Kumar (till December 2000)
Sipra Guha-Mukherjee
A.S. Nigavekar (till August 2000)
Rajaram Nityananda
T. Padmanabhan (from January 2001)
K.N. Pathak (from January 2001)
D.C. Reddy (till December 2000)
K. Siddappa (from January 2001)
N.J. Sonawane (from September 2000,)

Member Secretary

J.V. Narlikar,
Director, IUCAA.

Honorary Fellows

Geoffrey Burbidge,
University of California,
CASS, USA.

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

R. Hanbury Brown,
Andover, England.

A. Hewish,
University of Cambridge, UK.

Fred Hoyle,
Bournemouth, 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

till December 31, 2000

Richard Ellis,
Caltech, Pasadena, USA.

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

K. Babu Joseph,
Cochin University of Science and Technology
Kochi.

Vinod Krishan,
Indian Institute of Astrophysics, Bangalore.

J. Maharana,
Institute of Physics, Bhubaneshwar.

Franco Pacini,
Observatorio Astrofisico di Arcetri, Italy.

R. Rajaraman,
Jawaharlal Nehru University, New Delhi.

Ram Sagar,
Uttar Pradesh State Observatory, Nainital.

S.K. Trehan,
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IUCAA, Pune.

from January 1, 2001

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Raman Research Institute, Bangalore.

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

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

Pushpa Khare
Utkal University, Bhubaneshwar.

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

till December 31, 2000

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IUCAA, Pune.

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IUCAA, Pune.

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Vice-Chancellor,
Jawaharlal Nehru University, New Delhi.

D.K. Sinha,
Vice-Chancellor,
Visva Bharati, Santiniketan.

R.S. Tikekar,
Sardar Patel University, Vallabh Vidyanagar.

G. Ambika,
Maharaja's College, Kochi.

from January 1, 2001

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IUCAA, Pune.

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IUCAA, Pune.

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Vice-Chancellor,
Jadavpur University, Kolkata.

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

N.K. Dadhich,
IUCAA, Pune.

N. Unnikrishnan Nair, (from March 2001)
Vice-Chancellor,
Cochin University of Science and Technology,
Kochi.

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

R. Ramakrishna Reddy,
Sri Krishnadeveraya University, Anantapur.

The Academic Programmes Committee

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T. Padmanabhan (Convenor)
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S.V. Dhurandhar
R. Gupta
A.K. Kembhavi
V. Sahni
S. Sridhar
S.N. Tandon

The Standing Committee for Administration

J.V. Narlikar (Chairman)
T. Sahay (Member Secretary)
A.K. Kembhavi
T. Padmanabhan

The Finance Committee

R.P. Bambah (Chairperson)
A.S. Nigavekar (till September 2000)
N.K. Dadhich
G. G. Dandapat
R. P. Gangurde
J.V. Narlikar
O.P. Nigam
N. Raghavan
T. Sahay (Non-Member Secretary)

Members of IUCAA

Academic

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A.K. Kembhavi (Dean, Visitor Academic Programmes)
J. Bagchi
N.K. Dadhich
S.V. Dhurandhar
R. Gupta
S. Raychaudhury
A.N. Ramaprakash (from May 2000)
V. Sahni
Tarun Souradeep (from October 2000)
R. Srianand
S. Sridhar
S. N. Tandon

Scientific and Technical

T.D. Agarkar
N.U. Bawdekar
S.S. Bhujbal
M.P. Burse (from 30.3.2001)
V. Chellathurai
P.A. Chordia
H.K. Das
S. Engineer
D.V. Gadre
G.B. Gaikwad
S.U. Ingale
A.A. Kohok
P.A. Malegaonkar (till February 2001)
V.B. Mestry
A. Paranjpye
S. K. Pathak
S. Ponrathnam
V.K. Rai (from September 2000)
H.K. Sahu
S. Sankara Narayanan
S.K. Vijaianand (till May 2000)

Administrative and Support

T. Sahay (Chief Administrative Officer)
N.V. Abhyankar
V.P. Barve
S.K. Dalvi
S.L. Gaikwad
B.R. Gorkha
B S. Goswami
S.B. Gujar
R.S. Jadhav
B.B. Jagade
S.M. Jogalekar
S.N. Khadilkar
S.B. Kuriakose
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M.A. Mahabal
S. G. Mirkute
E.M. Modak
K.B. Munuswamy
K.C. Nair
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R.V. Parmar
B.R. Rao
M.A. Raskar
M.S. Sahasrabudhe
V.A. Samak
S.S. Samuel
B.V. Sawant
S. Shankar
D.R. Shinde
V. R. Surve
D.M. Susainathan
A.A. Syed
S.R. Tarphe
S.K. Waghole
K.P. Wavhal

Post-Doctoral Fellows

T.K. Das (from July 2000)
S. Konar
D. Mitra (August.2000 to February 2001)
T. Morel (from October 2000)
B.F. Roukema (till January 2001)
F. Sutaria (till December 2000)
P. Subramanian (from March 2001)
A. Thampan
R.G. Vishwakarma

Research Scholars

A.L. Ahuja (from August 2000)
U. Alam (from August 2000)
A. Deep (from August 2000)
A. Pai
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T.D. Saini
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S. Shankaranarayanan
J.V. Sheth
P. Singh
Y.G. Wadadekar

Project and Contractual Appointments

A.P. Chordia (from November 2000)
(Computer Centre)

T. Deoskar (till June 2000)
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M. S. Kharade (from February 2001)
(Project Officer , ERNET Project)

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Public Outreach Programme

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Quasi Steady-State Cosmology Project

N. A. Pradhan (August 2000 to January 2001)
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V S. Upreti (till June 2000)
(Project Officer, ERNET Project)

Part time Consultants

I. V. K. Babu (Sports)
D.G. Bhapkar (Gardening & Landscaping)
S. S. Bodas (Medical Services)

Visiting Members of IUCAA

Visiting Members

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K. Jotania,
Physics Division,
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M. Khan,
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P. Khare,
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A.C. Kumbharkhane,
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M.L. Kurtadikar,
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J.E.S. College, Jalna.

D. Lohiya,
Department of Physics & Astrophysics,
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G.P. Malik,
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Jawaharlal Nehru University, New Delhi.

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North Bengal University, Darjeeling.

K.K. Nandi,
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U. Narain,
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Meerut College.

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

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Department of Physics,
North Eastern Hill University, Shillong.

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Christ Church College, Kanpur.

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Osmania University, Hyderabad.

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

L.M. Saha,
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Zakir Husain College, New Delhi.

A.K. Sen,
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Assam University, Silchar.

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

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Department of Mathematics,
Visvesvaraya Regional College of Engineering,
Nagpur.

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

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

S. Singh,
Deshbandhu College, University of Delhi.

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

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

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

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

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

...till June 30, 2000

R. Bali,
Department of Mathematics,
University of Rajasthan, Jaipur.

Renuka Datta,
Bethune College, Kolkata.

S.S. De,
Department of Applied Mathematics,
University College of Science, Kolkata.

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

B. Ishwar,
Department of Mathematics,
B.R.A. Bihar University, Muzaffarpur.

S.N. Karbelkar,
College of Engineering & Technology, Akola.

P.S. Naik,
Department of PG Studies and Research in Physics,
Gulbarga University.

V.M. Nandakumaran,
International School of Photonics,
Cochin University of Science and Technology, Kochi.

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

P.C. Vinodkumar,
Department of Physics,
Sardar Patel University, Vallabh Vidyanagar.

...from July 1, 2000

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

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

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

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

Bijan Modak,
Department of Physics,
University of Kalyani.

B.C. Paul,
Physics Department,
North Bengal Unviersity, Darjeeling.

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

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

K. Shanthi,
Academic Staff College,
Mumbai University.

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

The Eleventh batch of Visiting Associates who were selected for a tenure of three years, beginning July 1, 2000.

S. K. Banerjee

Anil Borah

K. N. Iyer

A. Mittal

S. Sahijpal

K. Shanthi

B.C. Paul

The photographs of the following Visiting Assocaites from the eleventh batch are not available: Bijan Modak, M. Sami and P.K. Suresh

Appointments of the following Associates and Senior Associates from the eighth batch were extended for three years: Ng. Ibohal, Moncy John, Manoranjan Khan, Udit Narain, Ramkrishna Reddy, Asoke Kumar Sen, G.P. Singh, Santokh Singh and S.K. Srivastava.

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, Associates & Visitors
(A.K. Kembhavi)

Head, Recreation Centre
(S. Sridhar)

Head, Guest Observer Programmes
(Ranjan Gupta)

Head, Workshops & Schools
(Ranjan Gupta)

Head, Public Outreach Programmes
(A.K. Kembhavi)

The Director's Report

I invite you to browse through this report of an institution that was set up in 1988 to fulfill many different objectives. IUCAA is more than a research institute in astronomy and astrophysics (A&A). It has been given the mandate of providing facilities and know-how to the university sector so as to improve its level of teaching, research and development in A&A. The IUCAA provides on its campus an up to date library in A&A, an astronomical data centre, an instrumentation laboratory, a well kept guest house for visitors, and shortly in the future, a modern optical telescope and observatory at Giravali. Apart from inhouse research, it runs year-round pedagogical activities and also provides catalytic assistance to the university academics for guest observing in the leading observatories of the world. In addition, it has a well acclaimed programme of public outreach in science. This report contains a brief description of these activities for the year 2000-2001.

The highlight of this year's on-campus activities was the Foundation Day Lecture delivered by the distinguished social activist and Magsaysay award winner Ms. Aruna Roy. Choosing the topic Democracy and the Right to Information, Ms. Roy stressed the need for free availability of relevant information to all citizens so that they can take correct decisions in a participatory democracy. The lecture was followed by a documentary movie showing how transparency of government operation is necessary to get rid of corruption and wrong decisions. The lecture was well attended and had a profound impact.

The National Science Day (February 28) also was memorable for the tremendous public response to the various academic activities put on display, along with a well organized programme for the school students. Arvind Gupta, the freelance science educator from Delhi gave a talk to the school teachers on how to present science to students through demonstrations and experiments. The Homi Bhabha Centre for Science Education, Mumbai deputed a team with V. G. Gambhir to provide science-based demonstrations to the public. Students from the Jnana Prabodhini Prashala provided assistance in this important activity. In March, a special event of celebrating the 150th anniversary of the Foucault Pendulum attracted about 800 visitors who could also see the working model, which has been running at IUCAA for the past nine years.

Recognizing IUCAA's public outreach programmes, especially for school students, the distinguished litterateur and actor, Mr. P.L. Deshpande, had expressed his desire to make a donation to help IUCAA in these activities. After his death on June 12, 2000, his wife, Mrs. Sunitabai Deshpande has honoured that wish by announcing a donation of Rs. 25 lakhs for constructing the Muktangan Science Exploratorium in the Science Park at IUCAA. She has already made a part contribution towards this donation and when the full amount is received, a suitable building will be constructed in the Science Park area.

The IUCAA Telescope is progressing towards completion, with installation and the first light expected in the coming year. In the meantime, the observatory buildings are nearly complete and ready to receive the telescope as soon as it arrives. The buildings (see photographs in this annual report) are simple and elegant, in keeping with the style of the main IUCAA campus at Pune. In the meantime, academic discussions are taking place on the possible scientific projects to be taken on the telescope. An Optical Imaging Spectrograph, the instrument to be used with the telescope right from the beginning, is already constructed and tested.

It gives us great satisfaction to see the work at IUCAA recognized outside. T. Padmanabhan was elected Fellow of the Indian National Science Academy. Varun Sahni won the S.S. Bhatnagar award for physical sciences for his work in gravitational physics, cosmology and structure formation. R. Srianand was awarded the S.N. Ghosh Award (2000) by the Indian Society of Atomic and Molecular Physics, Ahmedabad. Naresh Dadhich received the Vaidya-Raychaudhuri Endowment Lecture award of the Indian Association for General Relativity and Gravitation.

IUCAA also receives awards for its gardens, especially in the rose shows. It was a special honour for me to be invited to speak on the success of IUCAA in Arun Shourie's national lecture series called Ideas that have worked. The title of my talk was: On Setting up a Scientific Institution. It was a pleasure to have Professor Yash Pal, the 'Founding Father' of IUCAA share his vision about the centre on that occasion.

We are happy to note that Professor Arun Nigavekar has taken charge as Vice-Chairman of the UGC. We welcome him as Vice-President of the IUCAA Council and look forward to his help and guidance in the years ahead.

Having reported on these happy and positive instances about IUCAA, let me share with you my misgivings too. It requires great cooperative effort on the part of several dedicated individuals to set up a scientific institution and to raise it to international standard. However, it is very easy to destroy such an institution through shortsighted bureaucratic interference. We look to an enlightened leadership at the UGC to ensure that this does not happen to IUCAA.

Jayant Narlikar

Awards and Distinctions

N.K. Dadhich

Two publications received Honourable Mention in the Gravity Research Foundation Essay Competition for 2000.

Nominated to deliver the Vaidya-Raychaudhuri Endowment Fund Lecture at the IAGRG meeting held at Nagpur, January 30-February 1.

S.V. Dhurandhar

Vidyeshwari Puraskar (Prabhuratna) for Science for the year 2000 by the Pathare Prabhu Society.

J.V. Narlikar

R.D. Karve Award (1998-99) of Maharashtra State for light scientific literature.

Order of Merit title bestowed by Jagatguru Shankaracharya from Hampi.

Honorary Doctor of Science, Calcutta University, January 15.

Rajarshi Shahu Award from the Rajarshi Shahu Chhatrapati Memorial Trust, Kolhapur, January 22.

Swami Vivekananda Award - 2001 from the Rashtriya Shikshan Sanstha, Dombivili, January 12.

T. Padmanabhan

Elected, Fellow of Indian National Science Academy, 2001.

V. Sahni

Shanti Swarup Bhatnagar award for the Physical Sciences for the year 2000.

R. Srianand

S.N. Ghosh award for young scientist for the year 2000.

Y. Wadadekar

R.K. Bhalla Award for outstanding reasearch student in Physics awarded by the Indian Physics Association.

Calendar of Events

2000

April 10-May 19
School Students' Summer Programme
at IUCAA

May 22-June 23
Introductory Summer School on
Astronomy and Astrophysics
at IUCAA

May 22-July 7
Vacation Students' Programme
at IUCAA

July 15-16
Workshop on Neutron Stars:
Isolated and in Binary Systems
at IUCAA

August 14
IUCAA-NCRA Graduate School
First Semester begins

September 20-22
Workshop on Nuclear Astrophysics
at IUCAA

September 30-October 1
HRD Workshop on Achieving Excellence
at Goa

October 3-6
Workshop on Stellar Structure and Evolution
at St. Berchman's College, Changanacherry

October 9-12
Workshop on Automated Data Analysis in Astronomy
at IUCAA

October 12-20
Workshop on Topics in General Relativity
at IUCAA

November 16-20
Introductory School on Astronomy and Astrophysics
at S.R.T. Marathwada University, Nanded

December 4-8
Workshop on Solar Physics
at IUCAA

December 12-20
Indo-French School on Star Bursts and the
Structure and Evolution of Galaxies
at IUCAA

December 15
IUCAA-NCRA Graduate School
First Semester ends

December 21-23
Workshop on Observing with IUCAA Telescope
at IUCAA

December 26
Seminar on The Information Age: Challenges and
Opportunities for the Library Profession
at IUCAA

December 29
Foundation Day

2001

January 1
IUCAA-NCRA Graduate School
Second Semester begins

January 8-12
Workshop on Astronomical Photometry and
Spectroscopy
at Bangalore University

January 17-19
Second Level, 1st Workshop on Astronomical
Photometry
at IUCAA

January 28-29
Discussion Meeting on Cosmology
at Nagpur

February 7-10
Young Astronomers' Meet
at IUCAA

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

Covariance of Hawking radiation

One of the main preoccupations of theoretical physicists for the last three decades has been the search for a consistent theory of quantum gravity involving the unification of quantum mechanics and general theory of relativity. Even though there are many models and approaches, (like Superstring theory and Loop quantum gravity) none of these have given a complete theory that works at the Planck energy scales.

The subject of quantum fields in curved space time [in which the matter fields are quantized while the metric is classical] is an area which might provide clues regarding the possible structure of quantum gravity. Understanding the origin of black hole entropy is one key issue in this area and has been an active field of research after Hawking's discovery of particle creation by black holes.

Hawking showed that quantum field theory in the background of a body collapsing to a black hole will lead, at late times, to a radiation of particles in all modes of the quantum field, with characteristic thermal spectrum at a temperature inversely proportional to the mass of the black hole. It is normally assumed that the evaporation process results from an instability of the vacuum in the presence of the background metric. The particles are produced at a constant rate suggesting that the Hawking radiation converts the mass of the black hole into energy, thereby decreasing the mass. The decrease in the black hole mass is a physical effect and should be independent of the coordinate systems used to analyse the process; that is, *Hawking radiation should be covariant.* However, the concept of a particle in quantum field theory is not generally covariant and depends on the coordinates chosen to describe the particular space-time.

The methods used earlier in the literature for calculating the black hole particle production involves either the evaluation of Bogoliubov coefficients by identifying the wave modes or calculation of the probability amplitude for the emission/absorption process, in the fully extended manifold. Recently, K. Srinivasan and *T. Padmanabhan* have obtained Hawking radiation using the method of complex paths (used in non-relativistic quantum mechanics). The authors modified the method of complex paths appropriately to produce a prescription that regularizes the singularity in the action functional and recovered Hawking radiation.

S. Shankaranarayanan and *Padmanabhan* (along with K. Srinivasan) have now applied the technique of complex paths to obtain Hawking radiation in different coordinate representations of the Schwarzschild space-time. The coordinate representations they consider, do not possess a singularity at the horizon (unlike the standard Schwarzschild coordinate). However, the event horizon manifests itself as a singularity in the expression for the semi-classical action. This singularity is regularized by using the method of complex paths and they find that Hawking radiation is recovered in these coordinates, indicating the covariance of Hawking radiation.

Vanishing of the cosmological constant

In recent years, there has been considerable interest in the idea of a brane world in which our (four-dimensional) world is considered to be a 3-brane embedded in a higher-dimensional space-time with large extra space dimensions. In these models, the gauge and matter fields are localized on the 3-brane and gravity is allowed to propagate in the extra dimensions. Since the Planck scale is traded for the size of the extra dimensions, the unification of gravity and gauge coupling can occur at scales as low as a TeV.

Sometime back, Lisa Randall and Raman Sundrum have considered a five dimensional warped space-time, in which the extra dimension need not be compact and that four-dimensional gravity can naturally arise at large distances. They showed that there exists a zero mass mode which looks like a four-dimensional graviton bound to the brane, together with a continuum of massive Kaluza-Klein modes arising from the linear fluctuations about the three-brane (four-dimensional Minkowski) background.

This work, however, assumed that the four dimensional world is a flat space-time which is quite unrealistic. *Padmanabhan* and *Shankaranarayanan* have now succeeded in solving the equation for graviton propagation in a *general* four dimensional background and finding an explicit solution for a zero mass bound state of the graviton. They used this solution to study a wider class of four-dimensional space-times including the four-dimensional Schwarzschild background and de Sitter universe.They find that this zero mass bound state is normalizable only if the cosmological constant is *strictly* zero, thereby providing a dynamical reason for the vanishing of cosmological constant within the context of this model. They also show that the results of Randall and Sundrum can be generalized without any modification to the Schwarzschild background.

Effective neutrino-photon interactions in a magnetised medium

It has been shown recently that neutrinos acquire an effective charge in the presence of a medium. *Sushan Konar*, along with Kaushik Bhattacharya, Avijit K. Ganguly (SINP, Kolkata) have demonstrated that the same result arises if there is an external magnetic field or a medium or both. Charged particles, like electrons, interact with photons and if the corresponding leptons are present then - through the lepton neutrino weak-interaction - an effective neutrino-photon interaction is generated. This can be interpreted as the neutrino acquiring an effective charge. They calculate this effective charge in a magnetised medium and show that the effective charge depends on the direction of the neutrino propagation with respect to the magnetic field.

Classical Gravity

Gravitational collapse in a constant potential bath

An interesting question in gravitational astrophysics has been the ultimate state of a collapsing massive star. Does it become black hole (BH) straightaway or does it first give rise to naked singularity (NS)? It has been generally accepted that either case is possible given the proper initial data. Since, there seems to be no physical justification to rule out the initial data giving rise to NS, the question is open and deserves consideration from various angles. The standard analysis, however, does not say anything about the nature of singularity. There exists no criterion for stability of the process either. Under the circumstances, it seems reasonable to study various situations and examine the results.

There is one specific case of the collapse of the null radiation fluid described by the Vaidya solution, in which there exists a parameter that measures the rate of collapse and demarcates the two cases of BH and NS. Sanjay Jhingan, *Naresh Dadhich* and Pankaj Joshi have attempted to study the stability of this case when the whole system is immersed in a constant gravitational potential bath. Such a constant potential is physically non-trivial in general relativity (GR) in contrast to the Newtonian theory. This is reflected by the fact that in GR, the absolute value of the energy can be determined. A collapsing system like a star can be thought of being located in a larger system (like a star cluster or a galaxy), which could produce a constant potential at the star's location. Jhingan, *Dadhich* and Joshi have studied the null radiation collapse in such a setting and found that the process is stable against this change. The potential does, however, appear in the critical value of the demarcating parameter which distinguishes the two end stages. This shows that the process giving rise to BH/NS seems to be quite robust and stable for the change of enviornment as indicated above.

Negative is positive

Energy associated with non-gravitational sources is always taken to be positive while gravitational field energy is always negative. The former produces attractive force between the particles while the latter's gravitational interaction is mediated through space curvature in general relativity. It is the positive energy of non-gravitational sources which produces negative field energy of gravity. By taking the specific example of the Schwarzschild spacetime, *Naresh Dadhich* demonstrates that the space curvature acts in consonance with the potential gradient (that is, curvature also makes free particles slide down towards the central mass point) only when it is negative. Negative curvature is produced by the negative field energy.

Dadhich argues that all non-localizable energy distribution should follow the characteristics of the gravitational field energy. That is, the "positive" energy condition for non-localizable energy is that it should be "negative". Whenever this condition is violated, it will produce an opposite effect, as is the case of the charged black hole in which positive energy density of electric field produces a repulsive contribution. In the case of de Sitter spacetime, the non-localizable energy density of vacuum is positive and hence gives rise to repulsion while in anti-de Sitter spacetime, the opposite situation arises.

This result has a non-trivial application in the recent work on the brane world model. The 4-dimensional universe with standard matter and fields is called the brane which is considered as a hypersurface in 5 (or higher dimensional) space called the bulk. One of the most popular models (due to Randall and Sundrum) envisages a bulk being a space with negative cosmological constant. The backreaction of the bulk on the brane manifests as a trace free stress tensor on the brane. That is, the free gravitational field energy in the bulk induces a trace free matter field on the brane. If we now consider a static black hole on the brane, then it would be located in a trace free matter field, which will obviously be a non-localizable energy distribution unless the bulk is anti-de Sitter having vanishing free field energy. *Dadhich* argues that the induced energy density must be negative so as to act in unison with black hole's gravity if the black hole's gravity is to enhanced as expected for high energy corrections to GR.

Dynamics of a field and particle

The equation of motion for a field is, in general, separate and independent of equation of motion for particle moving in the field. The motion of the particle is, however, governed by the field. Could there exist a relation between the two?

It is clear that there can be no direct relation. What at best could happen is that by adding some constraints on the equation of motion, one can deduce the field equation. In general relativity (GR), we, however, have the opposite situation, in which the equation of motion for the particle could be deduced from the field equation. This is because, solution of the field equation determines the space-time geometry and the particle follows the geodesics in this geometry.

In the previous year, *Parampreet Singh* and *Naresh Dadhich* have deduced the Maxwell's equation by demanding, (i) the force law in equation of motion for a particle should be linear in velocity and (ii) the whole system of equations should be solvable. It turns out that if one switches over to the relativistic framework, all this follows efficiently and elegantly. When the relativistic equation of motion is linear in the 4-velocity of the particle, then the corresponding field theory is the vector gauge theory, which could be Abelian or non-Abelian. Further, this deduction is independent of the background space-time which could be flat or curved.

The question arises as to what happens when the particle equation is quadratic in 4-velocity? Could it lead to GR? *Singh* and *Dadhich* show that this is exactly what happens. It is remarkable that the quadratic force law requires the space-time metric to be its potential and does not let the space-time to remain inert as in the case of all other forces. This marks a fundamental difference and indicates that the quadratic force is special.

They further argue that if the force field is globally non-removable, then space-time must be curved. For the curved spacetime, the Einstein's equation follows quite naturally and immediately from the Bianchi identity with proper identification of energy momentum distribution with the divergence free second rank symmetric tensor. Thus, the GR field equation for gravitation is deduced by demanding the force law to be quadratic.

The characteristic of gravity is, therefore, quadratic force law, while that of the electromagnetic field is the linear law. This feature brings about an interesting kind of synthesis between particle and field dynamics.

Gravitational Waves

The existence of gravitational waves (GW), which is predicted in general relativity, has long been verified indirectly through the observations of Hulse and Taylor. The inspiral of the members of the binary pulsar system named after them has been successfully accounted for in terms of the backreaction due to the radiated GW. However, detecting such waves with man-made antennas has not been possible so far. Nevertheless, this problem has received a lot of attention in this decade, especially due to the arrival of laser-interferometric detectors, which are expected to have sensitivities close to that required for detecting such waves.

The key to GW detection is the very precise measurement of small changes in distance. For laser interferometers, this is the distance between pairs of mirrors hanging at either end of two long, mutually perpendicular vacuum chambers. GW passing through the instrument will shorten one arm while lengthening the other. By using an interferometer design, the relative change in length of the two arms can be measured, thus signalling the passage of a gravitational wave at the detector site. Long arm lengths, high laser power, and extremely well-controlled laser stability are essential to reach the requisite sensitivity. GW detectors produce an enormous volume of output consisting mainly of noise from a host of sources both environmental and intrinsic. Buried in this noise will be the gravitational wave signature. Sophisticated data analysis techniques need to be developed to optimally extract physical information.

In about two years, several large scale detectors will go online. These include LIGO, composed of two Laser Interferometer Gravitational-wave Observatories situated in the United States, each with baselines of 4 km, VIRGO, an Italian/French project located near Pisa with a baseline of 3 km, GEO600, a British/German interferometer under construction near Hannover with a baseline of 600 m, TAMA in Japan, a medium-scale laser interferometer with a baseline of 300 m, and with funding approval AIGO500, the proposed

500 m project sponsored by ACIGA. The TAMA is currently the worlds largest detector in operation, since it came into operation in 1999. The first long-term continuous data was taken in the autumn of 1999 for a period of three days and about a third of the data is sufficiently good for serious search of GW. The LIGO detectors have had three engineering data runs and are now gearing up for a fourth engineering run in a few months time. The engineering runs are useful for detector diagnostics, where one aims to remove some of the noise in the hardware.

There are also separate proposals for space-based detectors which could be operational twenty-five years from now. Earth based detectors operate in the high frequency band $\sim 10-10^4$ Hz, while the space based detectors will operate in the low frequency band $10^{-4} - 10^{-1}$ Hz. The premier instrument in space is the Laser Interferometer Space Antenna (LISA). The European Space Agency (ESA) has selected LISA as one of the 'cornerstone' missions in the Horizon 2000+ programme and NASA has also got involved in effort. There is, thus, a possibility of flying LISA as early as 2010.

Data analysis has now been recognised as a key aspect in searching for gravitational waves. Experience in handling large volumes of data and the development of appropriate analysis algorithms will, therefore, play a vital role in the eventual success of gravitational wave detection. Prior to these instruments becoming fully operational, data analysis is also an essential diagnostic tool. In this worldwide effort, IUCAA has contributed substantially, especially, in gravitational wave data analysis through important international collaborations.

(i) IUCAA and the LIGO project team signed an MOU entailing the tasks IUCAA would undertake in return for LIGO-I data. IUCAA joined the Ligo Science Collaboration (LSC) under which *S. V. Dhurandhar* and his group are a part of an international group on network analysis, where the aim is to study the optimal way in which the data can be combined from different detectors while searching for a burst source. Another task is to extend the hierarchical scheme (previously devised by S.D. Mohanty and *Dhurandhar*) for searching for GW signals from inspiralling compact binary stars by adding an extra parameter, namely, the time-of-arrival. Including another parameter in the hierarchy further cuts down on the computational cost.

(ii) With the French Group led by J-Y Vinet of Observatory at Nice and P. Hello at LAL, Orsay, *Dhurandhar* has a collaboration under the IFC-PAR (Indo-French Centre for the Promotion of Advanced Research). The project which began in May 2000 addresses data analysis issues concerning the LISA project mentioned above. The problem of cancellation of laser frequency noise by appropriately combining data from the several data streams is being investigated as the first project.

(iii) Recently, a collaboration with the Japanese TAMA group was explored and a project outline has been submitted to the funding agencies DST-JSPS. The goals of the project are: (i) Evaluate search algorithms for coalescing binaries on real data from TAMA300 and the 20-metre detector at Kamiokande, (ii) estimate the computational costs for known X-ray sources such as Sco X-1 and determine errors in the parameters of the sources.

The work on the detection of inspiraling compact binaries with a network of laser interferometric detectors by *A. Pai, Dhurandhar* and S. Bose has been instrumental in deciding the topics of research in the LIGO and the Japanese collaborations.

Bose, *Pai* and *Dhurandhar* have formulated a coherent search strategy (phase information of the signal is crucially used) based on the maximum likelihood method, which optimally extracts the coalescing binary signal from the network data as described in last year's report. Further, using clever analytical maximisations, the strategy substantially cuts down on the computational cost. The strategy is analogous to the aperture synthesis used by radio astronomers.

Pai, Dhurandhar and Bose are now extending their analysis to include post-Newtonian corrections upto the 2.5 order. Preliminary results show that there is about an 8-fold increase in the computational cost.

Hierarchical search for inspiraling binaries:

During the past few months *A. Sengupta* and *S. V. Dhurandhar*, A. Lazzarini and T. Prince from Caltech have been extending the hierarchial search technique (developed by *Dhurandhar* and his collaborators and reported in previous annual reports) to a third parameter: the time-of-arrival. This work is part of the LSC tasks. Advantage is taken of the fact that most of the power in the chirp signal is at low frequencies $\propto f^{-7/3}$. Hence, the upper cut-off frequency can be substantially reduced - by something like a factor of 6 - without losing too much signal power and the data sampled at the reduced Nyquist frequency, saving the computational cost of the FFTs in the triggering stage. So far, the method is applied to the Newtonian templates and the gain in computational cost rises to about 45. A similar increase in gain is expected in the post-Newtonian case where it could increase to more than 150.

Continuous wave sources:

Continuous wave (CW) sources pose one of the most computationally intensive problems in GW data analysis.

The accretion of hot material onto the NS surface is a promising scenario among continuous wave sources. Here, the induced quadrupole moment is directly related to the accretion rate, which can be copious. The gravitational energy reservoir, moreover, can be continuously replenished, if persistent accretion occurs. The key idea behind this scenario is that gravitational wave radiation can balance the torque due to accretion. It has attracted considerable new interest in the past two years and has been fully revitalized by the launch of the Rossi X-ray Timing Explorer, designed for precision timing of accreting neutron stars. The physical process responsible for producing a net quadrupole moment is the change of composition in the NS crust, which in turn is produced by the temperature gradient caused by the in-falling hot material. If such mechanism does operate, LMXBs are extremely interesting candidate sources for earth-based detectors. Several systems would be detectable by LIGO operating in the "enhanced" configuration (LIGO II), if the detector sensitivity is tuned, through narrowbanding, around the emission frequency. In particular, Sco X-1, the most luminous X-ray source in the sky, possibly is marginally detectable by "initial" LIGO and GEO600 (the latter in narrow-band configuration), where an integration time of approximately 2 years would be required.

A. Vecchio and *S. V. Dhurandhar* estimated the cost for searching GW from the X-ray source Sco X-1. H. Tagoshi, N. Kanda, M. Fujimoto and *Dhurandhar* are proposing to study other X-ray sources, which could also be CW sources of gravitational waves. This work will be under the DST-JSPS cooperative research programme. Also, they propose to analyse the accuracy to which the physical parameters of the sources can be determined.

Cancelling laser frequency noise in LISA:

The goal of LISA is to detect and study low frequency astrophysical GW. The astrophysical sources that LISA could observe include galactic binaries, extra-galactic supermassive black hole binaries and coalescences, stochastic and 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.

In ground based detectors, the arms are chosen to be of equal length so that the laser light experiences identical delay in each arm of the interferometer. This arrangement precisely cancels the laser frequency/phase noise at the photodetector. This cancellation of noise is crucial since, the raw laser noise exceeds by several orders of magnitude of the other noises in the interferometer. The required sensitivity of the instrument can, thus, only be achieved by near exact cancellation of the laser frequency noise. However, in LISA, it is impossible to maintain equal distances between spacecrafts, and the laser noise cannot be cancelled in an obvious manner. Several schemes, some quite elaborate, have been proposed which combine the recorded data by suitable time-delays corresponding to the three arm lengths of the giant triangular interferometer. These schemes seem to have been obtained in a ad-hoc manner.

The salient achievement of the work (under the IFCPAR programme) by H. Arjunwadkar, *S. V. Dhurandhar* and J-Y. Vinet consists of providing a *systematic method* based on difference equations, which not only reproduces the previously obtained data combinations but can construct, in the mathematical sense, all the data combinations that cancel the laser noise. The importance of obtaining as many as possible data combinations is clear; it provides a selection for optimising the statistic for a given astrophysical source. The method involves advanced techniques of algebraic geometry. The set of data combinations is a module over a polynomial ring in three indeterminates - the three time-delays associated with the three sides of the LISA triangle. The problem then reduces to generating this module - in the literature called the first module of 'syzygies'. There are methods in the literature of algebraic geometry for obtaining the generators for such a module. In fact, there is a software called Macaulay 2 which computes the generators. The generators provide a natural parametrisation of the module; it will be useful for computing those data combinations that maximise signal-to-noise, provide accurate information about the physical parameters of the source, etc.

The advantage of this technique is that it is general enough to encompass the cancellation of acceleration noise in masses. Work on this aspect is being vigourously being pursued by the Indian and French teams.

Cosmology and Structure Formation

Geometrical analysis of large scale structure in the universe

The universe displays a clustering pattern which extends from the smallest to the largest scales. Thus, stars are organised into globular clusters and galaxies while galaxies are concentrated in clusters which in turn form superclusters. The extent of clustering in the universe ranges from scales of a few parsec to several tens or even hundreds of megaparsec. While statistical measures such as the correlation function measure the presence of clustering in the universe, they do not address the equally important issue of morphology. It is now abundantly clear that galaxies cluster together preferentially in elongated, anisotropic structures which gives the supercluster-void network, the appearance of being 'web' like. To further investigate the properties of the 'cosmic web' requires the development of sophisticated statistical tools which are sensitive to morphology. *Varun Sahni* and *Jatush Sheth* have been developing measures which rely on such geometrical quantifiers as 'volume', 'surface area', 'mean curvature' and 'Gaussian curvature' (or genus) with which to investigate the large scale structure of the universe. These statistical measures, collectively known as the 'Minkowski functionals' are sensitive probes of the shape, filling factor and topology of overdense regions (superclusters) as well as underdense regions (voids). They can, therefore, be used to study the geometrical and topological properties of large scale structure, quantifying issues which include: the presence of sheet-like and filament-like distributions in superclusters and voids, percolation properties of the supercluster-void network, etc.

In order to apply this method to galaxy surveys and N-body simulations, one needs to model a surface corresponding to individual clusters and superclusters and compute its surface area (S), enclosed volume (V), the integrated mean curvature (C) and the integrated Gaussian curvature or genus (G). (The genus describes the number of holes in the surface.) The shape of an individual cluster, supercluster or void is then described by two numbers: its 'filamentarity' $F = (C/G - S/C)/(C/G + S/C)$ and its 'pancakeness' $P = (S/C - V/S)/(S/C + V/S)$.

Sheth has developed software which models a surface for a given cluster or supercluster while simultaneously allowing the online computation of the Minkowski functionals and related statistics using the Marching Cubes Algorithm. The surface is modelled using 'triangulation' techniques (an example is shown in Fig. 1) which allow fairly complicated and topologically non-trivial surfaces to be represented in terms of an association of triangles. Mathematically, the Gaussian curvature of a given surface is focussed in the vertices of its triangles, while its integrated mean curvature is focussed in triangle edges. Therefore, the calculation of the Minkowski functionals reduces to the evaluation of the angles between neighbouring surfaces and other discrete geometric quantities. The computed values of area, volume and integrated mean curvature have been found to be 95% accurate for most surfaces while the genus is 100% accurate.

The clustering of galaxies can be studied by creating an equivalent density-distribution, which is generated on a grid by conserving the total mass. After generation of the density-distribution, a catalogue of clusters and superclusters is created by using the 'Clusterfinder' code developed specially for this purpose. Next, one computes the Minkowski functionals and Shapefinders for a given cluster by modelling its surface using the Marching Cubes Algorithm.

Sahni and *Sheth* will apply Minkowski functionals to the study of geometrical patterns characterising the large scale structure of the universe, using for this purpose, high resolution N-body simulations as well as galaxy catalogues. It should be pointed out that although the present software has been written keeping in mind applications to cosmology, in practice it can be successfully applied to a whole range of physical processes, including the study of filaments and sheets in the interstellar medium, gravitational lensing, etc.

Topology of the percolating universe

The process of gravitational clustering of a linear, Gaussian, primordial density perturbation field leads to highly non-linear and non-Gaussian field. *Tarun Souradeep* has been interested in a numerical study of topological descriptors of initially Gaussian and scale-free density perturbations evolving via gravitational instability in an expanding universe. The topology of the excursion sets, $E^{+}_{\delta_{th}} = \{\mathbf{x}|\delta(\mathbf{x}) \geq \delta_{th}\}$, of the evolving density field $\delta(\mathbf{x})$, is a sensitive probe of the process of gravitational clustering. In collaboration with S. Colombi and D. Pogosyan, *Souradeep* developed a statistical measure of the connectivity of the excursion set based on the number distribution of critical points (maxima, minima and saddle points) of the density field within the excursion set as a function of density threshold. The measure was later discovered to have firm mathematical footing in the Morse theory for critical points and was, in fact, the Euler characteristic of the excursion set. The main result is that independent of extent of non-linearity,

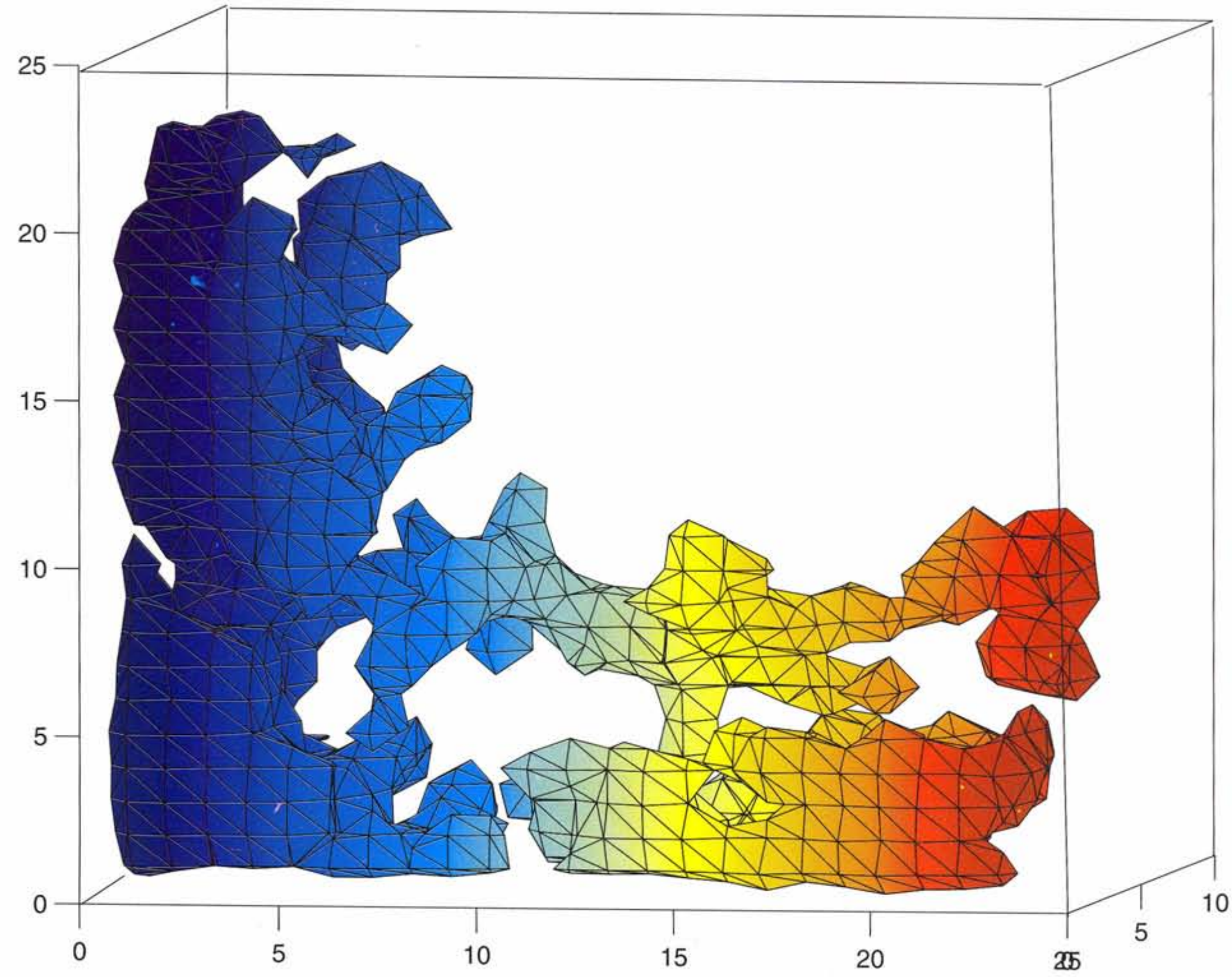


Figure 1: A supercluster in a Λ-CDM model is shown after triangulation.

the measured Euler number of the excursion set at the percolation threshold, δ_c, is positive and nearly equal to the number of isolated components, suggesting that these structures are trees. This study of critical point counts reconciles the clumpy appearance of the density field at δ_c with measured filamentary local curvature.

An important aspect of the work was to carefully evaluate and avoid numerical contamination in making accurate measurements on simulated fields on a grid in a finite box. The percolation threshold as a function of the smoothing scale shows two distinct regimes. For smoothing less than the grid size, the percolation threshold is a strong function of the smoothing scale. At larger smoothing scales, the variation of δ_c is mild. In the Gaussian limit, we measure $|\delta_c| > \sigma$ in contrast to widely held belief that $|\delta_c| \sim \sigma$, where σ^2 is the variance of the density field.

The accelerating universe and the cosmological constant

Recent observational work aimed at determining the fundamental parameters of the universe places considerable premium on Type Ia supernovae as 'standard candles'. The reason for this has to be with the high absolute luminosity of a Type Ia supernova ($M_B \simeq -19.5$ mag), which makes it possible to observe these objects at cosmological scales. Additionally, the variability of SnIa luminosity is small and an empirical relation exists between the decline in the luminosity of the supernova and its absolute luminosity. (A brighter supernova fades away more slowly than the one which is less bright.) These properties make Type Ia supernovae excellent standard candles with which one can probe the geometry of the universe and its expansion rate. Several dozen high redshift supernovae have been researched by two teams: the Supernova Cosmology Project and the High-Z Supernovae Search Team. Their results seem to indicate that high redshift supernovae appear *fainter* than expected in a standard spatially flat matter dominated FRW universe.

Within the framework of Einstein's theory of gravity, the apparent luminosity of an object is related to the rate of expansion of the universe. The observed faintness of high redshift supernovae can therefore, be taken to mean that the universe is expanding at a faster rate than it would in a standard matter dominated FRW model. In other words, the universe we live in is 'accelerating' ! In Einstein's theory, both the pressure of matter as well as its density, contribute to the acceleration of the universe through the equation $\ddot{a} \propto -(\rho + 3P)$. Since the density is always positive, the only way one can get the universe to accelerate is by postulating the existence of matter with negative pressure. Theoretically, the best known form of such matter is the cosmological constant Λ, introduced by Einstein in 1917. However, the energy density associated with Λ remains constant with time, and therefore, its currently observed value $\rho_\Lambda = \Lambda/8\pi G \sim 10^{-30}$ g cm^{-3} must also be a universal constant. Since, in an expanding universe, the densities of normal matter and radiation evolve rapidly $\rho_m \propto a^{-3}, \rho_r \propto a^{-4}$, one is forced into assuming that the ratio ρ_Λ/ρ_r was $\sim 10^{-53}$ at the electroweak epoch when the temperature of the universe was $T \sim 1$ TeV (it was even smaller at earlier times). Thus, while explaining the observed acceleration of the universe by means of a cosmological constant, one runs up against formidable fine tuning problems.

One way out of this dilemma emphasised by *Varun Sahni* is to assume that the cosmological Λ-term is not a fundamental constant but depends weakly on time. A theoretical construct with precisely, this property is a scalar field. For a slowly rolling scalar, the pressure and the density are related via $P \simeq -\rho$, i.e., the field pressure is negative with the result that the scalar field potential gives rise to an effective Λ-term $V(\phi) \simeq \rho_\Lambda = \Lambda/8\pi G$. *Sahni* and Limin Wang have studied the effects of scalar fields on the late time expansion of the universe. The potential which *Sahni* and Wang propose has the interesting property that, during the early history of the universe, the ratio between the scalar field density and radiation (or matter) remains constant. In other words, the scalar field 'tracks' both radiation and matter in such a way that the scalar field equation of state remains tuned to the background value. At very late times, tracking stops and the equation of state of the scalar field turns negative. At this point, the scalar field density begins to decrease at a slower rate than the matter density, with the result that the universe becomes scalar field dominated and begins accelerating at a redshift of $z \sim 0.5$ in agreement with observations. The 'tracker' property of the scalar field ameliorates the fine tuning problem which exists for the cosmological constant. This model is in good agreement with observations as shown in figure 2. A further property of this model is that it can describe *both* dark matter and a Λ-term (dark energy) within the same unified framework. In fact, the potential suggested by *Sahni* and Wang defines a new form of dark matter which they call *frustrated cold dark matter* (FCDM) due to its ability to frustrate gravitational clustering on small scales. The dark matter particle associated with FCDM has a very large Compton wavelength $\lambda_c = m^{-1}$, which can be of order of a kilo-parsec or smaller. Cold dark matter (CDM) made up of a condensate of ultra-light particles would be frustrated in its attempts to cluster on scales smaller than λ_c because of the uncertainty principle. Remarkably, the classical Jeans scale in this model turns out to be of the same order as the Compton wavelength. *Frustrated Cold Dark Matter* model could provide a natural explanation for two major difficulties faced by the standard cold dark matter scenario: (i) The dearth of halo dwarf galaxies: the number of dwarf's in the local group is an order of magnitude smaller than predicted by N-body simulations of the standard CDM model. (ii) The discrepency between observed shapes of galaxy rotation curves and simulated dark matter halos: Recent observations of low surface brightness (LSB) galaxies and dwarfs show them to possess rotation curves which indicate a constant mass density in the central core region. These observations are difficult to accommodate within the CDM model since, high resolution N-body simulations of SCDM halos indicate a cuspy central density profile having the form $\rho \propto r^{-1.5}$ in the core region. By suppressing gravitational clustering on scales smaller than the Jeans scale ~ 1 kpc, FCDM is expected to give rise to galaxy halos, which are less centrally concentrated and also to fewer dwarf galaxies, leading to better agreement between theory and observations. The scalar field model of *Sahni* and Wang can, therefore, account for both the acceleration of the universe as well as for its clustering properties.

Another solution to the fine tuning problem of the cosmological constant was provided by *R.G. Vishwakarma*. From the dimensional considerations he constructed a model of the universe in which Λ decays as the energy density ρ. Further, he has shown that this model, as well as many other variable Λ-models are in good agreement with the supernovae data and compact radio sources data.

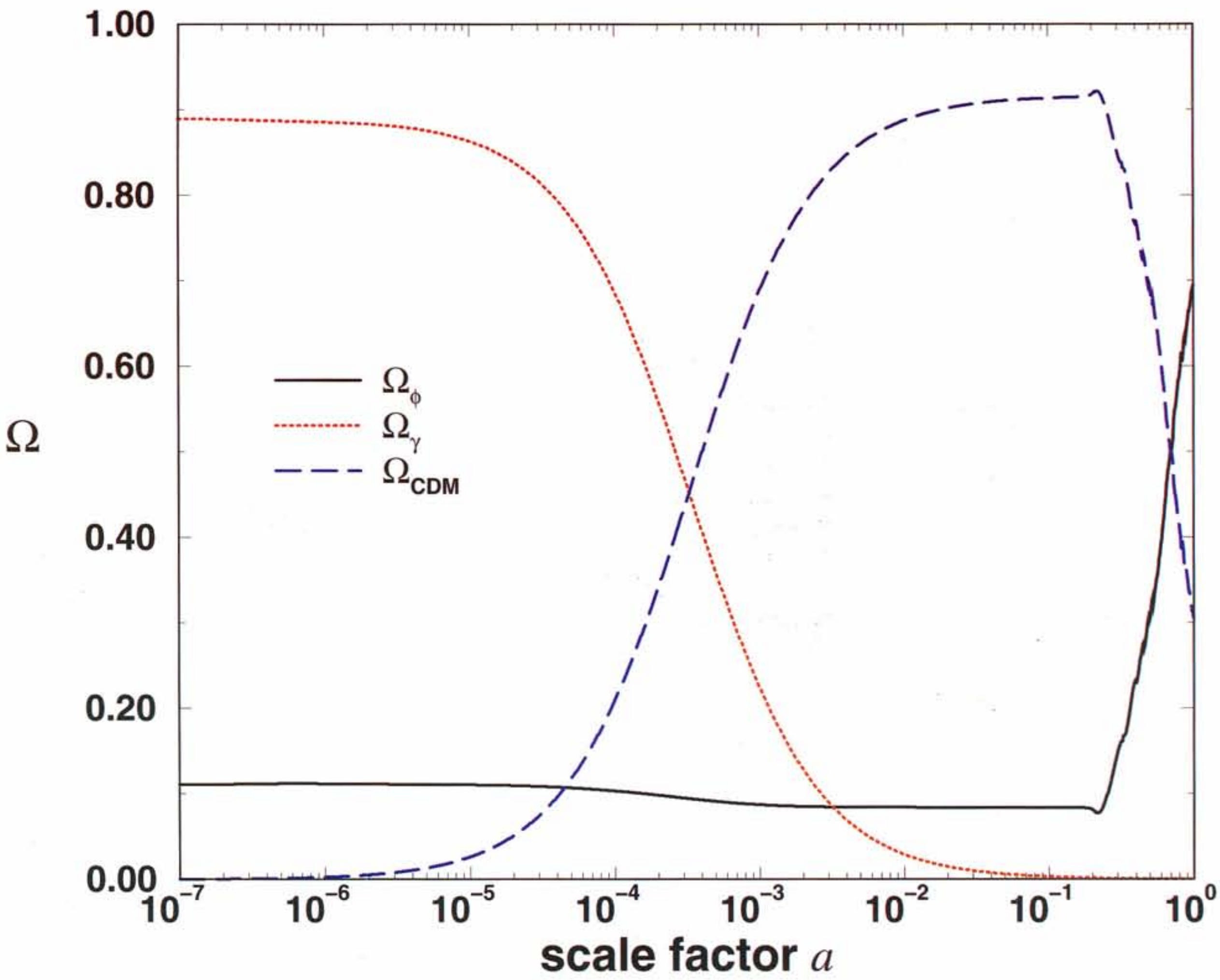


Figure 2: The evolution of the dimensionless density parameter for the 'dark energy' Ω_ϕ (solid line) is plotted against the expansion factor. Matter (dashed line) and radiation densities (dotted line) are also shown. At high redshifts $z \gg 1$ the scalar field displays the tracker property and contributes a fixed fraction to the total density of background matter/radiation. At later times, the scalar field begins to oscillate and the density in the dark energy rapidly dominates the mass density of the universe leading to $\Omega_\phi \sim 0.7$ today; from Sahni and Wang (2000).

Cosmology in higher dimensions

'Braneworld' models of the universe in which space-time consists of 4+1 dimensions while matter fields are confined to a 3+1 submanifold, called a braneworld are currently the focus of much study. *Varun Sahni* together with Roy Maartens (UK) and *Tarun Saini* have discussed the implications of this scenario for inflationary models. The Einstein equations in five dimensions give rise to a new term proportional to the square of the density, (in addition to the linear density term) in the modified Friedmann equations describing the evolution of the braneworld. In inflationary braneworld models, the presence of the quadratic density term causes the scalar field (inflation) to roll down its potential more slowly, resulting in greater inflation. Thus, the braneworld scenario appears to be conducive to inflation. However, virtually all braneworld studies have limited themselves to a homogeneous, isotropic universe, while the Einstein equations themselves admit to many more solutions. The homogeneity and isotropy of the universe is suported by observations of galaxies, QSO's and the cosmic microwave background, all of which indicate that we live in a universe which is remarkably uniform on very large scales. Yet the homogeneity and isotropy of the universe are difficult to explain within the standard relativistic framework since, in the presence of matter, the class of solutions to the Einstein equations which evolve towards a FRW universe is essentially a set of measure zero. The above statement is, however, only true for space-times containing 'normal' matter satisfying 'energy conditions' which ensure that

(i) negative pressures can never grow so large as to dominate the energy density: $T_{00} \geq |T_{ij}|$; (ii) the sum of the principle pressures of the fluid must be non-negative: $\sum_{i=1}^{3} T_{ii} \geq 0$. The inflationary scenario, based as it is on a form of matter which violates these energy conditions, radically alters the above picture. *Sahni*, Maartens and *Saini* have discussed the dynamics of inflationary cosmology in an anisotropic Bianchi I braneworld. One of the main conclusions of their study is that, no matter how large the initial anisotropy, it can never prevent inflation from occurring. In fact the amount of inflation is usually larger in the presence of anisotropy than in its absence (see Fig. 3). This result underlines the robustness of inflation in the framework of the braneworld scenario. It also shows that our observable universe could have had an anisotropic beginning since, anisotropies disappear very rapidly after inflation commences. A completely new and unexpected result of the investigation by *Sahni*, Maartens and *Saini* has been that the initial expansion of a Bianchi I universe filled with matter with equation of state stiffer than dust is *isotropic*. This is a uniquely brane effect since, such behaviour is impossible within the framework of standard general relativity.

Cosmic Microwave Background

Determination of the microwave background temperature at a redshift of 2.3377

One of the firm predictions of standard Big Bang model is the existence of relic radiation from the hot phase the universe has experienced at early times. The cosmic microwave background radiation (CMBR) has been discovered serendipitously by Penzias & Wilson in 1964. The fact that its spectrum follows with remarkable precision of a Planckian distribution over several decades in frequency is a strong argument in favour of the Hot Big Bang cosmology. However, the presence of the radiation at earlier time has never been proven directly. The temperature of its black-body spectrum is predicted to increase linearly with redshift $T_{\rm CMBR}(z) = T_{\rm CMBR}(0)\times(1 + z)$ and its local value has been determined very accurately by the Cosmic Background Explorer (COBE) $T_{\rm CMBR}(0) = 2.726\pm0.010$ K. Detecting the presence of relic radiation at earlier epochs and confirming the well defined temperature evolution is, therefore, a crucial test for cosmology. To perform this test, one can use the possibility that excited fine structure levels of the ground-state of atomic species can be partly populated by the Cosmic Microwave Background Radiation when the energy separation of the levels is similar to the energy at the peak of the radiation energy distribution.

The relative populations of excited levels can be measured from the absorption lines seen in the spectrum of distant quasars and thus, can be used to constrain $T_{\rm CMBR}$ at high redshift. The expected values make neutral carbon, C^0, particularly, well suited for this purpose. The ground state energy level is split into three levels (J = 0, 1, 2) with J = 0–1 and J = 1–2 energy separations kT corresponding to equivalent temperatures, T = 23.6 and 38.9 K respectively. However, the fine structure levels can also be excited by collisions (mostly with electrons and hydrogen) and by UV pumping followed by cascades. The ionization potential of neutral carbon, 11 eV, is below the ionization potential of hydrogen, 13.6 eV, and C^0 can only be seen in dense, neutral and highly shielded gas. Therefore, excitation by collisions cannot be neglected. To constrain $T_{\rm CMBR}$, the kinetic temperature, the particle density of the gas and the local UV radiation field must be known. As it is very difficult to disentangle these various excitation processes, all measurements up to now have led only to upper limits on $T_{\rm CMBR}$.

R. Srianand, P. Petitjean (IAP, Paris) and Cedric Ledoux (ESO, Munich) made the first measurement of $T_{\rm CMBR}$ at high redshift using the QSO spectrum obtained with VLT (as a part of an IFCPAR collaborative project). The measurement reported by this group was obtained in a unique absorption system, where absorption lines of neutral carbon in the three fine-structure level of the ground term, C^0, C^{0*}, C^{0**} are observed together with absorption lines of singly ionized carbon in its excited fine-structure level, C^{+*}, and absorption lines of molecular hydrogen (H_2) in the J = 0 to 5 rotational levels (see Fig 4). The population and depopulation of the first excited rotational level of H_2 (J = 1) from and to the ground state (J = 0) is controlled by thermal collisions. Therefore, the excitation temperature T_{01} is approximately equal to the kinetic temperature. The fine structure upper level of the C^+ ground-state doublet is mostly populated by collisions and depopulated by radiative decay. Therefore, once the temperature is known, the particle density can be derived from the C^{+*}/C^+ ratio. Finally, the UV radiation flux can be constrained from the populations of the J = 4 and 5 H_2 rotational levels.

Thus, for the first time, it is possible to constrain, directly from observations, the different excitation processes at play and determine a lower limit on the temperature of the CMB black-body spectrum. They find $7.0 < T_{\rm CMBR} < 13.5$ K at $z = 2.337$ when 9.1 K is expected in the Hot Big Bang cosmology (see Fig. 5).

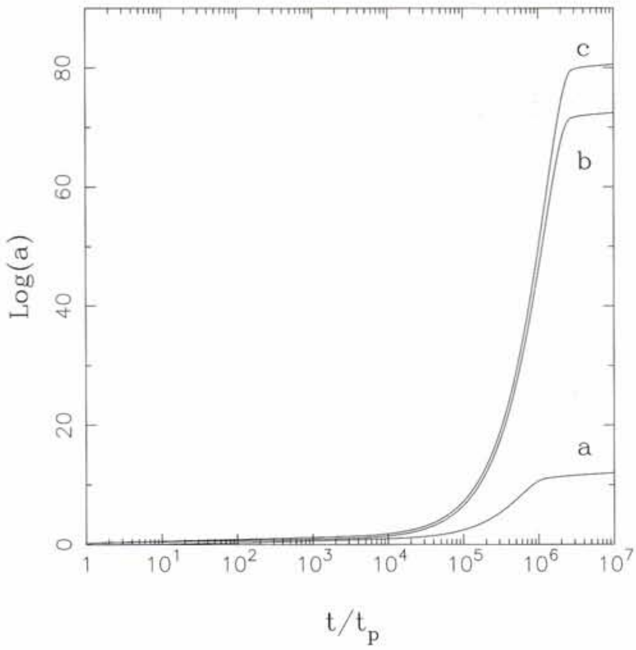


Figure 3: The evolution of the scale factor with time is shown for the braneworld model. The curves shown in increasing amplitude from bottom to top correspond to: (a) inflation in the general relativistic case; (b) inflation in an isotropic braneworld and (c) inflation in an anisotropic braneworld. We see that the effect of both the extra-dimensional term and cosmic shear is to produce more inflation; from Maartens, Sahni and Saini (2001).

Detailed compilation of CMB data

The primordial nature of the microwave background photons makes cosmic microwave background (CMB) observations an extremely valuable cosmological probe. The CMB comprises of the photons in the universe freely propagating to us from $z_{rec} \approx 1100$, carrying a well preserved, easy to decipher, record of the epoch of recombination and evolution of the universe since then. The tiny spatial inhomogeneity which seeded the formation of the large scale structure in the universe is expected to give rise to anisotropy in the CMB temperature on the sky. These anisotropies encode an immense wealth of information on the model of cosmology and formation of the observed large scale structure. Hence, observational successes in detecting CMB anisotropy have set off an intense interplay between theory and observation in the last decade.

The CMB anisotropy in a Gaussian model is completely specified by its angular two point correlation function. Most theoretical models predict statistically isotropic fluctuations, where the anisotropy can then be characterized solely in terms of an angular power spectrum $\mathcal{C}_\ell$ in the space of spherical harmonic multipole, ℓ. The immediate and primary objective of CMB observations is to estimate $\mathcal{C}_\ell$. Since the first detection of CMB anisotropy by COBE-DMR in 1992, there are now well over one hundred band power estimates of CMB anisotropy by a number of experiments probing various regions of ℓ space.

Typically, the sensitivity of a CMB anisotropy over the range of angular scales probed is characterized by a window function W_ℓ. It has become common to quote experimental results in terms of a flat band power estimate, that corresponds to the best estimate for the amplitude of a scale independent $\mathcal{C}_\ell$ over the scales probed by W_ℓ. *Tarun Souradeep* has assisted Ratra in creating a compilation of the published band power estimates, along with experimental window functions, that is publicly available at a website and tabulated in a publication as well.

In collaboration with S. Podariu, J. R. Gott, B. Ratra, M. Vogeley, *Souradeep* used weighted mean and median statistics techniques to combine individual CMB anisotropy detections, and determine binned, multipole-space, CMB anisotropy power spectra. This model independent combination of current data reveals a peak in resultant power spectra, however, the peak cannot as accurately located as claimed by model dependent analyses. Assuming that the CMB anisotropy is Gaussian and correlations between individual measurements are small, the derived weighted-mean CMB anisotropy power spectrum is not a good representation of the individual measurements in a number of multipole-space bins. This could mean that some observational error bars are underestimated, possibly as a consequence of undetected systematic effects. Discarding the most discrepant 5% of the

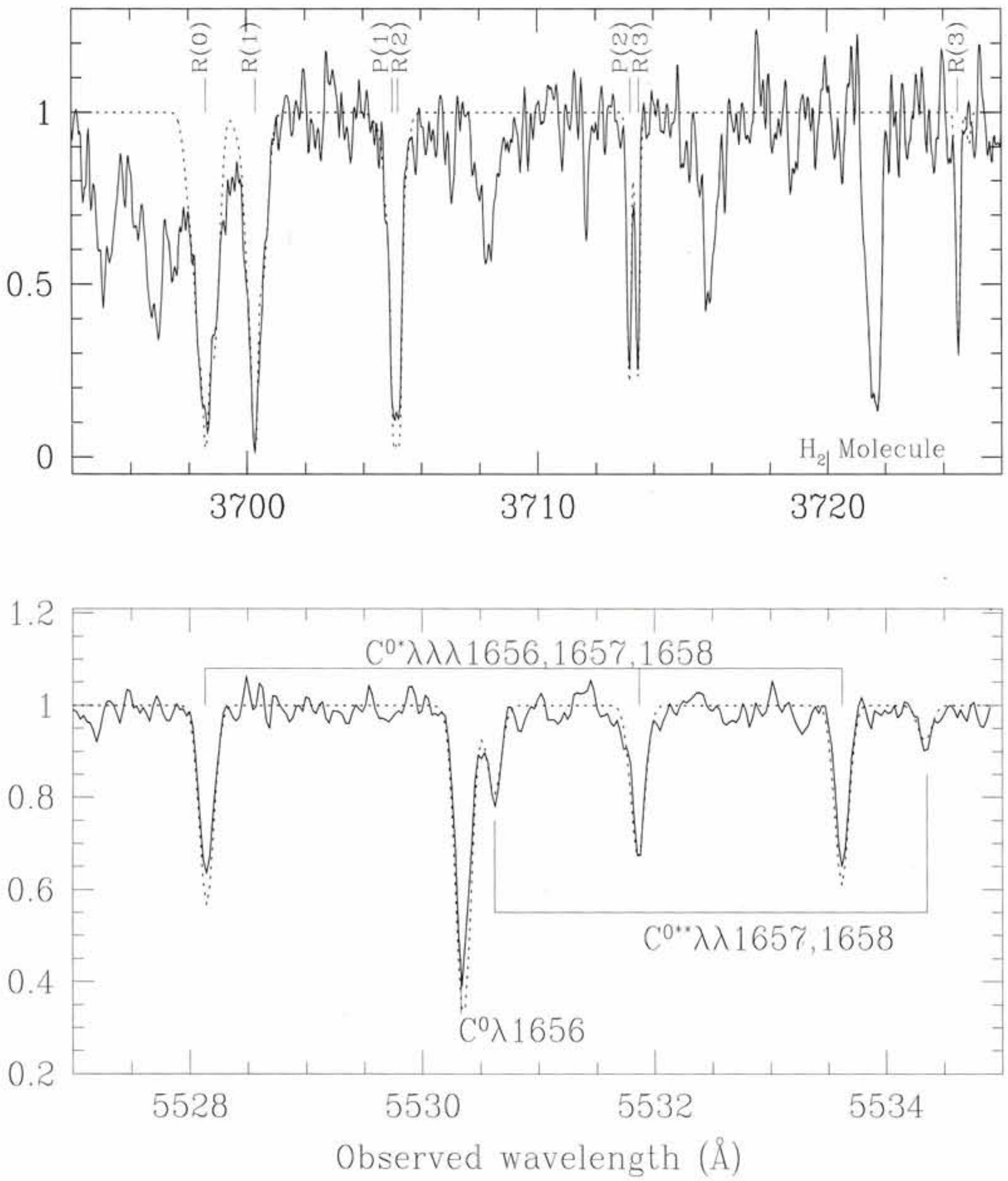


Figure 4: A sample of H_2 and C^0 absorption lines at $z_{abs} = 2.33771$. Portions of the normalized spectrum of the quasar PKS 1232+0815 taken with the Ultra-violet and Visible Echelle Spectrograph mounted on the 8.2 m KUEYEN telescope of the European Southern Observatory on the Paranal mountain in Chile. *Upper panel:* A selection of H_2 absorption lines from the $J = 0$, 1, 2 and 3 rotational levels from the v = 0–1 Lyman band. The model fit is overplotted to the data as a dashed line. *Lower panel:* Detection of absorption lines from C^0, C^{0*} and C^{0**} at $z_{abs} = 2.33771$ in the damped Lyman-α system. The model fit is over-plotted to the data as a dashed line.

measurements alleviates but does not completely resolve this problem.

Current CMB anisotropy data is of significantly higher quality than data that was available just a few years ago. Consequently, an accurate model of an experimental W_ℓ must now account for effects that were ignored for earlier experiments. *Souradeep* and Ratra have developed computationally-rapid methods to account for non-circularity of the beam in a long-scan CMB anisotropy experiment. This must be accounted for in an experiment like Python-V (Coble, et al. 1999) which has an elliptical beam and samples from a large enough area of the sky to prejudice use of the flat-sky approximation used in computing the window functions. With the Python-V team, *Souradeep* and Ratra are involved in an analysis of their data using their window functions corrected

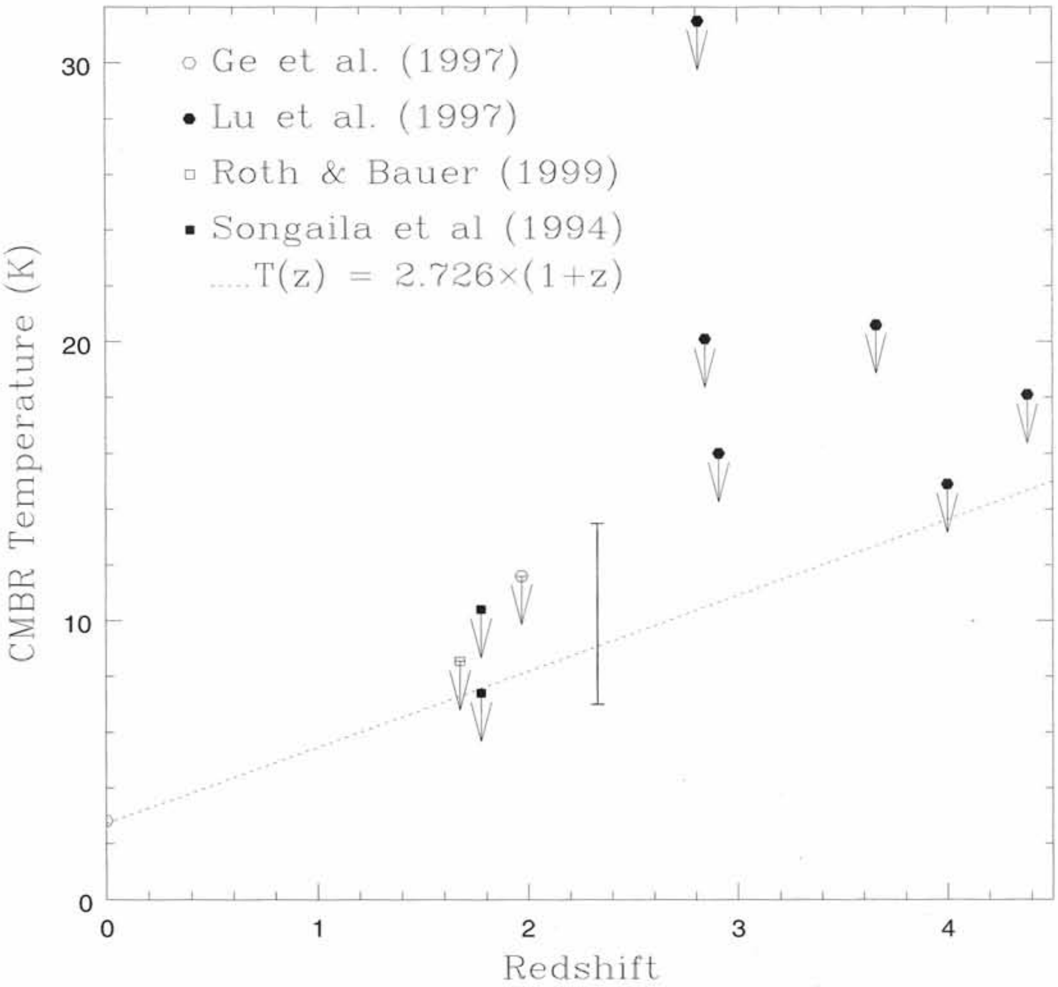


Figure 5: Measurements of the Cosmic Microwave Background Radiation temperature at various redshifts. The point at $z = 0$ shows the result of the Cosmic Background Explorer (COBE) determination, $T_{\rm CMBR}(0) = 2.726{\pm}0.010$ K. Upper limits are previous measurements using the same techniques described here. Our range, $7.0 < T_{\rm CMBR} < 13.5$ K at $z = 2.337$, is indicated by a vertical bar. The dashed line is the prediction $T_{\rm CMBR}(z) = T_{\rm CMBR}(0){\times}(1 + z)$.

for non-circularity and sky curvature. *Souradeep* and Ratra are also computing exact likelihood estimate over a grid of theoretical models given the Python-V data. The size of the data set with over 5000 effective pixels makes a full blown likelihood analysis which is a computational challenge.

Souradeep has been working on aspects of CMB anisotropy observations beyond the angular power spectrum, $\mathcal{C}_\ell$. There are interesting regimes to explore before going to non-Gaussian CMB anisotropy. The first step beyond is to recognize that there could be patterns in $\mathcal{C}_\ell$, which are more easily detected in the CMB anisotropy correlation but may be missed in $\mathcal{C}_\ell$ due to finite resolution (binning) in ℓ space. This point has been illustrated with the example of elliptical universe models, where the antipodal points of closed universe are topologically identified. At the next step, it is possible to conceive that the CMB anisotropy violates statistical isotropy. This could happen in case the universe had non-trivial global topology on scales not far beyond the horizon scale – a subject that *Souradeep* has investigated in detail earlier. At present, *Souradeep* is working on a measure for detecting general deviations from statistical isotropy in observed CMB maps. This measure has been tried on idealized, full sky, noise free CMB simulation with success and now awaits implementation on real data.

Counting the baryons: A new crisis in cosmology?

The temperature anisotropy of the Cosmic Microwave Background Radiation (CMBR) is caused by different physical processes operating at different angular scales. Studies show that the anisotropy pattern is flat (that is, independent of angular scale) at large scales but starts raising as one moves to smaller scales. There will be a characteristic peak (called acoustic peak) around one degree followed by more peaks with smaller heights. The pattern of anisotropies of the CMBR depends sensitively on the various parameters describing the universe - like the total energy density Ω_t, energy density in the form of the cosmological constant, Ω_Λ, energy density in baryons, Ω_B and the index n of the initial power spectrum. In particular, the location of the first acoustic peak in the temperature anisotropy as well as its height can be used to measure Ω_t and Ω_B.

The first results from the MAXIMA and BOOMERANG experiments, announced sometime back, were considered to be important in as much as they provide a detection of the acoustic peak in the CMBR and support the $\Omega_t = 1$ models. This data was analysed by several groups of people ever since it was made public.

Unfortunately, none of the published analysis emphasised certain key features, which forced *T. Padmanabhan* to investigate this data in collaboration with Shiv Sethi (HRI, Allahabad). They have reanalysed carefully the BOOMERANG, MAXIMA (and the more recent CBI) results in the context of simplest inflationary universes with $\Omega_t = 1$, $n_s \simeq 1$. They attempt to constrain three other parameters—h, Ω_B, and Ω_m —from these observations and show that though the data is consistent with the values of Ω_m and h inferred from other observations, the value of $\Omega_B h^2$ is too high (by about 50 percent) to be compatible with big-bang nucleosynthesis (BBN) observations at 2σ level for $n_s = 1$. Their best fit curve to the data is shown in Fig. 6, while the constraint on Ω_B is shown in Fig. 7. In fact, this inconsistency between the value for $\Omega_B h^2$ determined from CMBR data and the BBN data is statistically at a similar level compared to the inconsistency between the data and a $\Omega_m = 1, \Omega_\Lambda = 0$ model. While, several groups have tried to argue forcefully in favour of the non-zero value of the cosmological constant based on this data, the major inconsistency between BBN and CMBR has not been emphasised adequetely. *Padmanabhan* and Sethi bring this out clearly in their work and point out that until this inconsistency between the value of $\Omega_B h^2$ from this data and BBN is sorted out, all conclusions based on this data should be treated with caution.

Microwave background in the Quasi-Steady State Cosmology (QSSC)

Jayant Narlikar, R.G. Vishwakarma, Geoffrey Burbidge and Fred Hoyle have worked out the possible signatures of anisotropy in the microwave background as generated in the QSSC. The anisotropy arises from the portion of the MBR generated in the last cycle, largely because of concentrated starlight thermalized in the vicinity of clusters, close to the oscillatory minimum. Calculations show that for typical size of rich clusters around 5 - 6 Mpc, the power spectrum of the MBR will show a bump at harmonics 200 - 250. Smaller peaks are expected from galaxies at harmonics 500 - 1000.

Relativistic Astrophysics

Pseudo-Schwarzschild description of transonic spherical accretion

To compromise between the ease of handling Newtonian description of gravity and the realistic situations described by complicated general relativistic calculations, a series of 'modified' Newtonian potentials have been introduced to describe the general relativistic effects that are most important for accretion disk structure around Schwarzschild and Kerr black holes. Introduction of such potentials allows one to investigate the complicated physical processes taking place in disc accretion in semi-Newtonian frame work by avoiding pure general relativistic calculations in such a manner so that most of the features of space time around a compact object are retained and some crucial properties of the analogous relativistic solutions of disc structure could be reproduced with high accuracy. Hence, those potentials might be designated as 'pseudo-Kerr' or 'pseudo-Schwarzschild' potentials depending on whether they are used to mimic the space-time around a rapidly rotating or non rotating/slowly rotating (Kerr parameter $a \sim 0$) black hole respectively.

Although, a number of such 'pseudo' potentials are available in literature to study various aspects of disc accretion, no such potentials are available, which had been solely derived to describe spherically symmetric accretion on to a Schwarzschild (or Kerr) black hole. In two successive papers, *T. K. Das* and A. Sarkar analyse some of the 'pseudo-Schwarzschild' disc potentials (potentials introduced to study accretion discs around Schwarzschild black hole) to investigate whether those potentials could be used to study spherical accretion, and if so, to check which potential among those would be the 'best-fit' to approximate the full general relativistic description of transonic spherically symmetric accretion on to a Schwarzschild black hole. In doing so, they solve the equations of motion of spherically accreting fluid in full Schwarzschild space-time as well as for motion under various 'pseudo'-potentials to

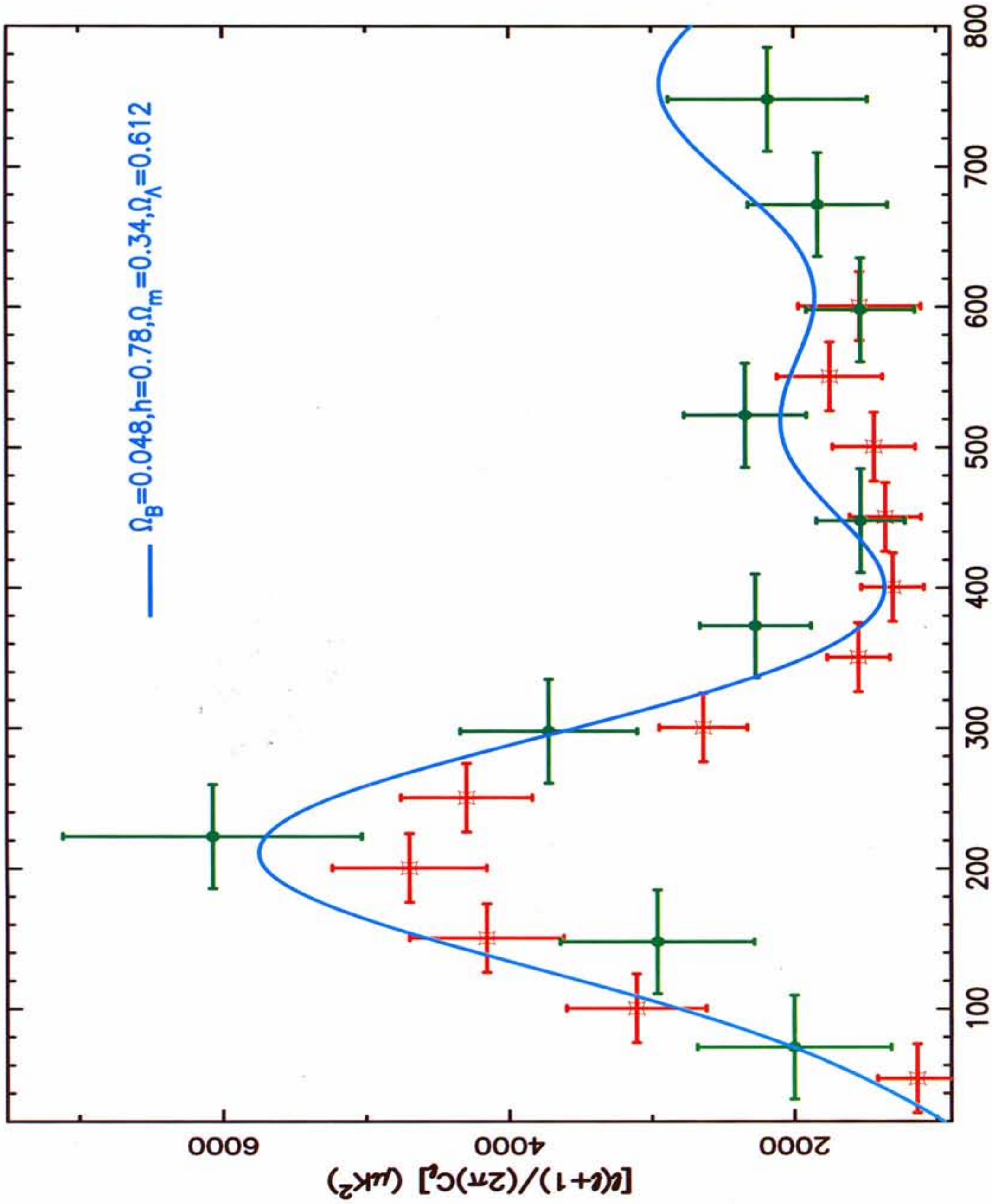


Figure 6: The best fit curve to MAXIMA and BOOMERANG data for a universe with $\Omega_m = 1$ and $n = 1$. The fit parameters are $\Omega_m = 0.34, \Omega_\Lambda = 0.612, \Omega_B = 0.048$ and $h = 0.78$. The best fit model is plotted along with BOOMERANG (empty polygons) and MAXIMA (empty circles) data points. The errors shown do not include calibration errors.

study the variation of different dynamical and thermodynamic quantities with radial distance measured from the accreting black hole for the full general relativistic spherical flow as well as for accretion using various 'pseudo-Schwarzshild' potentials and then the results obtained using such potentials were compared with the solutions of exact relativistic problems in Schwarzschild metric. It has been shown that though the potentials discussed in their work were originally proposed to mimic the relativistic effects manifested in disc accretion, it is quite reasonable to use most of the potentials in studying various dynamical as well as thermodynamic quantities also for spherical accretion onto Schwarzschild black holes.

It is worth mentioning that as long as one is not interested in astrophysical processes extremely close (within $1-2$ Schwrazschild radius) to a black hole horizon, one may safely use the 'pseudo' potentials discussed by *Das* and Sarkar to study spherically symmetric accretion on to a Schwarzschild black hole with the advantage that use of these potentials would simplify calculations by allowing one to use some basic features of flat geometry (additiv-

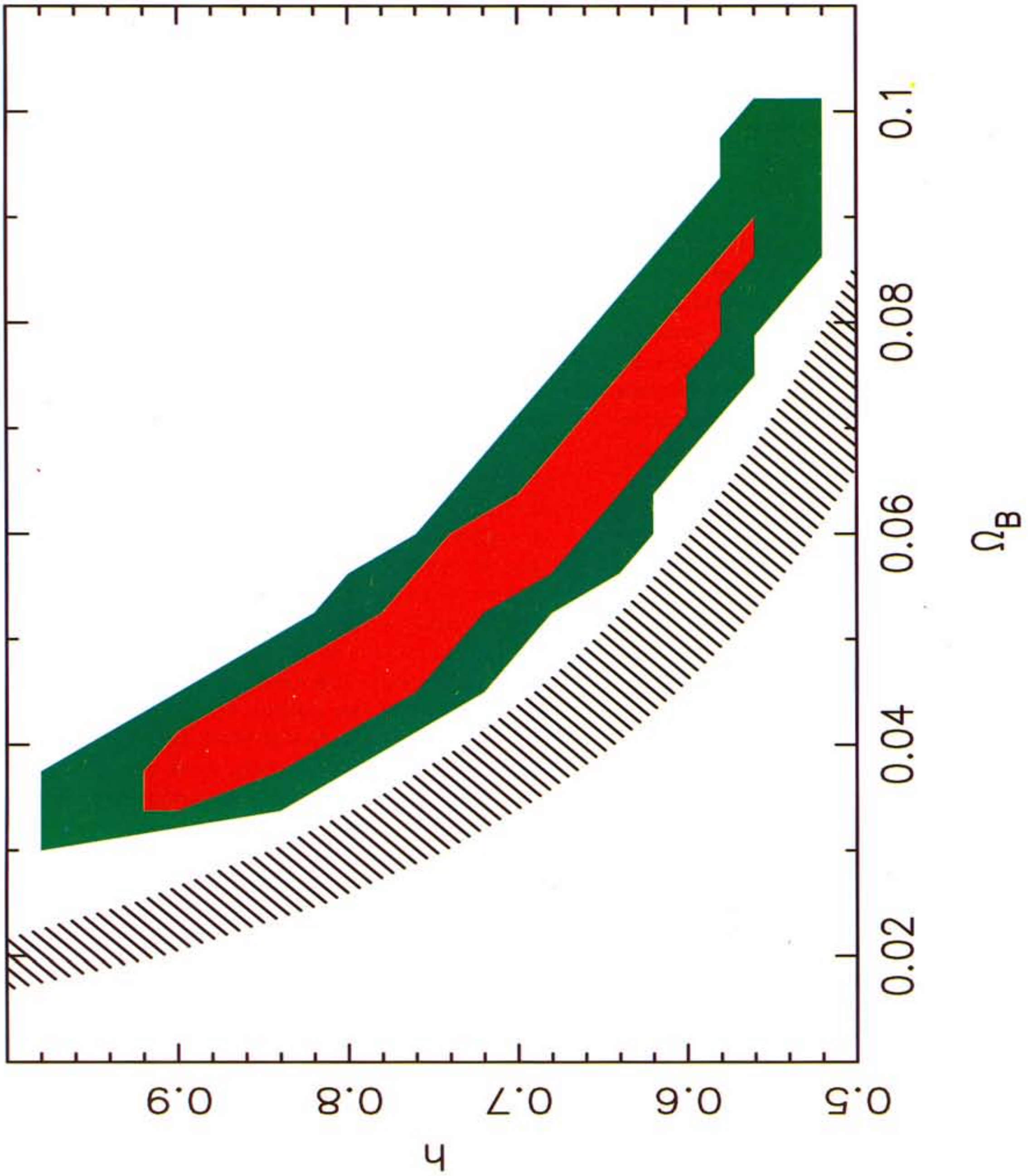


Figure 7: The contours in colour correspond to allowed 1 and 2 σ regions by CMBR observations. The cross-hatched region corresponds to the allowed region at 95% confidence ($\simeq 2\sigma$) from primordial nucleosynthesis.

ity of energy or de-coupling of various energy components) which is not possible for calculations in purely Schawarzschild metric. Also, one can study more complex many body problems such as accretion from an ensemble of companions or over all efficiency of accretion on to an ensemble of black hole in a galaxy or for studying numerical hydrodynamic or magnetohydrodynamic flows around black hole, etc. practically as simply as can be done in Newtonian framework, but with far more better accuracy.

Accretion-powered spherical outflows

Galactic and extra-galactic sources of jets and outflows are now widely believed to be fed by accreting black holes sitting at the dynamical centre of these sources. In the absence of any binary companion, spherically symmetric accretion may occur onto isolated central black hole if accreting matter has negligible amount of intrinsic angular momentum. This may happen when the central supermassive black hole at the galactic centre is surrounded by dense stellar cloud in such a way that the vector sum of the angular momentum of tidally disrupted matter (from a number of stars with trajectories approaching sufficiently close to the hole) almost vanishes. On the other hand, unlike the ordinary stellar bodies, black holes do not have their own 'physical' atmosphere, and outflows in these cases have to be generated from the accreting matter only. Hence, it is *necessary* to study the accretion and outflow (from various astrophysical sources powered by accreting compact objects) in the same framework, instead of treating the outflow separately from accretion phenomenon. At the same time, as the fundamental criterion for constructing any self-consistent physical model demands the minimization of the number of inputs to the model, one may conclude that modelling the astrophysical outflow needs a concrete formulation, where the outflow can be described in terms of minimum number of physical parameters governing the inflow.

Introducing a relativistic hadronic pressure supported steady, standing, spherically symmetric shock surface around a Schwarzschild black hole as the effective physical barrier that may be responsible for the generation of spherical wind, *T. K. Das* calculates the mass outflow rate (the measure of the fraction of accreting material being blown as outflow) in two successive papers in terms of minimum number of flow parameters by simultaneously solving the equation governing the accretion and winds around the central accretor. Not only a sufficiently plausible estimation of the above mentioned rate has been provided, dependence and variation of this rate on various physical parameters governing the flow was also successfully studied in his work. Outflow generation was investigated using pseudo-Schwarzschild framework as well as full general relativistic calculations for this purpose have also been performed.

Outflow driven contamination of metalicity to the outer galaxies

A number of observational evidences suggest that the fluid (in interstellar/ intergalactic plasma form) accreting onto black hole has potential to become as hot as its virial temperature. Through various cooling mechanism, such as Bremstruhlung and Comptonization, hot and tenious infalling gas may be cooled down to a temperature which supports significant nucleosynthesis to take place in accretion disks around black holes. Hot and dense shock-generated sub-Keplerian flow, after deviating from a cooler Keplerian disk, remains sufficiently hot producing the favourable temperature to produce heavier elements through significant nuclear reactions. Normally, the basic difference between the nucleosynthesis in sub-Keplerian advective accretion disk and that in the interior of ordinary stellar bodies is that while in stellar nucleosynthesis same set of nuclear reactions take place at different radii (because of the more or less uniform radial temperature distribution in the zone where nuclear burning is significant for stellar cases), radial variation of disk temperature for sub-Keplerian advective accretion simultaneously triggers different reaction/ set of reactions at different radii of the disk.

It is interesting to investigate whether the fate of the shock induced nucleosynthesis generated heavier elements could be predicted by the recent disc-outflow model first introduced by *T.K. Das* and S.K. Chakrabarti. One of the major speculations of that model was that outflows from the hot and dense post-shock sub-Keplerian flows (where the composition change is much more significant due to high temperature and large residence time of accreting material) would carry away modified compositions and contaminate the atmosphere of the surrounding stars and galaxies in general. Significant work in this direction is in progress by *Das*, B. Mukhopadhyaya and Chakrabarti to calculate the exact amount of percentage loss of several elements through collimated outflows. It is obvious that part of this outflow could be intercepted by the companion star (for black hole binary systems) and one can expect that these new elements may be detected in the stellar atmosphere through spectroscopic analysis of line emissions. For accreting super massive black holes, heavy elements produced in the disk may supply metalicity in the galaxies. Strong indications of disk-evacuation by wind found in above mentioned disk-outflow model suggests that overall such contributions to metalicity must not be neglected.

Gamma ray bursts: Birth cries of black holes

Gamma ray bursts (GRBs) are the most luminous objects in the sky and are unusual and extraordinary cosmic events. Ever since the discovery of quasars in mid sixties, it has been generally believed that the ultimate source of energy for the high energy astrophysical phenomena like quasars, active galactic nuclei and GRBs is the gravitational field.

There have been several proposals for source for GRBs, which include black hole and hypernova on one hand and various kinds of new and exotic fields and speculative physics on the other. The overall scenario is that there is a formation of a fire ball which gives out the initial radiation. One of the most natural processes to form a fire ball could be provided by gravitational collapse leading to ultra high densities which – in turn – can give rise to very high temperature. Pankaj Joshi, *Naresh Dadhich* and Roy Maartens have argued that divergingly high curvatures could be produced in gravitational collapse of massive star near its ultimate end state, black hole. The critical question is whether the event of such high curvature occurs before or after the formation of black hole horizon. In the latter case, the effects are not accessible to the external world, because no information can travel out of the horizon. On the other hand, in the former case, a fire ball could be produced by the diverging space-time curvatures which could give rise to shocks on interaction with the infalling collapsing matter. A burst of very high energy will occur for a very brief period before the fire ball is engulfed by horizon.

It turns out that the initial density profile leading to a visible fire ball is quite reasonable and realistic for neutron star collapsing into black hole with further accretion. This shows that GRBs could be produced naturally in gravitational collapse and in this sense they are really the birth cries of black holes. It may be noted that this proposal appeals only to well established classical physics in contrast to many others which resort to speculative and untested physics and phenomena.

Anomalous redshifts and ejection from galaxies

Work is continuing on the possible explanation of anomalous redshifts of quasars and galaxies in terms of ejection of newly created matter of low inertial mass. *Jayant Narlikar*, Halton Arp, *R.G. Vishwakarma*, S.K. Banerjee and P.K. Das have worked out detailed dynamical models of ejection with the progressive increase of inertia of ejected matter taken into account. Comparison has been made with the observations of quasar-galaxy associations with detailed matching of theoretical calculations with the observed parameters.

Quasar Absorption Systems

A Mini-survey of molecular hydrogen in the damped Lyman alpha systems:

Damped Ly-α systems (hereafter DLAS) seen in QSO spectra are characterized by very large neutral hydrogen column densities: $N(\mathrm{H\,I}) \geq 2 \times 10^{20}$ cm^{-2}, similar to what is usually measured through local spiral disks. The case for these systems to arise through proto-galactic disks is supported by the fact that the cosmological density of the absorbing gas at $z_{\mathrm{abs}} \sim 3$ is of the same order of magnitude as the cosmological density of stars at present epochs. Moreover, the presence of heavy elements ($Z \sim 1/10 Z_{\odot}$) suggests that DLAS are located in over-dense regions where star formation activity takes place and at low and intermediate redshifts strong metal line systems and DLAS have been demonstrated to be associated with galaxies. It has also been shown that the profiles of the lines arising in the neutral gas show evidence for rotation. Whether these arguments are enough to demonstrate that the high-redshift DLAS arise in large disks is a matter of debate, however. Indeed, simulations have shown that the high-redshift progenitors of present-day galactic disks could look like an aggregate of well-separated dense clumps. The kinematics could be explained by relative motions of the clumps with little rotation. Whatever may be their nature of the DLAs, if they are related to star forming region then they should show H_2 molecules.

Molecular hydrogen has numerous UV absorption lines, which, for $z_{\mathrm{abs}} > 1.8$, are redshifted into optical wavelengths. The physics of the molecule excitation is well documented. Formation of H_2 is expected on the surface of dust grains if the gas is cool, dense and mostly neutral, and from the formation of negative hydrogen if the gas is warm and dust free. On the other hand, destruction is mainly due to UV photons. The effective photo-dissociation of H_2 takes place in the energy range $11.1 - 13.6$ eV through Lyman-Werner band line absorption. Therefore, information on the kinetic and rotational excitation temperatures, the particle density and radiation field can be derived from good quality data.

Recently, P. Petitjean (IAP, Paris), *R. Srianand* and Cedric Ledoux(ESO, Munich) have undertaken a survey of molecular hydrogen in the high redshift damped Lyman alpha system (as a part of an IFCPAR project). In the first part of the survey they looked for H_2 molecules in eight high-redshift damped Lyman-α (DLA) systems using the ESO Ultra-violet and Visible Spectrograph on the VLT. In addition, they have investigated two systems using ESO public data. Their sample also includes the only system, where H_2 was previously detected and studied at high-spectral resolution. Altogether, their sample consists of eleven absorbers with $1.85 < z_{\mathrm{abs}} < 3.4$.

They confirm the presence of H_2 in the $z_{\mathrm{abs}} = 2.3377$, metal-poor ($[\mathrm{S/H}] = -1.53$), system toward PKS 1232+082. The derived molecular fraction, $f = 2N(\mathrm{H_2})/(2N(\mathrm{H_2})+N(\mathrm{H\,I})) = 1.5\times10^{-4}$, is two orders of magnitude less than what has been claimed previously from low-resolution data. The physical conditions within the cloud can be constrained directly from observation. The kinetic temperature and particle density are in the ranges, respectively, $130 < T < 300$ K and $5 < n_H < 20$ cm^{-3}. In addition, UV pumping is of the same order of magnitude than in our Galaxy. The upper limits on the molecular fraction derived in eight of the systems are in the range 1.2×10^{-7}–1.6×10^{-5}. There is no evidence in this sample for any correlation between H_2 abundance and relative heavy element depletion into dust grains. This should be investigated using a larger sample, however. The molecular abundance in a few DLA systems (and in particular in the two systems where H_2 is detected) is consistent with what is seen in the Magellanic clouds. But most of the DLA measurements are well below these values. This is probably partly due to small amounts of dust and/or high UV flux. They argue, however, that the lack of molecules is a direct consequence of high kinetic temperature ($T > 3000$ K) implying a low formation rate of H_2 onto dust grains. Most of the DLA systems arise in warm and diffuse neutral gas.

A near-solar metallicity damped Lyman-α system toward the BAL quasar Tol 1037−2703

The remarkable similarity of four C IV absorption systems at redshift $1.95 < z_{abs} < 2.14$ in the spectra of Tol 1037−2703 ($z_{em} = 2.20$) and 1038−2712 ($z_{em} = 2.33$) separated by only 17.9 arcmin on the sky has created considerable interest in the past. However, the nature and origin of these common absorption systems are still unclear. There are arguments and counter arguments for (i) the absorption being produced by a super−cluster sitting in front of the two quasars and (ii) part of the systems being intrinsically associated with the QSOs. *R. Srianand* and P. Petitjean (IAP, Paris) have used a high resolution and high S/N ratio spectrum of Tol 1037−2703 of quality an order of magnitude better than previous data to investigate the nature of the systems close to the quasar redshift, mainly the broad outflow and the systems at $z_{abs} \sim 2.082$ and 2.139. As it is now established that the absorbing gas physically associated with the QSOs often shows some or all of: (i) partial coverage, (ii) excited fine-structure lines, (iii) time variability, (iv) broader albeit smoother profile, (v) high metal enrichment one can investigate the nature of these systems using these indicators.

Srianand and Petitjean have reported the detection of a Broad Absorption Line (BAL) outflow in the spectrum of the z_{em} (Mg II) = 2.201 QSO Tol 1037−2703 with three main BALs at 36000, 25300 and 22300 km s^{-1}outflow velocities. Although, the overall flow is dominated by high ionization lines like N V and C IV, the gas of highest velocity shows absorption from Mg I, Mg II and Fe II. Covering factor arguments suggest that the absorbing complexes are physically associated with the QSO and have transverse dimensions smaller than that of the UV continuum emitting region ($r < 0.1$ pc). They show that the C IV absorption at $z_{abs} = 2.08$ has a covering factor $f_c \sim 0.86$ and the absorption profile has varied over the last four years (see Fig. 8). The detection of absorption from excited fine structure levels of C II and Si II in a narrow components embedded in the C IV trough reveals large density inhomogeneities. IR pumping is the most likely excitation process.

The $z_{abs} = 2.13$ system is a moderately damped Lyman-α system with log N(H I) $\sim$ 19.7. The weakness of the lines together with the high quality of the data, makes the metallicity measurements particularly reliable. The absolute metallicity is close to solar with [Zn/H] = −0.26. The α-chain elements have metallicities consistently solar (respectively +0.05, −0.02, −0.03 and −0.15 for [Mg/H], [Si/H], [P/H] and [S/H]) and iron peak elements are depleted by a factor of about two ([Fe/Zn], [Cr/Zn], [Mn/Zn] and [Ni/Zn] are equal to −0.39, −0.27, −0.49, −0.30). Lines from C I are detected but H_2 is absent with a molecular to neutral hydrogen fraction less than 8×10^{-6}. From the ionization state of the gas, they argue that the system is situated $\sim$ a few Mpc away from the QSO. High metallicity and low nitrogen abundance, [N/Zn] = −1.40, favour the idea that metals have been released by massive stars during a star burst of less than 0.5 Gyr of age.

Their study (which was part of an IFCPAR project) suggests that some of the common C IV absorption line systems seen in the two nearby QSOs satisfy the requirement of the gas being physically associated with the central region of the QSOs. Thus, careful study of the near by QSO sightline will be useful to understand the role of QSO outflows in enriching the inter galactic space.

Detection of H_2 molecules in the damped Lyman-α system at z_{abs} = 1.9622 toward 0551−366

Search for the H_2 molecules in high redshift damped Lyman-α systems by Cedric Ledoux (ESO, Garching), *R. Srianand* and P. Petitjean (IAP, Paris), as a part of an IFCPAR project has resulted in a few new detections. They reported the detection of H_2, C I, C I* and C I** in four components of the $z_{abs} = 1.961$ DLA system toward Q 0551−366 and a detailed analysis of the physical conditions in the gas. They also confirm the presence of H_2 in the $z_{abs} = 1.9731$ DLA system toward Q 0013−004 (Ge & Bechtöld 1999). The HI column density, N(H I) = 2.8×10^{20} cm^{-2}, is estimated using the Voigt profile fitting. There are six and five distinct components where, respectively, C I and C I*

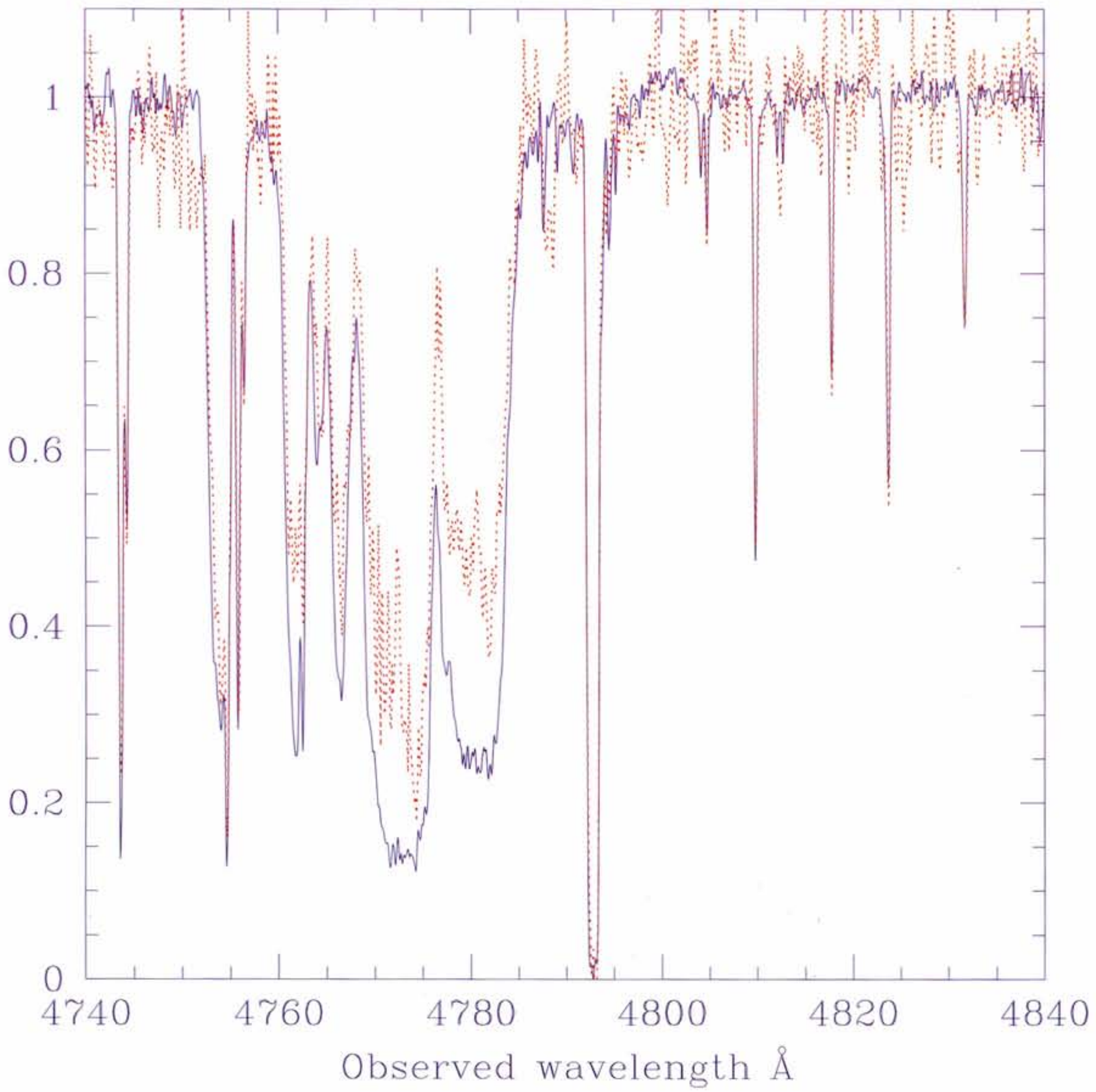


Figure 8: Time variability of C IV absorption. The continuous line corresponds to our UVES data (Srianand & Petitjean, 2001) and the dotted line is the CASPEC spectrum from Lespine & Petitjean (1997). The resolution of the UVES spectrum is degraded to match that of the CASPEC data.

absorption lines are detected. Only two of them show detectable amount of H_2. In the case of high redshift absorbers, it is an usual procedure to use Zn abundance to get Fe abundance metallicity and Cr/Z abundance ratio get the dust to gas ratio. Zn metallicity seen in this system is close to solar, whereas the iron-peak elements (Fe, Cr and Ni) are depleted compared to zinc with $[X/Zn] \sim \sim -0.8$, probably because they are tied up into dust grains. They show that the dust depletion pattern is similar in individual components and very much similar to that seen in the warm neutral medium in our galaxy. This clearly demonstrates that the presence of H_2 molecules is *not* directly related to the dust to metal ratio but rather strongly dependent on the physical conditions within the gas (density and temperature). The components that show H_2 have kinetic temperature $\sim$ 100 K. Estimated radiation field is roughly a factor 2 higher than that seen in our galaxy and two orders of magnitude higher than the UV background at that reshift, suggesting insitu star formation in the absorbing region.

Using the column densities of C I, C I* and C I** lines from the three components, they get the CMBR temperature. In the case of components that show H_2, the values are not identical and higher than the value predicted from the standard Big Bang (i.e., 8 K). Thus, influence of local physical conditions in these components are substantial. Assuming the CMBR temperature to be 8 K, using the kinetic temperature obtained from the H_2 levels, they get the range in hydrogen density using the level population of C I. For the components without H_2, the upper limits on T_{CMBR} is very close to the big-bang prediction and these components most probably have low densities.

As the gas is mostly neutral, the electron densities are much lower than ($\sim 10^{-3}$ times) that of H and the formation of H_2 is mainly mediated by dust grains rather than through H^-. The non-detection of H_2 in components that show similar dust-to-metal ratio and similar column densities of heavy elements is a consequence of lower density (and possibly higher temperature). From the derived physical conditions in all the systems, where H_2 is detected till date, *it is clear that the components that show H_2 have larger densities $\geq 30\ cm^{-3}$ and low temperature $\leq 230K$.*

Semi analytic approach to understanding the IGM

T. Padmanabhan, R. Srianand and *T. Roychoudhury* have started investigating various aspects of the IGM last year (as a part of an IFCPAR project) and some preliminary results were mentioned in the annual report last year. They have now made significant further progress in this direction.

Analytic derivations of the correlation function and the column density distribution for neutral hydrogen in the intergalactic medium (IGM) have been obtained, assuming that the non-linear baryonic mass density distribution in the IGM is lognormal. This ansatz was used earlier by Bi and Davidsen (1997) to perform 1D simulations of lines-of-sight (LOS) and analyse the properties of absorption systems. *Padmanabhan, Srianand* and *Roychoudhury* have adopted a completely analytic approach, which allows them to explore a wide region of the parameter space. The analytic results have been compared with observations wherever possible, to constrain various cosmological and IGM parameters, and they show good agreement.

They find that the effects on the line-of-sight correlation function of Lyman alpha forest, due to (i) change in cosmology or (ii) the slope γ of the equation of state of the IGM are of the same order. This implies that one *cannot* constrain both the parameters simultaneously. However, it is possible to constrain γ and its evolution using the observed LOS correlation function at different epochs provided one knows the background cosmology. They show, how one can use the constraints on the evolution of γ, obtained using the LOS correlation, as an independent tool to probe the reionisation history of the universe.

Their models also reproduce the observed column density distribution for neutral hydrogen and the shape of the distribution depends on γ. The calculations suggest that one can rule out $\gamma > 1.6$ for $z \simeq 2.31$ using the column density distribution. However, one cannot rule higher values of γ at higher redshifts.

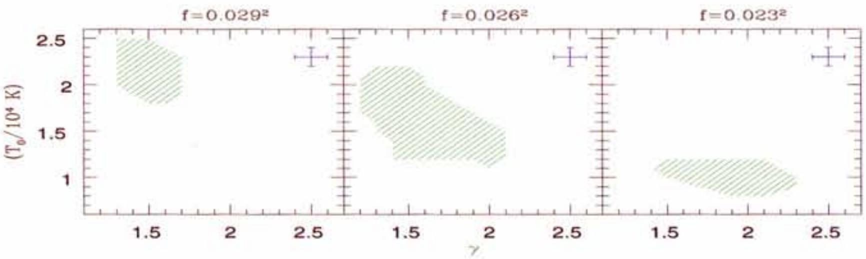
They have also performed one dimensional simulations along the lines of sight to model the intergalactic medium (IGM). Since, this procedure is computationally efficient in probing the parameter space – and reasonably accurate – they use it to recover the values of various parameters related to the IGM (for a fixed background cosmology) by comparing the model predictions with different observations. For the currently favoured LCDM model ($\Omega_m = 0.4$, $\Omega_\Lambda = 0.6$ and $h = 0.65$), they obtain, using statistics obtained from the transmitted flux, constraints on (i) the combination $f = (\Omega_B h^2)^2/J_{-12}$, where Ω_B is the baryonic density parameter and J_{-12} is the total photoionisation rate in units of $10^{-12}\mathrm{s}^{-1}$, (ii) temperature T_0 corresponding to the mean density of the IGM and (iii) the slope γ of the effective equation of state of the IGM at a mean redshift $z \simeq 2.5$. They find that $0.8 < (T_0/10^4\mathrm{K}) < 2.5$ and $1.3 < \gamma < 2.3$, while the constraint obtained on f is $0.020^2 < f < 0.032^2$ (see Fig. 9).

This result is of importance because of the constraint it places on baryonic density. A reliable lower bound on J_{-12} can now be used to put a lower bound on $\Omega_B h^2$, which can be compared with similar constraints obtained from Big Bang Nucleosynthesis (BBN) and CMBR studies. Under the reasonable assumption of $J_{-12} > 1.2$, the lower bound on $\Omega_B h^2$ is in violation of the BBN value, but is in agreement with the value obtained from MAXIMA and BOOMERANG.

Extragalactic Astronomy

Centres of galaxies

Centres of almost all galaxies are believed to be harbouring supermassive black holes (SMBH). Kinematic and photometric observations of a nearby galaxy, M31, have confirmed presence of a SMBH of mass about 3.3×10^7 solar masses. *S. Sridhar* and *Niranjan Sambhus* have been pursuing a study of the stellar dynamics in the vicinity of this black hole. They use the photometric information to obtain the gravitational potential of the region, and hence obtain the orbital structure in the region close to the black hole. They show that the nuclear stellar disk around the SMBH in M31, is rotating with a speed of, not greater than $20 kms^{-1}$. They generate stellar orbit libraries and are currently trying to build a self consistent model



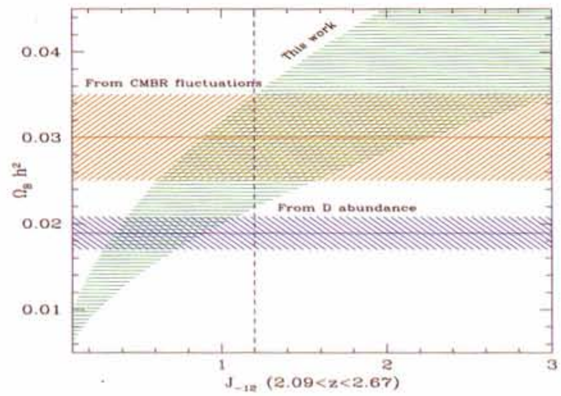


Figure 9: The top figure shows the constraints obtained in the $\gamma - T_0$ space for different values of $f = \Omega_B h^2/J_{-12}$, *using transmitted flux statistics.* The shaded regions denote the range allowed by observations. The boundaries are uncertain by an amount 0.1 along γ axis and by 1000K along the T_0 axis because of finite sampling, which is shown by a cross at the upper right hand corners of the panels. The bottom figure shows the comparison of the bounds on $\Omega_B h^2$ obtained from our simulations with those obtained from Big Bang Nucleosynthesis (BBN) and CMBR analyses. The lower horizontal bound shows the region allowed by BBN (Burles, Nollett & Turner 2000) while the upper band shows that allowed by BOOMERANG and MAXIMA data (Bond, et al. 2000; Padmanabhan & Sethi 2000). The bound on $\Omega_B h^2$ arising from the current work is shown as a function of J_{-12} by the curved band running from left bottom to the right top.

that explains the photometric as well as the kinematic data.

The bulges of galaxies

A.K. Kembhavi and collaborators have developed the concept of the "photometric plane" for galaxies, which was reported last year. Galaxies are tightly distributed about a plane in the three dimensional space of photometric parameters characterising the bulge. Such a planar relation, which they call the "photometric plane", has been seen for galaxies in clusters and in the field.

A near infrared study of galaxies in the intermediate redshift cluster CL 0024+167 and the low redshift cluster Abell 2877 has indicated that they too lie on the photometric plane. The few points that deviate significantly from the plane are all late type disc galaxies that are believed to have been formed by a different formation mechanism from the rest. The photometric plane is thus proving to be a powerful probe of homology in bulges, with bulges having a certain formation history tightly clustering around the plane at low and moderate redshifts, while bulges that formed in other ways are widely scattered about the plane. Investigations into other implications of the existence of a photometric plane are on. Observations of clusters, in the near-infrared band of galaxies have been obtained by *Kembahvi* and collaborators for this purpose using large aperture telescopes.

Discovery of a new hyperluminous IR galaxy

The European Large Area *ISO* Survey (ELAIS) was the largest open time *ISO* programme, and consists of multi-wavelength observations with *ISO* over a total area of 12 square degrees (to a depth of about 1, 2, and 100 mJy at 6.7, 15, and 90 μm, respectively).

T. Morel, et al. have discovered a new hyperluminous infrared galaxy in the course of this survey. This object has been detected by *ISO* at 6.7, 15, and 90 μm, and is found to be a broad-line, radio-quiet quasar at $z = 1.099$. On the basis of a detailed multi-component model fit of the spectral energy distribution, they derive a total IR luminosity: $L_{\rm IR}$ (1-1000 μm) $\approx 1.2 \times 10^{13}\ h_{65}^{-2}\ L_{\odot}$ ($q_0 = 0.5$), and argue for the existence of a star burst largely contributing to the far-IR output. In addition to his involvement in the follow-up programme, *Morel* is also currently investigating the IR colour properties of ELAIS galaxies.

Line imaging of SNR's

Near-IR [Fe II] lines are widely used to derive the supernova rate of star burst galaxies. However, this quantity critically hinges on the assumed values of the [Fe II] luminosity and [Fe II]-emitting lifetime of a *single* supernova remnant (SNR); both of which are considerably uncertain.

In order to better calibrate the supernova rate of star burst galaxies, *T. Morel*, et al. have launched a near-IR [Fe II] line-imaging survey of a sample of 42 SNRs in M33. A wide range of [Fe II] λ1.644 μm line luminosities is observed (18-695 $L_{\odot}$). Their observations suggest that the SNRs with strong [Fe II] emission are entering the radiative phase and that the density of the postshock gas largely controls the amount of [Fe II] emission. This, together with an estimate of the typical [Fe II]-emitting lifetime, allowed them to present an empirical relation for the supernova rate in star burst galaxies.

The existence of 1720 MHz maser emission in SNRs has been recently claimed as evidence for an interaction between the SNR blast wave and adjacent molecular gas. This compact maser emission is believed to be induced by collisional excitation of OH by the H_2 molecules as shocks propagate through the molecular cloud. If this interpretation is correct, shocked H_2 molecules should be found in vicinity of the maser locations.

Morel, et al. have obtained H_2 1-0 S(1) images of the regions of maser emission in a number of northern SNRs. Spectacular complexes of filaments were unveiled. This supports a model in which the maser emission arises from the region at the interface between the SNR and the molecular material, while the H_2 emission is produced by shocks penetrating deeply into the molecular cloud.

Polarization of gamma ray burst afterglows

Substantial evidence have now accrued in support of models for gamma-ray bursts (GRB) and their afterglows based on synchrotron cooling of shock-accelarated electrons in an ultra-relativistic ejecta swept up by an expanding fireball from an ambient inter-stellar medium. However, it is not understood how the very large magnetic fields which are prerequisites for this emission process to be efficient, could be created/have existed at the location where the emission occurs, which is far from the compact object which exploded. For a long time it was thought that these magnetic fields would be completely tangled up so that the GRB afterglow will not have any net polarization, even though synchrotron emission mechanism itself is highly polarizing. However, recently several models have been proposed predicting polarization as high as few times 10% in the afterglows. Many of these models break the symmetry of magnetic fields by assuming that the ejecta is beamed – an assumption which has been gaining popularity over the last couple of years. These models predict very clear signatures in terms of the amount and position angle of linear polarization in relation to the afterglow light curves. However, all of these models are severely under-constrained because of the lack of accurate polarization measurements of afterglows. The main difficulty in measuring the polarization of the afterglows is due to their faintness coupled with their rapid fading nature. This necessitates the use of an instrument capable of measuring simultaneously, the two orthogonal polarization components that define a Stoke's parameter. So far the few partially successful observations have been carried out with an instrument on VLT. *A.N. Ramaprakash* is working on using the IUCAA polarimeter for observing afteglow polarization using telescopes in India.

Missing optical afterglows of GRBs

Observational verification of the prediction that gamma-ray bursts should be followed by relatively long-living afterglows at other wavelengths ranging from X-rays to radio was a major breakthrough that happened in this field over the last few years. Then the launch of the Italian-Dutch satellite Bepposax, with its suite of wide-field instruments to detect the bursts and narrow-field instruments that locate their X-ray afterglows precisely, provided the opportunity for undertaking rapid reaction ground-based observations of the afterglow light curves. However, a look at the observations of a few hundred bursts that have accumulated over the last three years or so, show very clearly that there is a dearth of optical afterglows which cannot be explained by observational limitations. Only about 50% of the bursts with X-ray afterglows and therefore, precise localizations show detectable optical afterglows while, only about 35% show detectable radio afterglows. This is puzzling since the gamma-ray burst models predict very stringent restrictions on the decay index of the afterglow light curves. *A.N. Ramaprakash*, along with Koshy George, from Mahatma Gandhi University is working on understanding this issue using data on these bursts which are already available.

Galaxy and Interstellar Medium

Interstellar dust and extinction by composite porous grains

In continuation of the ongoing research on modeling of interstellar dust grains, (in collaboration with D.B. Vaidya (Gujarat College, Ahmedabad), J.B. Dobbie and P. Chylek (Dalhousie University, Halifax, Canada)), *Ranjan Gupta* has reported the extinction curve with composite particles of silicate and graphite inclusions in a recent paper. Fig. 10 shows the interstellar extinction curve in the wavelength region of 0.55μm - 0.20μm.

A proposal was submitted in 1998 by *Gupta* (and Asoke K. Sen, IUCAA Associate) to India-Japan Cooperative Research Programme operated by DST, New Delhi and JSPS, Japan, entitled, "Light scattering by irregularily shaped particles", in collaboration with Tadashi Mukai (Kobe University, Japan). This proposal has now been approved and subsequent to the exploratory visit made in March 2000 by both the parties, both *Gupta* and Sen visited Kobe University again in March 2001 to continue the programme. Further work is in progress to simulate observed polarization versus scattering angle curve with DDA and T-matrix methods.

Stellar Physics

Accretion disks around rotating neutron stars and strange stars

Observations of neutron stars mainly concern issues related to obtaining bulk parameters like mass and radii of these objects. The possibility of constraining the property of matter composing neutron stars (or in other words, the equation of state of neutron star interiors) from such observations, therefore, provides the chief motivation of such ventures. The last decade particularly, has seen an intense activity in this field, with the launching of several X–ray satellites, equipped with state-of-the-art detectors. Among the systems inferred to contain neutron stars, are a particular class of objects called low mass X–ray binaries (LMXBs) that exhibit X–ray bursts. LMXBs contain a compact object (either a blackhole or a neutron star) gravitationally peeling off matter from the outer environs of an evolved dwarf companion star, that fills its Roche lobe; the matter (due to the proximity of the companion) spirals in, forming an "accretion disc" around the compact object. In these systems, X–ray bursts (classified as Type–I bursts) are believed to be signatures of the presence of a hard surface (as opposed to Type–II bursts that occur due to instablities in the accretion disc), signalling the presence of neutron stars.

In an accretion disc, the incoming matter loses angular momentum to exterior co–rotating layers, as a result of viscous friction and, in consequence, spiral inward. The viscous heating at each co–rotating layer radiates away at least part of this heat. The standard theory (based on Newtonian formalism) of accretion discs, assumes each layer to be in thermal equilibrium and that all of the viscous heat generated to be radiated away. The resulting spectrum, therefore, appears as a "sum of black–bodies". An essential modification to this theory comes in the form of inclusion of general relativity and rotation of the central accretor (at least for the inner parts of these discs), into the calculations. General relativity manifests itself in two ways: first, in relocating the inner edge of the accretion disc from the surface of the star to the innermost stable circular orbit (ISCO) and secondly, in redistributing the contributions to the total luminosity from an extended disc and that from a narrow boundary layer girdling the neutron star (which, within Newtonian formalism are equal). The effect of rotation (including general relativistic effects) will be to shrink the boundary layer and lower its contribution to the total luminosity.

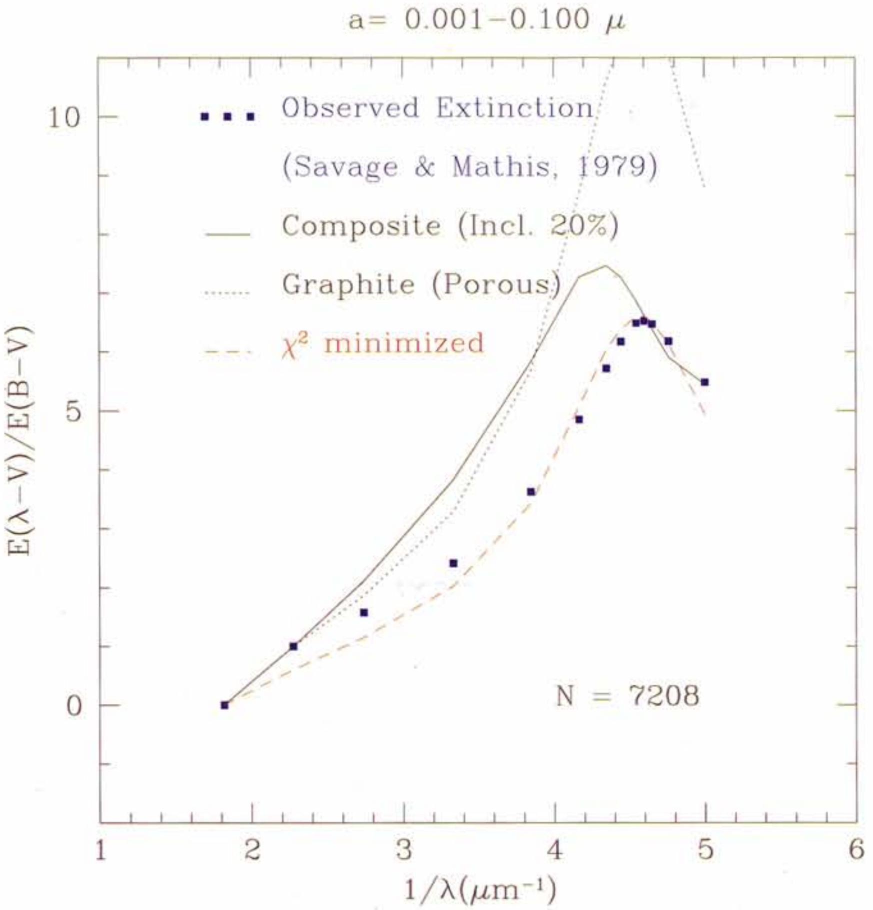


Figure 10: Comparison of the observed interstellar extinction curve with the best fit model curve of composite grains (N=7208) with 20% of volume fraction of inclusions and porous graphite grains.

S. Bhattacharyya, R. Misra and *A.V. Thampan* have computed the spectra of accretion discs around rotating neutron stars in the appropriate space-time geometry for several different equations of state, spin rates and masses. The analysis involved the computation of the relativistically corrected radial temperature profiles and the effect of Doppler and gravitational redshifts on the spectra, omitting light bending effects for simplicity. Comparing the relativistic accretion disc spectrum with that from a Newtonian disc, it was shown that the difference between the two arose primarily due to the different radial temperature profiles for the relativistic and Newtonian disc solutions. In order to facilitate direct comparison with observations, the authors presented a simple empirical function that describes the numerically computed relativistic spectra well. This empirical function (defined by three parameters including normalization) was also shown to describe the Newtonian accretion disc spectrum adequately – implying the potential use of this function to distinguish the two. In particular, the authors showed that the best fit value of one of the parameters (termed β-parameter) ≈ 0.4 for the Newtonian case, while it ranged from 0.1 to 0.35 for relativistic case depending upon the inclination angle, EOS, spin rate and mass of the neutron star.

The above calculations were improved upon by S. Bhattacharyya, D. Bhattacharya and *Thampan* by including the full light bending effects in computing the observed spectrum. The authors find that light bending significantly modifies the high-energy part of the spectrum; in particular, depending on the viewing angle, the authors conclude that light bending effects amount to enhancing the observed flux (from that calculated ignoring this effect) at ~ 10 keV by as much as 250%.

On the theoretical front, the suggestion that degenerate matter can minimise its ground state energy through an incarnation as strange quark matter (composed of u, d and s quarks) rather than Fe^{56}, have led to the speculation of existence of "strange" stars. These theoretical suggestions have, in recent times, received much attention due to the observation that the central accretors in at least two LMXBs seem to have radii significantly lower than that predicted for neutron stars composed of standard neutron star matter. Observationally distinguishing strange stars from neutron stars, require detailed analysis of the salient differences - both theoretical and observational - between them.

S. Bhattacharyya, *Thampan* and I. Bombaci have constructed constant gravitational mass equilibrium sequences of rotating strange stars, in order to identify key differences in structure properties of these two objects. They find that even though the structure parameters for a given mass and rotation rate of the two objects do not quantitatively differ much, the qualitative behaviour of these with varying rotation rates differ significantly. In particular, the authors show that the radius of the ISCO, an important parameter deciding the energetics in accreting systems, is (for nearly all rotation rates) located significantly distant from the surface of the strange star: a property not seen in rotating neutron stars (for which, this radius is located at the surface of the star for sufficiently high rotation rates). In addition, the authors show that the location of the ISCO shows a non–monotonic behaviour with rotation rates: a behaviour absent in both rotating black holes (described by Kerr metric) as well as rotating neutron stars. The authors find that the parameter playing a significant role in this non–monotonic behaviour is the radial gradient of the Keplerian angular velocity at the ISCO. The authors further calculate the temperature profiles of accretion discs around rotating strange stars with a view of applying it to the systems: SAX J1808-36 and 4U 1728 -34, inferred to contain strange stars as central accretors.

Neutron stars with super-strong core magnetic fields

There has been strong observational indications for the existence of a class of neutron stars with extremely large magnetic fields ($B \gtrsim 10^{14} - 10^{15}$ G). Assuming that such strong fields reside in the core of a neutron star, *S. Konar*, along with Somenath Chakrabarty (Kalyani University) investigates the possible modification of the structure and hence, the evolution of the crustal magnetic field manifest at the surface.

Effect of diamagnetic screening on the magnetic field of accreting neutron stars

The idea of diamagnetic screening of the pulsar magnetic field by the material accreting onto the surface of the star, has been around for some time. *S. Konar* and Arnab Raichaudhury (IISc, Bangalore) find that if the screening does take place on a time-scale of material flow over the neutron star surface, the diffusive time-scales are such that the effects would not be long-lived. But more importantly, such a screening never takes place. As any kind of stretching of the field lines (for the creation of the toroidal field at the expense of the dipolar field strength) is immediately restored over the Rayleigh-Taylor overturn time-scale, which is a few microseconds. Therefore, the diamagnetic screening is not an effective way of pulsar field reduction.

Stellar spectral classification

As the observations for Coude Feed spectral library have been nearly completed with several runs made at Kitt Peak over past 3-4 years, *Ranjan Gupta* has now submitted a DST-NSF Indo-US proposal for consideration in collaboration with H.P. Singh (Delhi University) and Jim Rose (University of N. Carolina, USA) and his team, The proposal entitled 'A Comprehensive Digital Library of Stellar Spectra' envisages setting up of this library on web in a user friendly way, which will be of great value for researchers in areas of galaxy population studies, stellar spectral classification, etc.

Automated classification using neural networks

Automated classification using neural networks has recently found many applications in Astronomy. These range from classification of stellar and galactic spectra, differentiating between stars and galaxies from imaging data, to detecting defects on CCD's, etc.

Sajith Philip, in collaboration with *Yogesh Wadadekar* and *Ajit Kembhavi* has developed a new technique called the Bayesian Difference Boosting Neural Network (DBNN) for automated classification problems in astronomical data analysis. DBNN has many advantages over previously known techniques. It requires fewer parameters for training and its training times are an order of magnitude shorter. Since DBNN is based on Bayesian probability estimates, it is immune to divergent training parameters that often appear in the training set due to noise in the observation. This means that the performance of the network is likely to be significantly better than its competitors when studying faint astronomical objects. They have demonstrated the capabilities of their technique by applying it to the star-galaxy classification problem.

The star–galaxy classification problem addresses the task of labeling objects in an image either as stars or as galaxies based on some parameters extracted from them. Classification of astronomical objects at the limits of a survey is rather a difficult task, and traditionally has been carried out by human experts with intuitive skills and great experience. This approach is no longer feasible, because of the staggering quantities of data being produced by large surveys, and the need to bring objectivity into the classification, so that results from different groups can be compared. It is, thus, necessary to have machines that can perform the task with the efficiency of a human expert (but at much greater speed) and with robustness in the classification, over variations in observing conditions.

DBNN gives accurate (>97% correct) classification over a wide range of brightness levels, in a very short time. It seems that reliable classification of sources from all-sky optical surveys such as the Sloane survey will now be possible in reasonable amounts of time. Efforts are on to apply the technique to other classification problems in Astronomy.

Instrumentation

Near infrared array camera

A 256 × 256 near infrared array detector has been obtained on loan from IOA, Cambridge, UK, and a liquid nitrogen cooled camera is being designed around it by *A.N. Ramaprakash.* This camera would use a modified version of the CCD Controller developed in our laboratory; the controller is being modified to cater for the higher sampling rates, required for the infrared array by *P. Chordia, D.V. Gadre* and *S.N. Tandon.*

Imager spectrograph for IUCAA telescope (IFOSC)

Progress on this instrument was reported earlier. Fabrication of this versatile imager spectrograph (about which, some details were reported in previous annual reports) has now been completed in collaboration with the CSIO of Chandigarh, and Copenhagen University Observatory of Copenhagen. This instrument can be switched from one mode to the other, e.g., from photometric imaging (which requires excellent weather conditions) to spectroscopic observations (which can be done in less than excellent conditions) in a few minutes. The instrument uses lenses and grisms, and is similar to the well known instrument EFOSC of the European Southern Observatory, and has the capacity to either image a field of about 11.5 arcmin square, or do long slit or multislit spectroscopy (with a resolution upto 3000) in the band 400 nm to 8500 nm. A calibration unit, consisting of filter wheels and calibration lamps, has been developed and integrated with this spectrograph by *H.K. Das, D.V. Gadre, R. Kharoshe, A. Kohok* and *S.N. Tandon.*

Some initial tests have been carried out on the spectrograph by *Das* and *Tandon*, and it has been found that at a level of > 0.1 % brightness, there is no more than one ghost image, and that the central brightening on the detector is no more than 2% ; these results show that use of multilayer-wide-band-anti-reflection coatings on the lenses has been very effective. The Council of Scientific and Industrial Research, and the Department of Science and Technology provided financial support for this instrument.

The IUCAA Faint Object Spectrograph Camera will be the main instrument on the IUCAA telescope, mounted on its direct Cassegrain port. The versatality of this instrument can be further enhanced by adding polarimetric capability to it. Different techniques for adapting the instrument for this purpose are being explored currently. *A.N. Ramaprakash* is working on this along with other members of the instrumentation group.

Cambridge Infrared Panoramic Survey Spectrograph

A near-infrared integral-field spectrograph is being built at the Institute of Astronomy, Cambridge, UK. This is the first fibre-fed infrared spectrograph and it also employs optical techniques to suppress the atmospheric OH lines, which limit the sensitivity of near-IR instruments. This instrument is in the final phase of integration and testing, and will soon be commissioned on the Gemini North telescope. *A.N. Ramaprakash* has been working with the group in Cambridge during the design and construction of this instrument. He is continuing the collaboration and had visited the institute from June to December, 2000. His main observational interest with the instrument is the study of the dynamics of ultra-luminous infrared galaxies (ULIRGs), which are now thought to be powered by merger-induced star bursts.

Near Infrared Picnic Imager

IUCAA has recently managed to borrow a 256 × 256 element near-infrared detector from the Institute of Astronomy, Cambridge, UK. It is proposed to build a JHK band camera with polarimetric capabilities using this detector. This instrument will be used on one of the Cassegrain side ports of the IUCAA telescope. *A.N. Ramaprakash* has been working on the design of this instrument along with other members of the IUCAA instrumentation group. IUCAA's CCD controller will be adapted to acquire data with this camera. *Ramaprakash's* primary observational interest with this instrument is the study of gamma-ray burst afterglow polarization.

Automated photoelectric telescope by the universities

The Automated Photoelectric Telescope has been successfully installed at Bhavnagar University by IUCAA Visiting Associate, S.P. Bhatnagar in consultation with *Ranjan Gupta* and the first light images have been obtained (see IUCAA Khagol January 2001 issue). The Bangalore University APT will now be transferred to Bangalore and installed with the modified software now in use at Bhavnagar.

(II) RESEARCH BY VISITING ASSOCIATES

Theoretical Physics

B. Bambah

B. Bambah has studied polynomially deformed Lie algebras, which arise in the study of the dynamical symmetries of the the quantum mechanics in spaces of constant curvature. In collaboration with V. Sunilkumar and R. Jagannathan, Bambah has applied these to super-integrable and quantum optical systems. She has also studied the salient features of dynamical chaos in classical gauge theories with spatially homogeneous fields. She has discussed the chaotic behaviour displayed by both Abelian and non-Abelian gauge theories and the effect of the Higgs term in both cases.

V.H. Kulkarni

Using the variational formulation of the Fermat principle and exploiting its analogy with the Hamilton principle of mechanics, V.H. Kulkarni, in collaboration with A.A. Rangwala and A.A. Rindani, has introduced an optical Lagrangian to show that the Euler - Lagrange equation results in the ray equation of optics. This was applied to (a) bending of a light ray near a massive star (b) its bending in a non-magnetised thermal plasma.

G.P. Malik

G.P. Malik, with L.K. Pande, has been concerned with a reexamination of results obtained in the Landau-Ginsberg-Abrikosov theory of superconductivity in the light of work done by him earlier (with J. Subba Rao, Gautam Johri and Krishna Sengupta) in the soliton theories.

Usha Malik

Within the framework of the temperature-dependent approach to dynamics as spelt out by G.P. Malik, L.K. Pande and V.S. Varma, Usha Malik, with G.P. Malik, has been concerned with the derivation of some of the results of the BCS theory of superconductivity. The idea here is to establish that the approach followed by these authors gives credible results in fields as diverse as QED, QCD and superconductivity.

Additionally, she has shown that the confining term in the widely used form of QCD potential is derivable from the gluon super propagator for an exponential form of gluon self-interaction, if one assumes that the gluon-gluon coupling constant has the character of a running coupling constant.

P.N. Pandita

In super symmetric models, because of the presence of the super symmetric partners of the known particles, there are Yukawa couplings which violate baryon or lepton number. P. N. Pandita along with B. Ananthanarayan has carried out a detailed renormalization group study of these B and L violating Yukawa couplings involving the highest generations, and the corresponding soft super symmetry breaking parameters. It has been shown that in the Yukawa sector, there is only one infrared fixed point corresponding to non-trivial fixed point for top- and bottom-quark Yukawa couplings and the highest generation B violating coupling. All other fixed points are either unphysical or unstable. They have obtained the exact solutions of these equations in a closed form, and then depicted the infrared fixed point structure of these Yukawa couplings. Approximate analytical solutions for these couplings, and the soft super symmetry breaking couplings were obtained in terms of their initial values at the unification scale. Numerical study of the infrared fixed surfaces of the model was carried out, and the approach to fixed point was depicted.

Non-Linear Dynamics

G. Ambika

One dimensional discrete systems or maps with two parameters model a variety of interesting physical situations like coupled non-linear oscillators, electronic circuits, lasers, insect populations, cardiac cell simulations, oscillatory chemical reactions, etc. In these, one of the parameters takes care of the strength of the non-linearity, while the other is mostly additive in nature and comes from the coupling or additional forcing terms. If the non-linearity is more than quadratic , then these maps are capable of exhibiting distinctly different dynamical behaviour,viz., Bubbling or bistability. G Ambika and Sujatha N V , analysed the mechanism of occurrence of these features in the bifurcation scenario of such maps and established that it is the sign of the third derivative of the map function that decides whether it will support bistability or bubbling during bifurcation. The work has been extended to scaling behaviour of Lyapunov exponent (LE) and the fractal dimensions near the onset of chaos. It is found that linear scaling is the general behaviour in the immediate neighbourhood of the transition point, while overlap scaling follows the usual Huberman-Rudnick relation. However, fractal dimensions follow three different scaling regions, the dimensions increasing rapidly with the parameter at first, then slowly and finally saturate just before the band-merging point.

V.C. Kuriakose

Optical solitons find applications in ultra high speed communication systems. There are several factors like inhomogeneity, fibre loss or gain, etc. can affect the electromagnetic wave propagation through optical fibres. Higher order non-linear Schrodinger equations (HNSEs) are then used to describe the wave propagation. Optical switching and phenomena like wavelength division multiplexing require the use of coupled higher order non-linear Schrodinger equations. In this connection Vinoj and Kuriakose have studied the integrability of a system of coupled HNSEs and obtained single soliton and two soliton solutions and evaluated Lax pairs of the system. They have also studied an inhomogeneous NSE, which governs the wave propagation through inhomogeneous optical fibres. Ganapathy and Kuriakose studied the wave propagation through a birefringent optical fibre described by a coupled NSE and studied the integrability of the system and obtained soliton solutions. Shaju and Kuriakose have studied fluxon dynamics in non-uniform coupled Josephson junctions in an ac bias analytically and numerically. They obtain a threshold value of the ac bias current at which dc motion of the fluxon exists in junctions. Their studies include perturbed single and coupled homogeneous and non-homogeneous junctions.

L.M. Saha

In nonlinear dynamics, one is mainly concerned with problems on stability, instability and chaos emerging during the evolution of a dynamical system. Some investigations are also confined to the problem of chaos control and synchronization of various signals by using some recently invented methods and techniques. Such problems involve the use of chaos for constructive purposes.

Towards application of these ideas, L.M. Saha, in collaboration with M.K. Das, Y. Tanaka and others has been engaged in work related to the chaotic motion of satellite and search for stable and unstable orbits in restricted three body problem when the primaries are radiating bodies. An effort is under way to investigate the problems of binary stars within the domain of restricted three body problem.

Quantum Theory

R.S. Kaushal

From the point of view of classical quantum correspondence, while there are several situations when a quantum result reduces to a classical one in a certain limit, not many cases are known when a classical result gives rise to a quantum one. R.S. Kaushal has been pursuing one such a route from classical to quantum domain by way of identifying the equation of motion of a time dependent harmonic oscillator with the stationary state Schrodinger equation. An interesting part of this approach is that there emerges a geometric constraint in the Schrodinger quantum mechanics (SQM) in terms of a space invariant. In fact, irrespective of the form of the potential in the SQM, there exists a fundamental phase in the quantum wave function which manifests through a mathematical construction termed as 'space invariant'. This invariant, while it accords the possibility of a non-linear superposition principle in the SQM, however, suggests an alternative to account for the geometry of the quantum system with reference to a particular phenomenon. Kaushal has further emphasized that some of these features are the natural outcome of a more general result based on the Sturm-Liouville theory.

Quantum Gravity

Subenoy Chakraborty

For a quantum theory of gravity, the introduction of new variables by Ashtekar has solved many difficulties in canonical formulation. In particular, the constraints are in simple polynomial form using these new variables and consequently, it may be possible to develop a quantum theory of gravity. S. Chakraborty and N. Chakraborty have applied these new variables to classical and quantum cosmology. They have obtained well known classical solutions for spherically symmetric space-time with perfect fluid in phase space using Ashtekar variables. They have also able to apply these new variables to quantum cosmology to obtain the wave function of the universe for some particular space-time model.

Quantum Cosmology

S. Biswas

The method of CWKB developed by S. Biswas has been applied to obtain the wave function of the universe. At present, there are two approaches to introduce time into the framework of Wheeler-DeWitt equation: time before quantization and time after quantization. Using the first approach, he obtained a Schrodinger-Wheeler-DeWitt (SWD) equation, usually valid in low curvature region. For ground state, he used an adiabatic ansatz to obtain the wave function of the universe and continued the wave function in the high curvature region. He used the method of CWKB to consider complex paths in complex scale factor space. Repeated reflections between the turning points are identified to take into account the wormhole contributions. The wormhole-dominated wave function so obtained resembles very much the Hartle - Hawking wave function.

B. Modak

Bijan Modak has reformulated the canonical quantization formulation of the curvature squared action of Horowitz (PRD 31,1169 (1998)) and has constructed the Wheeler-Dewitt equation in the Schrodinger form and as a consequence, he has obtained the probability density and current density.

B.C. Paul

It is known that the quantum creation of an open universe needs an unusal scenario. Coleman and De Luccia (CD) suggested a mechanism which leads to a nearly homogeneous open universe with density parameter $\Omega < 1$ at the present epoch. However, the CD scenario can be realised only at the cost of making very fine tuning. Recently, an alternative mechanism was suggested by Hawking and Turok (HT). The HT mechanism makes use of the no boundary proposal of Hartle-Hawking and provides for a novel technique of creating an open inflationary universe described by a singular instanton obtained in a mini super space model with an inflaton field. B.C. Paul in collaboration with S. Mukherjee and R. Tavakol has studied the quantum creation of an open inflationary universe in higher derivative theories. Converting the higher derivative theories into a theory of a self interacting scalar field, minimally coupled to Einstein gravity, by a conformal transformation, they obtain singular HT instanton solutions for a range of values of the parameters of the theory. They obtain both non-singular and singular instanton. The scalar field clarifies the special features of the two types of solutions. In the non-singular type, the scalar field sits on the top of the maximum of the potential. This gives an indication that the Lorentzian constraints of this solution ($\alpha < 0$) may be unstable. There is no HT instanton for $\Lambda < 0$. Thus, the HT instantons solutions are not very generic in nature in the theories.

Quantum Field Theory in Curved Space-time

S. Biswas

S. Biswas is studying various aspects of particle production in curved space-time using the method of complex trajectory WKB approximation. Earlier, the method has been applied to mainly time dependent problems with successful results. It is a matter of investigation if the same technique is applicable in space dependent problem. He studied this aspect considering particle production in e.m. field both in space and time gauges using the method of CWKB and obtained gauge independent results in such a case. He also studied particle production in de Sitter space-time both in time and space dependent gauge, and obtained identical results using CWKB. In his approach the reflection coefficients differ from the results obtained by others. To ensure the correctness of CWKB, he obtained the famous gauge invariant result of Schwinger. He established that the CWKB reflection co-efficient is related to the connected part of the S-matrix element whereas others' results (those who use Landau's technique) are related to the disconnected part.

V.C. Kuriakose

Quantum gravity still being a dream, to study the effects of gravity on quantum fields, one must opt for some semi-classical treatment. Arun, Minu Joy and V.C. Kuriakose have studied a scalar field with quartic self coupling in 3+1 dimensional spatially flat RW space-time at one loop order. Divergenceless expression for the energy-momentum tensor is obtained using the effective potential method. Minu Joy and Kuriakose have studied a scalar field with ϕ^6 interaction in Bianchi space-time in 3+1 dimensions and found that the model can be regularized using the effective potential method. They evaluated the finite temperature effective potential and found that this model can be used to understand first order phase transitions which took place in the early universe. They have also studied the same model in 2+1 dimensions and studied bubble nucleation associated with phase transitions which took place in the early universe. It was found that the phase transitions depend on the space-time curvature and the coupling to gravity.

Gravity in Higher Dimensions

Subenoy Chakraborty

Primordial black holes in higher dimension have been discussed and the effect of extra dimensions have been studied by S. Chakraborty and N. Chakraborty. Also, S. Chakraborty has investigated the behaviour of a test particle around a charged dilatonic black hole.

S. Chakraborty and F. Rahaman have studied topological defects, particularly domain walls and textures. Global texture in four and higher dimension have been investigated and their gravitational fields have been studied by them. They have also considered spherical domain walls both in four and higher dimensions and have examined their gravitational field by the motion of a test particle.

Sujit Chatterjee

Higher dimensional theories are now an active field of research in attempts to unite gravity with all other forces in nature as also the recent interests in models where the universe is a 3-brane embedded in a higher dimensional bulk. Moreover, the recent analysis of de Lapparent, et. al. of CFA redshift survey and also the observations of Saunders, et. al. of IRAS survey indicate that the large scale structure of the universe does not show itself as a smooth and homogeneous distribution of matter as was thought earlier. As higher dimensional inhomogeneous models are not adequately addressed in the literature so far, S.Chatterjee, et. al. are studying the inhomogeneous models and its implications in the framework of higher dimensional space-time.

B.C. Paul

B.C. Paul has carried out an analysis of a n-dimensional vacuum Einstein field equations in which 4-dimensional space-time is described by a Friedmann Robertson-Walker (FRW) metric and that of the extra dimensions by a Kasner type Euclidean metric is carried out to explore the inflationary universe scenario of a 4-dimensional universe. The higher dimensional field equations are interpreted as 4-dimensional Einstein equations with effective matter properties. The effective matter part is then treated as viscous fluid. The theories of imperfect fluid given by Eckert, truncated Israel-Stewart and full Israel-Stewart (FIS) theories are considered to obtain cosmological solutions for a flat model of the universe. The imperfect fluid assumption admits here power law inflation for the 3-physical space in some cases. In FIS theories, there is a solution with decreasing mode of temperature of the universe determined by the viscosity.

A. Sil

A singularity becomes naked when non-spacelike geodesics can escape from it in future directions. Penrose first articulated the idea that classical general relativity contains a built-in safety feature that precludes the formation of naked singularities in gravitational collapse. Singularity must be hidden inside an event horizon. This hypothesis, which has become known as 'Cosmic Censorship Conjecture', is generally accepted as the central unresolved issue in classical general relativity. Although at present, there is no precise mathematical formulation of this conjecture, there exist a number of counter examples to it in the literature. Most of these counter examples either belong to Vaidya space-time or to Tolman-Bondi (TB) space-time. A. Sil, in collaboration with A. Banerjee and S. Chatterjee first extended the TB solution of gravitational collapse of spherically symmetric dust distribution to multi-dimensional space-time to investigate whether dimensionality has any role to play in the nature of singularities. They found strong curvature naked singularity existed in a five dimensional TB like space-time at the centre of a self-similar collapse for the marginally bound case. S.G. Ghosh and A. Beesham have recently shown that the result can be extended to the non-self-similar case also. However, their investigation was restricted to the marginally bound case only. Sil and collaborators have investigated the existence of naked singularity in all the cases of marginally bound, unbound and bound gravitational collapse of inhomogeneous dust sphere in five dimensional space-time for both self-similar and non-self-similar cases. They find that the limiting value of inhomogeneity parameter beyond which the singularity becomes naked in a marginally bound non-self-similar collapse, as found by Ghosh and Beesham is incorrect. They also find existence of naked singularities in bound and unbound cases for both self-similar and non-self-similar collapses.

R.S. Tikekar

Relativistic Kaluza-Klein (KK) theories in five or more dimensional space-times are highly significant, especially in the context of the unification of fundamental interactions. Godel's discovery of the model describing a rotating dust universe led to the study of the relativistic field equations with axisymmetric rotating fluid sources and their solutions. R. Tikekar and L.K.Patel formulated the KK field equations for cylindrically symmetric rotating matter distributions and studied the physical relevance of several solutions of the system. This set of solutions is the first such set reported and includes KK counterparts of known relativistic space-times.

N.K. Dadhich, Patel and Tikekar have shown that the global monopole solution in the KK space-time follows as dual of the corresponding vacuum solution in the KK theory. Following the procedure which uses duality transformation and obtains the space-time duals of vacuum space-times it is also shown that the dual of five dimensional flat space-time describes the space-time of a massive global monopole admitting a massless limit analogous to the four dimensional dual flat solution. New families of exact solutions of Einstein's field equations representing gravitational field of thick domain walls in five dimensional KK space-times have been obtained. They have also obtained higher dimensional generalization of McVittie solution, which describes the space-time of a mass particle in Robertson-Walker universe of higher dimensions.

Exact Solutions

S. Chaudhuri

Using the soliton technique of Belinskii and Zakharov, S. Chaudhuri has constructed some exact solutions of stationary axially symmetric space-times. The solutions are well behaved at spatial infinity and possess monopole and other higher mass multipole moments. The event horizon is surrounded by the infinite redshift surface.

S. Chaudhuri generated some magnetostatic solutions of Einstein-Maxwell field equations by the technique of Das-Chaudhuri. The solutions are asymptotically flat and reduce to the Schwarzschild form in the absence of magnetic field. Using Kerr metric as seed, Chaudhuri has reproduced Bonnor's magnetostatic solution.

Ng. Ibohal

Ng. Ibohal and Azad Singh have studied Kerr-Schild form metrics, based on the known metrics like Robertson-Walker metric, Reissner-Nordstrom metric, de Sitter metric and Bertotti-Robinson metric, looking for new metrics. They have also applied the Newman-Janis algorithm to these metrics. They are able to find new properties of these metric functions.

R.S. Tikekar

R.S. Tikekar and V.O.Thomas have shown that a core envelope model of relativistic compact star in equilibrium can be described on the background of pseudo-spheroidal space-time. The continuity of matter density and fluid pressure across the boundary separating the core from the envelope is a highly significant feature of this set up.

Alternative Theories of Gravity

Asit Banerjee

Low energy effective string field theory has been widely studied in recent time. Dilaton field naturally appears coupled with Einstein-Maxwell fields when the low energy limit of the string theory is considered. Asit Banerjee has considered exact cosmological models in homogeneous anisotropic space-time and are constructed with dilaton scalar field and Liouville type dilatonic potential interacting with electromagnetic fields coupled with gravity. The dynamical behaviour and singularities of these models were studied. Thick non-static domain wall was discussed in the context of the Brans-Dicke theory of gravity. An exact solution was obtained with the assumption that the pressure perpendicular to the plane of the wall is linearly proportional to the energy density. When the Brans-Dicke parameter tends to infinity, the scalar field becomes constant and a special solution given previously by Goetz is obtained, but unlike in that solution, the space-time does not admit of any horizon.

Narayan Banerjee

Recent observations of the distant supernovae suggest that the present universe is in a state of accelerated expansion. Naturally, there is a search for a "quintessence matter field", which can give rise to such an accelerated expansion. Narayan Banerjee in collaboration with A.A. Sen and D. Pavon has been looking for an accelerated expansion scenario in Brans-Dicke theory. They have found that this is possible even without a quintessence matter. But, in order to get a decelerated expansion in a finite past consistent with the nucleosynthesis, either Brans-Dicke theory has to be modified or the model has to be endowed with a quintessence scalar field.

D. Lohiya

Any claim of a consistent framework for standard cosmology is, at best, incomplete, if it does not address itself to the cosmological constant problem. The only ansatz that has been proposed involves an anthropic principle to account for a small cosmological constant. Such arguments are not dynamic and have little predictive power.

Daksh Lohiya has considered generalized scalar tensor theories, in which the non-minimal coupling dynamically diverges throughout a Freidmann universe with the exception of compact domains over which the effective gravitational constant is dynamically held to a universal value. The expansion scale factor evolves linearly in time and has characteristic predictions. Concordance with the Hubble diagram, nucleosyntheses have been demonstrated.

B. Modak

B. Modak has obtained the gravitational coupling function in the scalar-tensor theory following the Noether symmetry approach. Asymptotically, the theory goes over to Einstein's gravity with a finite value of the coupling function.

G.P. Singh

In modern cosmological theories, the cosmological 'constant' remain a focal point of interest due to its relevance to the inflationary expansion, matter creation, entropy and age problems of the universe. G. P. Singh, in collaboration with A. Beesham and T. Singh, has studied the effect of a varying cosmological term and bulk viscosity during evolution of the universe in a generalized scalar-tensor theory. It was observed that the cosmological term decreases rapidly whereas the coupling parameter increases with expansion of the universe. He has also studied viscous cosmological models with varying gravitational and cosmological 'constants' in the context of higher dimensional space-time.

Early Universe

B. Bambah

Bindu Bambah has been working on particle production in a rapidly expanding quark gluon plasma using the techniques of particle production in expanding space-times. Connections between particle physics and cosmology have been basically using elementary particle theories in Cosmology. With the prospect of new heavy ion colliders whose aim is to create very high energy collisions in the lab aimed at reproducing a "mini big bang" in the lab and has turned the trend in the opposite direction. The hope is to find new states of matter at very high energies and densities and to study the spontaneous symmetry breaking mechanism. The situation is very similar to the conditions for particle production in early universe studies and many ideas set forth for particle creation in the early universe may be tested in the lab. Of these, the spontaneous symmetry breaking mechanism occupies an important role in particle physics, cosmology and condensed matter physics. The understanding of this phenomenon has led to cross fertilization between these fields and many new ideas have come. For non-equilibrium situations like the early universe and heavy ion collisions, the dynamics of the transition of a system from a symmetric to a broken symmetry state leads to the formation of new structures and the generation of entropy in the form of particle production. Manifestations of this at different scales of time and temperature are domain formation in a ferromagnet, large scale structure formation and cosmic string formation in the cosmology and the formation of disoriented chiral condensates in high energy collisions. Bambah is using the techniques of particle production proposed by cosmologists to study the evolution pion field in a rapidly expanding system.

This results in "quenched domain " formation known as the disoriented chiral condensates. This "vacuum bubble" is similar to the configurations found in inflationary cosmology. This is a metastable state which will decay emitting pions and the signals for this transition from a metastable vacuum to the true vacuum is a burst of coherent pions. This could be a plausible explanation of the Centauro and Anti-Centauro events seen in cosmic rays.

Deepak Chandra

The ongoing experiments in heavy ion collisions at RHIC and CERN aim to study the behaviour of QCD at high energy densities. Perturbative finite temperature QCD methods and relativistic transport theory have been used to study the early stages of the nuclear collision by computer simulation. The initial picture that emerges is that of a QCD fireball of 150 fm^3 created at the initial temperature of 300-350 Mev which is about twice the critical temperature Tc. Studies of quark-hadron phase transition in the early universe, in heavy ion collisions and in high density nuclear matter point to the importance of interactions in both the phases. Deepak Chandra along with Ashok Goyal has studied the rate of formation of the hadron bubble for interacting QGP and hadron resonance gas (HRG). They have examined closely the effects of interactions on the dynamics of the phase transition as the hot plasma of quarks and gluons is created and the temperature drops to Tc, where a phase mixture of QGP and HRG develops. They find that the prefactor given recently by Csernai and Kapusta plays a crucial role in the behaviour of the nucleation rate unlike the case in the early universe where the exponent dominates. They have solved the rate equations to study the time evolution of the transition including interactions for different parameters like bag pressure and surface tension. Chandra and Goyal have also studied the quark-gluon phase transition in the early universe looking at the evolution of the universe in small as well as large supercooling scenario. They have estimated the parameter range in which quark nuggets can be formed.

A. Goyal

Spontaneous symmetry breaking (SSB) is one of the most important concepts in particle physics. The idea that underlying symmetries of nature are larger than that of the vacuum, plays a crucial role in the unification of forces. The expectation that symmetries that are broken today are restored at high temperatures is of great interest in cosmology and astrophysics. During its evolution, the universe passed through a series of phase transitions from a high symmetric phase to a lower symmetric phase associated with spontaneous breakdown of symmetry. In particular, when the universe was at a temperature of the order of 200 GeV, there was a phase transition which broke electro-weak symmetry and later at around 100 MeV, the universe passed from deconfined quark gluon phase to confined hadronic phase. These phase transitions could have left relics in the form of observable signatures. In the early universe, the temperature, density, external magnetic field and strong gravity play an important role. Also phase transitions could take place in the core of neutron stars at high density and high magnetic field. Ashok Goyal with Meenu and Deepak Chandra has studied the phase structure in the presence of strong gravity and external magnetic field. They studied in particular the Chiral Symmetry structure and showed that the magnetic field has the effect of enhancing chiral symmetry breaking even at high densities unless one goes to unreasonably high magnetic fields. The effect of gravity on the other hand is to restore the chiral symmetry. These findings have astrophysical implications in terms of modifying the equation of state. Goyal and Chandra then studied the dynamical evolution of the phase transition by taking the bubble expansion and reheating into account and showed that in a large supercooling scenario, the transition takes place slowly and there is an actual possibility of quark nuggets being formed through the well known mechanism through the cosmic separation of phases, surviving to the present epoch. This opens up the exciting possibility of identifying these objects with the MACHOS and could contribute to the dark matter density.

V.O. Thomas

Problems in cosmology such as estimates of age of universe, mass density of universe, etc., have motivated reconsideration of the cosmological constant. It is possible that in an evolving universe, the cosmological and gravitational constants may be functions of time. Further, recent observations suggest a large cosmological constant at the early epoch as the basis of inflationary model with a small cosmological constant at a much later epoch. V.O. Thomas has studied models with variable cosmological and gravitational "constants".

Cosmology

Farooq Ahmed

Galaxies cluster together on very large scales under the influence of mutual gravitation and characterization of this clustering is a problem of current interest. A moderately dense system of galaxies clustering gravitationally in the expanding universe can be studied on the basis of Virial Coeficient technique. Farooq Ahmad and Naseer Iqbal have developed a theory which is applicable to point masses as well as to the extended structures clustering under the influence of gravitation. Using statistical homogeneity and pair wise interaction assumptions, the functional form of b, ratio of gravitational correlation energy to (twice) kinetic energy, emerges from the equations of state itself. However, a simple functional form of b for non-point mass system clearly indicates its dependence on the softening parameter and cell size. They show that softening parameter and cell size have non-negligible effect on the thermodynamics of gravitational clustering of the galaxies. Various aspects associated with gravitational clustering of the systems comprising of non-point masses are examined in detail and analytical expression for distribution functions is also derived from the ensemble theory.

Their results clearly indicate that non-linear gravitational clustering of galaxies in the cosmological many body (non-point masses) problem advocates evolution along an adiabatic hypothesis. This is confirmed with the comparison of N-body simulation results for the distribution functions and expansion scale which match very closely with their results.

S.K. Banerjee

S.K. Banerjee and J.V. Narlikar have studied, in collaboration with F. Hoyle, N.C. Wickramasinghe and G. Burbidge the standard redshift-magnitude test as applicable to standard cosmology as well as to Quasi-Steady State Cosmology. Necessary modifications were made with intergalactic dust taken into account, and it was found that the redshift dependent absorption due to the presence of intergalactic dust affects the observed m-z relation in the QSSC, which is another indication that the model (QSSC) is along the right lines. Finally, they have considered the fit to the supernova m-z data (for sixty supernovae of Type IA used by Perlmutter, et al., 1998 and Riess et al., 1998).

Moncy John

Some recent observations on Type Ia supernovae indicate the presence of components other than ordinary matter and radiation in the cosmic fluid. These new components are speculated to be vacuum, quintessence, etc., with exotic equations of state. Several other observations, like that of the age of the universe, gravitational lensing, etc., too endorse this view. In a cosmological scenario governed by laws of general relativity, a multi component cosmological perfect fluid presents some interesting possibilities. When the fluid is uni-component, the conservation law implied by Einstein equation is valid for that component, whereas there are no such conservation laws for individual components in a multi component system; only the total energy-momentum tensor can be a conserved quantity. Thus, it is more natural to consider energy transfer between various components during the cosmological evolution. Specifically, there can be creation of one component at the expense of other components and the creation rate is not determined by the fundamental equations of relativity. This can cause fluctuations in the expansion rate of the universe. Moncy John, C. Sivakumar and K. Babu Joseph have explored this possibility to explain the scatter in the supernovae Hubble diagram. They have developed a stochastic approach to cosmology by calculating the probability density function for the Hubble parameter in the Fokker-Planck formalism. By analysing the recent supernova data, they find that the theoretical results are compatible with observational data.

M. Sami

Recent developments in super string theory have opened up new interesting direction in the construction of cosmological models. Being inspired by these developments, it was recently conjectured that our four dimensional universe may be described by the dynamics of a four dimensional brane embedded in a space-time of higher dimensionality. The field equations on the brane get contribution from dynamics of extra dimensions and differ from the usual Einstein equations. This property can be used to address a number of problems of the standard cosmology within the framework of the new theory called "Brane World Cosmology". M. Sami has been working on a project related to brane world cosmology in collaboration with V. Sahni , Tarun Souradeep and Yuri Shtanov. They have studied relic gravity waves from brane world inflation. They also found an exact inflationary solution on the brane.

S.K. Srivastava

Two types of space-times are used for manifestation of gravitational interactions. One is static space-times representing geometry around compact objects, e.g.., Schwartzschild space-time, Riessner-Nordstrom space-time and others. The others are homogeneous and inhomogeneous models representing the expanding universe. Former type of models do not give any information about the expanding universe and the latter type are unable to account for gravitational effect of individual objects in the expanding universe. So, models exhibiting local gravitational effect of an individual object as well as expansion of the universe simultaneously are required to discuss evolution of the universe in a more natural way.

Continuing his work on dual nature of the Ricci scalar, P.K. Srivastava has derived cosmological models of the universe exhibiting local gravitational effect of an individual object as well as expansion of the universe simultaneously. Moreover, these models provide an inhomogeneous generalization of Robertson-Walker type models. One of these exhibits expansion like radiation model while another has exponential expansion providing sufficient inflation. These models are derived using physical methods of phase transition and spontaneous symmetry breaking and not through conventional approach of solving complicated Einstein's field equations.

Production of spinless and spin-1/2 particles is demonstrated in these models. It is suggested that the later universe emerged as a back-reaction of the produced particles during the inflationary period of the universe. According to the emerging cosmological scenario, the universe started from the big-bang like situation with the initial temperature 2×10^{18} GeV = 2.32×10^{31} K and attained the steady-state spontaneously around the age 6.48×10^{9} years. It is discussed here how these models explain evolution of the universe in the beginning and how the cosmic background radiation originated. A possible explanation for abundance of matter over antimatter, in the observed universe, is also given. Production of sufficient amount of baryons to maintain the steady-state of the universe is discussed. Creation of these baryons in the hot regions of galaxies is suggested. The possibility that these baryons might have formed hydrogen molecules around galaxies is discussed. Results obtained here are consistent with observations.

R.S. Tikekar

R.S. Tikekar and N. Dadhich continued efforts of exploring the possibilities of constructing spherically symmetric, non-singular cosmological models in relativistic framework. This search resulted in obtaining two models with a non-adiabatic perfect fluid source accompanied with heat flux. The first model describes an ever-existing universe which witnesses transition from the phase of contraction to the phase of everlasting expansion. The second model describes an ever-existing universe oscillating between two regular states. A highly relevant feature of this model is that it predicts blue shifts without violating GR or invoking non-conservation of matter.

Quasars

S.K. Banerjee

Recently, S.K. Banerjee, J.V. Narlikar and R.G. Vishwakarma, in collaboration with P.K. Das and Halton Arp, applied the 1980-calculations of Narlikar and Das on dynamics of ejection of lumps of newly created matter from galactic nuclei, high redshift X-ray quasars found near low redshift galaxies. The variable mass hypothesis interprets the excess redhift found in quasars as arising from their low mass and the dynamics of ejection describes further details like the physical separation between the parent galaxy and ejected quasar, the quasar velocity, whether it is bound or not to the galaxy. A consistent picture emerges from these calculations in which a typical quasar starts its life as a young lump of matter ejected from the parent galaxy with the speed of light and zero rest mass, which starts growing with age. As the redshift decreases with increasing mass, the quasar passes through a continuous sequence of decreasing redshift. Whether it will altogether escape from the gravitational attraction of the galaxy will depend on the energy of initial ejection. It is possible that some of the quasars seen in isolation are the 'escaped' quasars. On the other hand, the bound quasars will move in steadily shrinking orbits around the parent galaxy. The present calculation gives a method of deciding which quasars are bound.

Gravitational Lensing

P. Khare

Pushpa Khare analysed the observed image separations of lensed QSO images and showed that contrary to the earlier belief these are not correlated with the source redshift. Average image separation as a function of source redshift was calculated taking into account the amplification bias, assuming the lenses to be isothermal spheres with cores, for flat models. Observations were found to be roughly consistent with the theoretical results for models which assume the lens distribution to be (i) Schechter luminosity function which, however, can not produce images with large separation and (ii) the mass condensations in a cold dark matter universe, as given by the Press-Schechter theory, if an upper limit of $1\text{-}7 \times 10^{13}$ M_O is assumed on the mass of the condensations.

Galactic Dynamics

D.K. Chakrabarty

D.K. Chakrabarty and his student Parijat Thakur have studied the projected properties of triaxial modified Hubble mass model. The model seems to be most useful as a simple analytical example of a model with ellipticity variations and isophote twists. Continuing this work, Chakraborty along with Thakur and Mousumi Das, has studied the correlations in the projected properties of triaxial generalisation of modified Hubble model and Dehnen's g - models. These correlated properties are exploited to set constraints on the intrinsic shapes of mass models, using the techniques of Bayesian statistics.

Chanda Jog

Chanda Jog has studied global asymmetry in spiral galaxies. The halo potential is believed to have an elliptical component due to galaxy interactions, and the embedded disk can respond to this. The self-consistent disk response was obtained and the net disk ellipticity was shown to be important in only the outer optical disk. From the observed disk ellipticity, the true ellipticity of 0.1 was obtained for the dark matter halo in a typical spiral galaxy.

Jog with C.A. Narayan, has studied the dynamical effects of a massive, extended complex of molecular hydrogen gas of mass ~ $10^7\ M_O$ on the galactic disk components. Such complexes are now observed to be common in spiral galaxies. A massive, extended complex is shown to result in a significant vertical constraining of disk stars and gas around it. This may explain the long-standing puzzle of corrugations observed in a spiral galaxy. The resulting potential is shown to be non-uniform on scales of the inter-complex separation, with interesting implications for galactic dynamics.

Interstellar Matter

A.C. Kumbharkhane

Galaxies are huge collections of stars, planets, unseen "dark matter", gas and dust held together by mutual gravitational attraction. The vast bulk of the volume of a galaxy is filled with the interstellar medium (ISM), the gas and dust which exist between the stars. The ISM is made up of a number of components, which can be described by the hydrogen gas densities, their temperatures, and their state of ionizations. The radio recombination lines are useful probes of ionized regions in the galaxy and in external galaxies. Radio recombination lines corresponding to the transitions from different quantum levels occur over the entire radio frequency range. A.C. Kumbharkhane, in collaboration with Nimisha Kantharia, NCRA, Pune has initiated work on recombination lines. Their interest is to study the recombination lines of hydrogen at low frequency using the Giant Meter Radio Telescope (GMRT).

M.L. Kurtadikar

Higher order Cyanopolyynes HC_nN (n=7,9,11,13) are long chain linear molecules detected in laboratory and in interstellar medium in 1990s. Collision induced cross sections and line widths of these molecules are of astrophysical significance and are required in many calculations. Using a normalised semi classical perturbation method, known as Effective Straight Line Trajectory (EST) approach, collision induced cross sections and line widths of HC_7N, HC_9N, $HC_{11}N$ and $HC_{13}N$ colliding with H are computed. The EST approach has been developed by M.L. Kurtadikar and Mehrotra and applied for computation of the collision induced parameters of many other systems of interstellar interest. In the EST approach, an arbitrary multiplication factor RX is used, which is a measure of significance of the curved trajectory of the colliding particles. For the optimum value of this factor the collision induced cross sections and line widths are computed for temperatures 50 K to 300 K, with an interval of 50 K and for the rotational transitions $J_i - J_f$ (0–1, 1-2, ..., 9–10).

Star Formation

A.C. Borah

The Pulsational Mode of Gravitational Collapse (PMGC) is a phenomenon in the gravitational condensation of a collapsing dust mass, if some dust particles are charged. A.C. Borah in collaboration with A.K. Sen, C.B. Dwivedi and S. Bujarboruah has derived the dispersion relation for this process and solved for frequencies using available astronomical data.

K. Indulekha

K. Indulekha has been analysing the evolution of young star clusters prior to gas removal. Dynamical friction of the stars on the gas causes the stellar cluster to shrink with respect to the parent gas. Using the two component virial equation along with an evolution equation for the random kinetic energy of the stars, she has determined (a) the lower bound on the star formation efficiency (SFE) for the formation of a bound cluster, (b) the apparent SFE and its relation with the actual SFE and (c) the final radius and velocity dispersion of revirialized clusters after gas removal. The results are being compared against observations of galactic clusters. The work was done in collaboration with Vijaygovindan and S. Ramadurai.

Neutron Stars

Somenath Chakrabarty

Somenath Chakrabarty and his Ph.D. student Nandini Nag have studied the effect of strong magnetic field of magnetar on the crustal lattice structure. In particular, they have studied the deformation of atomic lattice points in presence of strong magnetic field. They have also studied the variation of electric quadrupole moment of the atoms with magnetic field strength. The equation of state of crustal matter with quadrupole-quadrupole interaction has been obtained.

Chakrabarty has evaluated with basic field theoretic technique the tensorial form of electrical conductivity of dense nuclear matter at the core region of a strongly magnetised neutron star (magnetar). He is at present using this tensorial form of electrical conductivity to study the magnetic field evolution at the core region of a magnetar.

Chakrabarty and his another Ph.D. student Tanusri Ghosh have studied the effect of strong magnetic field on the quark-hadron phase transition at the core of a magnetar. They have shown that a first order transition is absolutely forbidden if the magnetic field strength exceeds 10^{15} Gauss. According to their model calculation, a metal-insulator type second order transition is possible if the field strength is less than 10^{20} Gauss. However, their chemical evolution study of nascent quark matter has shown that quark matter in b equilibrium becomes energetically unstable if the field strength exceeds 4.4 x 10^{13} Gauss.

Chakrabarty and Ghosh have studied the neutrino emissivities of degenerate quark matter in the presence of strong magnetic fields. The results are compared with the corresponding non-magnetic cases. They have shown that the direct URCA process plays a crucial role in the presence of strong magnetic fields. They have investigated the transport of both non-degenerate as well as degenerate neutrinos in dense quark matter in the presence of strong magnetic fields. The absorption and scattering of neutrinos by various (charged and neutral) components in the presence of strong magnetic fields have also been studied. The modified form of charged-current charged-current and neutral-current neutral-current interactions in the presence of such strong magnetic fields is obtained.

Strange Stars

Jishnu Dey

Jishnu Dey and his student Subharthi Ray have been working on strange stars with a realistic equation of state. They have considered the possibility that radio pulsars are strange stars.

Mira Dey

Mira Dey is trying to understand, along with her collaborators and students, the high density bulk matter made out of u,d,s quarks (strange matter) and the possibility of forming quark stars (strange star) in the light of experimental constraints set on the Mass-Radius requirements of some X-ray bursters and pulsars. The star formed out of strange matter is rather compact. The model is extended to explain the quasi periodic oscillations (QPOs) in the X-ray power spectrum. The objective is to apply more realistic QCD motivated model incorporating, among others , chiral symmetry restoration (CSR), to fix the parameters of the model from astrophysical observations. She is investigating the finite temperature effects on the equation of state.

Baryon magnetic moments (specially that of W ⁻) are also objects of Dey's study in connection with recent experiments. The large N expansion suggests a general idea of a HF calculation for baryons. But to implement this for magnetic moment is rather a stringent test of the model. A realistic potential was used and interestingly, the density dependence of the model parameters could be deduced too.

T.C. Phukon

Recently, a new class of low-mass X-ray binaries (LMXBs) with a strange star as the central compact object have been proposed to explain the observed kilohertz quasi-periodic oscillation (kHz QPO) lines. These lines were discovered in the X-ray fluxes of nearly 14 neutron stars in LMXBs with Rossi X-ray Timimg Explorer (RXTE). The identification of the high frequency kHz QPO lines with the orbital frequency of stable circular orbit allows many authors to determine the mass of the neutron star. It has been recently shown that the strange star model based on the popular MIT Bag model with massive strange quark mass and lowest order QCD interactions allow frequency as low as 1.0 kHz, in agreement with RXTE observations. In principle, a bare strange star is unlikely to exist in nature due to various accretion processes. Soon after the formation, a strange star could be covered with a thick or thin nuclear crust, possibility which is particularly natural in the case LMXBs. T.C. Phukon has examined this possibility with a strange star equation of state (EOS) based on MIT Bag model. He investigates the relationship between the parameters of the EOS and the crust mass of the star. He has found that the parameters of the EOS are constrained with a limit, which is fully consistent with the stability criterions of strange matter and the standard Keplerian interpretation of the kHz QPO lines may lead to the conclusion that the QPO sources can be modeled with a strange star with a thin crust. The minimum crust corresponding to QPO line of 1.0 kHz is found to be about 3.0×10^{-5} M_{sun}. The maximum mass depends on the parameters of the EOS.

Santokh Singh

The structure and evolution of strange stars are usually studied in the MIT Bag model. An alternative description of quark matter is studied by using density Dependent Quark Mass (DDQM) model as it effectively includes the first order QCD coupling corrections and is much easier to work with Santokh Singh in collaboration with J.D. Anand, N. Chandrika Devi and V.K.Gupta has studied the bulk viscosity of SQM in DDQM model. It was found that at low temperatures and high relative perturbations, the bulk viscosity is higher by 2 to 3 orders of magnitudes while at low perturbations the enhancement is by 1-2 orders of magnitudes compared to earlier results. Also, the damping time is 2-3 orders of magnitudes lower, implying that the star reaches stability much earlier than in MIT Bag model calculations.They have studied the radial oscillations of strange stars in strong magnetic fields in DDQM model. It was found that higher magnetic field can support higher masses as well as lower radii. The rotational rates become slower leading to increased stability.

Convection

H. P. Singh

H.P. Singh, in collaboration with K. L. Chan, I. W. Roxburgh, E. Saikia and M. P. Srivastava has carried out full three-dimensional simulations of turbulent compressible convection for a three-layer (stable-unstable-stable) configuration in order to study the behaviour of penetrative convection at the bottom of a stellar-type convective envelope. Several models have been computed, and the effect of horizontal resolution, vertical resolution, aspect ratio and the time statistics on the extent of penetration have been viewed. It has been observed that while the vertical resolution and the aspect ratio of the box influence the penetration distance considerably, there is some effect of increasing the horizontal resolution on the penetration distance for the range of parameters considered. A horizontal resolution of 35 x 35 may be sufficient for a vertical grid count of 64. They expect that a further increase in the vertical resolution will require a corresponding increase in the horizontal resolution. However, there is little effect of the time statistics once the fluid is thermally relaxed.

Solar Coronal Heating

Udit Narain

Solar corona is the outermost part of the atmosphere of the Sun. The temperature of the corona is of the order of million degree Kelvin. It lies in between two cooler regions namely the chromosphere (temp. ~ 10000 K) and the interstellar space (temp. ~ 100000 K). In spite of losses by conduction, radiation and solar wind flows, the temperature of the solar corona remains stationary. To replenish the losses and to maintain its million degree temperature some source of heating is necessary.

A number of mechanisms to explain the high temperature of the corona have been proposed. Some of them are waves (acoustic, magnetoacoustic, Alfven) generated in the convection zone of the Sun by the convective motions, current/magnetic field dissipation, velocity filtration, etc. Heating by Alfven waves is one of the important mechanisms.

Satellite X-ray pictures of the solar corona show that it contains a variety of structures such as open-field regions (coronal holes) and closed-field regions (coronal loops), which are generated by coronal magnetic fields. Udit Narain and his students have investigated the heating of solar coronal loops by linear resonant Alfven waves, generated by the foot-point motions in the photosphere (temperature ~ 6000 K). They arrive at the following conclusions: The solar coronal loops are heated in several layers or throughout the volume of the loop. A coronal loop heated in one layer by an axisymmetric wave cannot account for observed non-thermal velocities unless heating by non-axi-symmetric waves is also taken into account.

Solar System Studies

P.P. Hallan

P.P. Hallan has studied the non-linear stability of equilibrium point L4 in the restricted three body problem, when one or both the primaries are triaxial rigid bodies or the bigger primary is a triaxial rigid body and a source of radiation. It has been found that the equilibrium point L4 is stable in all the three cases in their range of linear stability except for three mass ratios. The effect of perturbations in Coriolis and centrifugal forces on the location and stability of the equilibrium point in the Robe's restricted three body problem has also been studied. It has been found that there is only one equilibrium point and the range of stability increases or decreases depending upon whether the perturbation point lies in one or the other of the two regions in which the perturbation plane is divided by a line.

S. Sahijpal

Isotopic anomalies found in the earliest formed solar system phases that are found in primitive meteorites have played an important role in understanding the origin and the early evolution of the solar system. Among the important results, S. Sahijpal and collaborators have found that the presence of the shortest mean-life ($\tau \sim 1$ Million years) radio-nuclides in the early solar system could be the result of their fresh nucleosynthetic production inside a star just prior to the formation of the solar system. This inference is based on the detailed calculations on the cosmogenic production rates of some of the short-lived radio-nuclides in the early solar system. He has also been working on the oxygen isotopic compositions of the earliest condensed solar system grains. Oxygen isotopic studies provide valuable information about the pre-solar and early solar system environments.

Plasma Physics

Manoranjan Khan

Manoranjan Khan has studied the wave-wave interaction and dust-dust interaction in a dusty plasma in collaboration with M.R. Gupta, S. Sarkar and S. Ghosh. An interesting result has been obtained for the generation of dust ion acoustic shock wave in collisionless dusty plasma which is new in this process. Investigations have been done to study the effect of finite ion inertia and dust drift on small amplitude dust acoustic soliton. Effect of non-adiabacity of dust charge variation on dust acoustic waves and properties of small amplitude dust ion acoustic solitary waves having dust charge variation were also studies. In collaboration with B. Chakraborty, S. Sarkar and others, a theory of Landau damping of ion acoustic waves in a dope plasma has been developed.

S. N. Paul

S.N. Paul has theoretically investigated the formation of ion-acoustic solitary waves and double-layers in multi component plasma consisting of electrons, positive ions and negative ions, using the methods of reductive perturbation and pseudo-potential. The structure of solitary waves including its width and amplitude and double-layers in a drift multi component plasma have been graphically discussed considering different values of the plasma parameters. It is found that the concentration of negative ions, thermal effect and the presence of streaming ions have significant contribution to the amplitude and width of the solitary waves and double-layers. It is interesting to see that the characteristic of solitary waves are drastically changed in the presence of a small percentage of cold electrons together with the warm electrons in plasma. Effects of higher-order non-linearity in plasma on the formation of solitary waves and double-layers in the multi-component plasma have also been studied and the results are compared with the experimental observations. In the bounded plasma, ion-acoustic solitary waves and double-layers show different behaviours as compared to that in the infinite plasma. It is found that the amplitude and width of the solitary waves depend on the radius of the cylindrical wave guide and the concentrations of positive and negative ions.

Atmospheric Physics and Chemistry

K.N. Iyer

A study of seasonal differences of diurnal total oscillations in the zonal and meridional winds using Indian MST radar located at Gadanki (13.5^0 N, 79.2^{0}E) shows that, in different seasons, this tropical middle atmosphere is dominated by diurnal tides with amplitudes of 2-3 m/s at lower heights and 8-10 m/s at upper heights. Vertical wavelengths are ~3-4 km in the lower troposphere and ~5-7 km in the upper troposphere. These diurnal oscillation with large amplitude and short wavelengths are probably produced by locally generated non-migrating tides. The diurnal non migrating tides with amplitude ~10 m/s observed in August over Gadanki may be associated with latent heat released by deep conductive clouds. Using the same radar observations, K.N. Iyer and his collaborators have studied equatorial waves in the tropical middle atmosphere using daily measurement over a 3-4 month period. The characteristics of these waves observed during monsoon months, such as their periods ~10-16 days, vertical wavelength of 8-10 km, variations in the zonal component being larger than in meridional component and large amplitude during easterly background wind, tend to identify them as Kelvin waves. The observations of scintillations of VHF (250 MHz) signals from geo stationary satellite over a long period at Rajkot have been used to compute communication system parameters such as bit error rate, message reliability, cumulative distribution function and signal statistics to assess the effect of ionospheric irregularities on communication system degradation.

The association between ionospheric scintillations (ESF) and the equatorial electrojet (EEJ) current in the ionosphere has been investigated. It was found that EEJ strength was low (15 nt) on days of weak pre-midnight scintillations and high (75 nt) on days of strong pre midnight scintillations. The reason for this was found in the fact that the post sunset pre-reversal enhancement in equatorial F region vertical drift which critically controls the development of ESF, is well correlated with EEJ strength. Study of Meridion scale Travelling Ionospheric Disturbances (TID) employing a novel radio astronomic technique with the observations of radio sources using the antenna array and receiver at Rajkot has enabled the determination of their periods and velocity of propagation.

S.K. Pathak

The distribution of ozone and other trace gases in the atmosphere is governed by the complex interaction of dynamical, chemical and radiative processes. These processes determine both the absorbed solar flux and radiative transfer. The importance of ozone radiation absorption in the atmosphere and the general kinetics of the stratospheric ozone depletion mechanisms have motivated a great deal of research work on various atmospheric and environmental species. Despite extensive laboratory studies, the knowledge of both the spectroscopy and the photo dissociation of trace molecules in the troposphere and in the stratosphere still needs to be enhanced. S.K. Pathak has been studying the spectroscopy, and collision dynamics of those molecular species which are playing an important role in providing fundamental data necessary for understanding the current environmental problems such as ozone depletion, global warming, and air pollution monitoring. The role of intermediate mechanisms, their identification, and involvement in the processes related to the studies of ozone depletion compounds and atmospheric sink compounds still remains unclear in the view of atmospheric dynamics of chemical species. In order to understand the problem of ozone destruction by the chlorofluorocarbons, ClO_x and NO_x compounds, the photolysis of such species by UV radiation must be understood in detail. The destruction of the terrestrial ozone layer by the emission of molecular compounds generated by industry (e.g., chlorofluorocarbons) and through intensive farming (e.g., emission of nitrogen oxides) has potentially disastrous consequences for the future ecological balance of the planet. Research work on photolysis of various molecular compounds at different atmospheric heights is in progress in collaboration with research groups at the University of London and University of Reading, UK. Photolysis rates as a function of wavelength have been plotted for a number of molecular species. It is concluded that photolysis at the shorter wavelength plays a significant role in stratospheric ozone loss, and has to date been largely underestimated in global models.

R. Ramakrishna Reddy

To understand the troposphere chemistry the measurement of NO_x and CO is very important especially in the tropical region. In the case of NO_x rich air, the production of NO_2 takes place by the reaction of NO with HO_2 or RO_2, which ultimately helps in ozone production. R. Ramakrishna Reddy has carried out surface measurements of trace gases like NO_x and CO over rural site at Anantapur (14.62^{0}N, 77.65^{0}E) for the period August 1999-June 2000. NO_x and CO show diurnal variations opposite to that of urban sites. During the day time, the concentration of NO_x was varied between 3 to 20 ppbv and the concentration of CO varies in between 200 to 1200 ppbv. Diurnal variations in NO_x and CO are a manifestation of combined effects of local emission, boundary layer processes, chemistry and local wind pattern. NO_x concentration is observed to be maximum during autumn and winter sessions and minimum during summer. Whereas, CO concentrations are higher during autumn and summer, and low in winter season. The variations of NO_x and CO are correlated with wind parameters. It is observed that polluted air mainly comes from the north-east side and cleaner air from south-east side. Seasonal variations of NO_x and CO have also been studied.

Atomic and Molecular Physics

Suresh Chandra

Observation of an interstellar line in absorption against the Cosmic Microwave Background (CMB) is an unusual phenomenon, and it obviously occurs when excitation temperature T_{ex} of the line is less than the temperature of the CMB (T_{ex} < 2.73K) It requires rather peculiar physical conditions in the molecule, generating the line. Up to now, only two lines have been reported in absorption against the CMB. The first one is the $1_{10}- 1_{11}$ transition of formaldehyde (H_2CO) at 4.831 GHz, and the second one is the $2_{20}- 2_{11}$ transition of cyclopropenylidene (C_3H_2) at 21,590 GHz. Suresh Chandra and his collaborators W.H. Kegel and A.K. Sharma have been investigating this phenomenon and are of the opinion that the transitions $2_{20} - 2_{21}$ and $2_{20} - 2_{11}$ in asymmetric top molecules may exhibit absorption, even against the CMB. This phenomenon may help in identification of asymmetric top molecules in some cosmic objects, as the kinetic temperature in the cosmic objects may not be sufficient to generate emission spectra of the molecules.

Chandra and his collaborators A.K. Sharma and S.H. Behere have been investigating the potential energy curve for diatomic molecules. They have shown analytically that all features of the potential-energy curve for a diatomic molecule can be reproduced when the Dunham coefficient Y_{20} is negative.

L.K. Jha

L.K.Jha, along with B.N.Roy, has carried out theoretical calculations on single and double ionization of atoms / ions by electron impact. Such calculations are important for applications in upper atmosphere physics, astrophysics and plasmas. Considering the astrophysical importance of magnesium atom and non-availability of sophisticated calculations on double ionization in the literature, electron impact single and double ionization cross sections for magnesium have been calculated in the binary encounter model. In case of double ionization, contributions of inner shell ionization and Auger emission have been included in the work. It has been found that the electron impact single ionization cross sections of magnesium observed experimentally are well explained by considering ionization of 3s shell only and at the same time the double ionization cross sections show reasonably good agreement with the recent experimental observations. Substantiation of the view point of Peach, and Boivin and Srivastava that a vacancy in the 2p shell of magnesium leads to double ionization is a remarkable feature of the present investigation. Apart from this work, calculations of electron impact single and double ionization cross sections for gallium have been carried out following the approach discussed above. The calculations of double ionization cross sections for atmospheric ions, e.g., C^+, N^+, O^+, and Ne taking into consideration the focusing action of ionic target are in progress.

Observational Astronomy

M.K. Das

In collaboration with H.P. Singh, S.K. Gupta and others, M.K. Das has been observing stellar variability using a three channel photometer at U.P. State Observatory (now called State Observatory), Nainital. Rapidly oscillating stars, white dwarfs and delta Scuti variables have been observed with the help of newly developed three channel fast photometer to understand their astro seismological characteristics. A photon/pulse counting technique is used to measure the intensity of the stars. The pulses from photo multipliers are amplified and discriminated from the dark noise pulses using a lower level threshold. An interface card is used to receive and digitize the data from three channels. It has timing circuits to ensure an accurate clock and integration times. The interface card communicates with a PC through a serial port. The software along with interface card can acquire the data simultaneously from three channels, which can be stored in ASCII files. The analysis of various photometric light curves obtained for the variables is underway.

Since the light curves in general show non-linear behaviour, a procedure has been developed which uses the photometric observations directly and computes various parameters that quantify the non-linearity present in the data. For this, Das and his collaborators have considered various simple non-linear model time series and discussed the results obtained using different measures that distinguish the underlying process as a linear system from a non-linear one. They have primarily used indicators which are suited well only for testing the non-linearity in a small time series. This is due to the fact that the photometric observations of variable stars taken on a night constitute a small time series only. They have extended the analysis using the real time series, i.e., photometric observations of some delta Scuti stars as a beginning. The programme automatically parameterize various nonlinear indicators like time asymmetry of the light curve, run of data correlation with time and statistics related to testing hypothesis.

V.C. Kuriakose

Our understanding of elliptical galaxies has experienced a profound change in the last few years. They were considered to be simple objects consisting of an ensemble of stars. But the recent observations using Charge Coupled Devices reveal several new properties of elliptical galaxies. Standard procedures are now available to process these images. In collaboration with A.Kembhavi, C.D. Ravikumar and V.C. Kuriakose have started analysing images of some elliptical galaxies using Image Reduction and Analysis Facility package.

S.K. Pandey

As a part of an ongoing research programme on surface photomtery of galaxies, S.K. Pandey has now focussed on studying properties of dust in early-type galaxies to investigate the nature, origin and evolution of dust in these galaxies. Optical (BVRI and H-alpha) as well as near infra-red(NIR) (J, H and K) observations of a sample of early-type galaxies with well known dust features were planned during the year and proposals were submitted to various observatories in the country. Due to unfavourable sky conditions, only a part of the sample could be observed. Imaging observations of ten early-type galaxies in the NIR (JHK) bands were conducted during January 2001 using the observing facilities available at Mt. Abu (PRL). Optical BVRI and H-alpha images of three galaxies were taken from Vainu Bappu Telescope at Kavalur (IIA) during March 24-26, 2001. Analysis of the multiband data is in progress. M K Patil, A K Kembhavi, D. K Sahu, U. Joshi and the research group at PRL are involved in the programme.

Pandey has been working on chromospherically active stars (CAS). Differential photometric observations of well known CAS as well as suspected CAS were carried out in BVRI bands using 16" Meade telescope equipped with SSP-3A photometer at IUCAA, during February-March, 2001. Preliminary analysis of the data shows significant changes in the shape of the light curve and amplitude of the light variation in most of these stars when compared with their corresponding data for the past years. Detailed analysis of the data in the frame work of star-spot models is in progress. RS CVn stars, a class of CAS, are known to have variable light curves. With an objective to investigate the nature of short term variation in these systems, the light curves of two bright and prominent RS CVn stars :V711 Tau and UX Ari, obtained for the period 1998-2000 using the 14" Celestron telescope with SSP-5A photometer and BVR filters at Raipur were analysed using the spot modeling technique. The results indicate that the short term variations in these stars are mainly due to redistribution of stars spots on the stellar surface. Padmakar Parihar and Sudhanshu Barway are involved in this research programme.

P. Vivekananda Rao

During the year 2000-2001, photometric observations of the binary stars: FZ Ori, UV Psc, TW Cet and FO Hya were made by P. Vivekananda Rao using the 1.2 m telescope of the Japal-Rangapur Observatory. Observations and analysis on the binary star UV Psc have been completed. It is found that main sequence eclipsing binaries are competitive with the stars observed with the intensity interferometry in defining the radiative flux relation for stars 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 stars with late type components properly removed for the starspots effects would be very promising in solidifying the radiative surface flux and temperature scales. It is found that UV Psc has secular variations in the mean brightness out of the eclipse and during the primary eclipse that are not explained by spot models and indicate luminosity changes in the primary star. The spots on UV Psc 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 degrees 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 altitude drifts in the spot regions have been noticed.

Vivekananda Rao has completed the observations and analysis on the eclipsing binary FZ Ori. The main results are that FZ Ori shows asymmetries in the light curves like most of the W type contact systems which are attributed to spots on one or both the components. The light curves do not show any asymmetry unlike the observations of El Bassuny. This could be explained that the system may be in its quiescent phase during the period of our observations.

H.P. Singh

In collaboration with Ranjan Gupta (IUCAA), H.P. Singh has carried out principal component analysis and artificial neural networks to classify several spectral databases and the procedure has been extended to the IRAS low resolution sources.

P.K. Srivastava

P.K. Srivastava, in collaboration with A.Pramesh Rao of NCRA, has been taking radio continuum observations of galactic sources using GMRT. He has observed the bright emission nebula W51, which is a large complex with multitude of HII regions with varying compactness and structures. HII regions are molecular clouds associated with massive hot stars, where all the hydrogen is completely ionized. Most of the radio spectrum from these regions is continuum radio emission. The entire W51 complex is about 1 deg. in the sky lying near the tangent point in the Saggitarius arm at about 7kpc.The observations were done at 236,330,610 and 1420 MHz and the source has been mapped using AIPS. The analysis of the images to determine the spectra and other physical parameters of W51 is in progress.

Srivastava has also observed, during this session, the radio emission at 330 MHz from the flare stars UV Ceti, AD Leo and YZ CMi. These stars have been reported to flare and emit radio flux of the order of tens of mJy during periods extending from milliseconds to several minutes. However, no flux from these stars has been found down to the level of 1-2 mJy for integration time of more than 4 hours.

X-ray Astronomy

K.Y. Singh

The nature of the compact object in Cygnus X-3, a bright binary system in the galactic plane of our galaxy is a reason of much debate: it is not established, as yet, whether it is an X-ray pulsar, a black hole or a neutron star. This X-ray source was observed recently (July 3-13, 1999 and October 11-24, 1999) by the X-ray telescope in the Indian X-ray Astronomy Experiment IIXAE) on board the Indian remote sensing satellite IRS P-3. K.Y Singh and his research student N.S. Singh have studied Cygnus X-3 using the Indian satellite data and have detected non-linearity in the arrival time of the 4.8 hour binary modulation of the X-ray light curve of the X-ray source. Further analysis of the light curve of Cygnus X-3 using the Indian satellite data and archival data from other satellites (ROSAT, ASCA and RXTE) has brought to light that the orbital period of Cygnus-X-3 decays. It appears that the decay of the orbital period is due to mass loss from the companion star and that the compact star in this binary system has an accretion disk with an extended corona. K.Y. Singh has also studied some aspects of multi particle production in hadron-nucleus interactions – an area of high energy physics, using the available data of hadron-emission interactions at accelerator and cosmic ray energies.

Instrumentation

M.N. Anandaram

M.N. Anandaram and B.A. Kagali have constructed a computer controlled telescope using a 14 inch f/11 Celestron optical tube assembly for teaching and research applications. The telescope has a heavy duty fork type equatorial mount fitted with precision machined 24 inch drive disks for both axes. These are friction driven by stepper motors through one inch rollers. They have used an open loop control system triggerable by an ST-4 CCD camera to acquire and track any target object. The telescope can home in on any target within a range of two arc-minutes. They have employed a commercial stepper motor controller card for which they have written a user friendly pc based telescope control software in C. Photometry using a solid state photometer, and imaging by an ST-6 CCD camera are possible. This project is suitable for those wishing to construct some parts of a telescope and understand the principles of operation. A simpler model of this telescope could use DC motors instead of stepper motors. This work was reported, jointly with S.P. Bhatnagar, in the "Astronomy for Developing Countries", at the 24th General Assembly of IAU held in Manchester in August 2000.

S.P. Bhatnagar

S.P. Bhatnagar has been continuing his activities with 14" Automated Photoelectric Telescope, developed at IUCAA and currently installed at Bhavnagar. Several improvements to software and hardware were made for improving the operation and ease of use during the year. A handpad was added which shares in parallel, an interface with the ST4 Tracker. The handpad allows fine movements of the telescope while tracking, for final guiding either during observations or photography. Photometric observations using the IUCAA photometer as well as ST4 CCD camera have been initiated at Bhavnagar. It is planned to study suspected variables using the Bhavnagar APT.

(III) IUCAA-NCRA GRADUATE SCHOOL

One IUCAA research scholar, Ali Nayeri, has defended his Ph.D. thesis titled "Gravitational Clustering in Different Scenarios", to the University of Pune during the year of this Report. The abstract of the same is given below :

Gravitational Clustering in Different Scenarios

Ali Nayeri

Cosmology is the study of evolution of the universe as a whole; how the universe has come to its existence and how it has evolved to its present feature. Among different issues in cosmology, perhaps, formation of large scale structures in the universe is the most controversial one. These structures, apparently, evolve from the unknown initial conditions of a rather smooth early universe to the present time. To understand this evolution exactly, one should know about the model of cosmology we live in, the amount, composition and distribution of matter in the universe, the initial spectrum of density fluctuations that give rise to these structures, and the formation and evolution of galaxies, clusters of galaxies, and larger scale structures. Detailed knowledge of the large-scale structure provides constraints on the formation and evolution of galaxies and larger structures, and on the cosmological model of our universe, including the mass density of the universe, the nature and amount of dark matter, and the initial spectrum of fluctuations that gave rise to the structure seen today. In spite of tremendous improvement of our knowledge of the large scale structure, there are some main unsolved problems in this field such as the determination of mass density, the evolution of large scale structures with time, the nature of dark matter, whether the structure forms by gravitational instability or some other mechanism, the exact shape of initial spectrum of fluctuations that give rise to the structure we see today and whether the initial fluctuations were Gaussian or non-Gaussian. The aim of this doctoral thesis is to investigate some aspects of large scale structure formation in the universe in a different contexts and related issues in gravitational dynamics.

In order to build a structure formation model, three key features should be specified: (i) a model for the background universe, (ii) some mechanism for generating small perturbations in the early universe and (iii) the nature of dark matter. An expanding Friedmann-Robertson-Walker (FRW) model is usually taken to be the background universe. Such a model is completely specified if the composition of the energy density and the present value of Hubble constant are specified. Primeval fluctuations can be generated either by inflation or topological defects. A model for structure formation is completely specified by its initial conditions and the full temporal and spatial behaviour of the stresses in its dark sector. The dark sector contains the elements in the model that do not interact, directly, with the photons at any observable redshift. It can include, but not limited to, cold dark matter (CDM), neutrinos, cosmological constant and supersymmetric particles. In this thesis, we make an attempt to understand some generic aspects of gravitational clustering of dark matter and the mechanism of generating the initial fluctuations in different scenarios.

A chapterwise summary of this thesis is as follows :

In *chapter 1*, we briefly review the background which will be needed in *chapters 2, 3* and *5*. We discuss some earlier work which has been done in the study of FRW models, cosmological perturbation theories, and the mechanism of producing the initial fluctuations. Using the general relativity (GR) at large scales is a must. Universe shows to some extend a very homogenous and isotropic feature. The real universe, however, is not smooth on scales less than $100 Mpc$ and inhomogenous structures can be observed. As long as these inhomogeneities are small, their growth can be studied by the linear perturbation theory. Once the deviation from the smooth universe become large, linear theory fails and we have to use other techniques to understand the non-linear evolution.

The spherical model is one simple technique to study nonlinear regime. When perturbations have wavelengths much smaller than Hubble radius, which is a characteristic length for applicability of GR, they may be studied in the context of Newtonian gravity, since the effect of GR due to curvature of space-time is ignorable. Thus, Newtonian analysis can be invoked for these models.

To the first approximation, the problem of structure formation reduces to understanding the formation of dark matter halos in an expanding universe, since observations suggest that visible astrophysical system like galaxies, clusters, etc. are embedded in the halos of dark matter. The dark matter is usually assumed to be made of elementary particles interacting with each other only through gravity. We need to understand, how small perturbations in dark matter density will evolve as the universe expands and whether they can grow sufficiently fast to form the dark matter potential wells.

A Friedmann universe with power law expansion for the scale factor, however, fails to explain

the origin of galaxies on having any natural seeds for the origin of density inhomogeneities and on the physical processes which can give rise to coherence on inhomogeneities exist today. An inflationary model can solve both these problems. The seeds for density perturbations can be provided by the early quantum fluctuations of the scalar field which derive inflation. During the inflationary phase, the universe expands exponentially. During this period, the Hubble radius remains constant, but the proper wavelengths grow exponentially. Given any model for inflation, it is, therefore, possible to compute the spectrum and amplitude of the density perturbations.

In *chapter 2*, we generalize the Friedmann equations in arbitrary dimensions by finding the general form of the Newtonian gravitational constant, G, and hence the gravitational coupling constant κ. This has been done by comparison of FRW cosmological models and their Newtonian counterparts. It is now a common belief among cosmologists and relativists that although the space-time appears to be smooth, nearly flat and 4-dimensional on large scale, at sufficiently small distances and early times it is highly curved, with all topologies and arbitrary dimensions. The initial idea of Kaluza-Klein has been extensively used in unified theories of fundamental interactions. There, the extra dimensions are assumed to be compactified to Plankian size, and therefore, do not display themselves in macroscopic processes. The multidimensional cosmologies based on these ideas have been extensively studied in the recent years.

The dimensional dependence of the gravitational constant, κ, may have various and serious field-theoretic and astrophysical consequences hitherto unnoticed. For instance, it is interesting to see which changes are to be expected if the results of this dimensional dependency are combined with the Kaluza-Klein paradigm. By noticing that and comparing with observations of the cosmic microwave background, some models of Kaluza-Klein cosmologies are ruled out, while others turn out to be viable, with the number of extra dimensions being constrained by the COBE and Tenerife experiments.

The real universe contains inhomogeneous structures like galaxies, clusters, etc. and, in any theory of the formation of these structures, it is essential to understand the evolution of small inhomogeneities in the early universe. In principle, it is straightforward to work out the general relativistic theory of linear perturbations. By. linearizing Einstein's equations, we can obtain a second-order differential equation. In practice, however, there are many complications and conceptual difficulties which make this analysis highly non-trivial. One issue is the so-called "gauge problem" which arises due to nonuniqueness of splitting the metric and matter variables into a zeroth order background and small, first-order perturbations. Since a relabeling of coordinates can make a small perturbation in the stress tensor large or even generate a component which was originally absent, one must care to factor out effects due to coordinate transformations, when analysing relativistic perturbations. There are two different ways of handling these difficulties in general relativity. One approach is to analyse a perturbation in a particular gauge. In this case, one specifically identifies the points of a fictitious background space-time with those of real space-time. In this method, however, we cannot fix the gauge completely and the residual gauge ambiguities can create some problems. The second method is to construct the perturbed physical variables in a gauge-invariant manner. The gauge-invariant approach is conceptually more attractive since, there is no need for specific identification of the points between the two space-times, though it is more complicated and the physical meaning of variables do not, in general, possesses any simple interpretation and becomes obvious only for specific observers.

It is convenient to divide the cosmological perturbations into two subclasses: (i) Perturbations with wavelengths larger than the Hubble scale, for which we have to use some form of a general relativistic theory of perturbations and (ii) small-scale perturbations for which the evolution of mass density can be studied using Newtonian theory. In this context, all physical quantities can be defined unambiguously to the order of accuracy needed. In general, the application of Newtonian equations is further restricted to non-relativistic matter and cannot be used for relativistic component even for scales much smaller than Hubble radius.

In *chapter 3*, we re-examine the basic equations describing a Newtonian universe with *uniform pressure* and find a way for obtaining the same evolution equation for density contrast as could be obtained by the full relativistic approach. We achieved this goal by using the modified continuity equation in an expanding background. We extend the results to a multi-component universe with different equations of state. We shall then consider a two fluid universe in the context of "*pseudo Newtonian*" cosmology. Comparison with the fully relativistic two-component universe reveals the high accuracy of density contrast equations in the pseudo Newtonian cosmology. This may help us to extend the domain of validity of Newtonian cosmology in order to analyse some problems of formation of structures even in the radiation dominated phase and scales bigger than Hubble radius, which, in turn, may help us to by pass the gauge fixing problem arises in GR.

Gravitational instability theory requires many uncertain inputs, any of which might be wrong without invalidating the Big Bang theory. This motivates that one can study the problem of large scale structure formation in different and alternative cosmologies. One of the known alternative cosmologies is the so called *Quasi-Steady State Cosmology* (QSSC). *Chapter 4* is devoted to the problem of formation of large scale structure within the framework of QSSC. The primary process of creation of matter and the resulting dynamics of ejection of matter from regions of strong gravitational fields plays a key role. To understand its working, a toy model is used, in which from a set of randomly distributed creation centres, a new generation of centres is created as part of an iterative algorithm. It is shown that the system develops clusters and voids along with filamentary structure, within a few iterations. The two point correlation function and density distribution function for these simulations are shown to reproduce the observed clustering of the large scale structure in the real universe.

In *chapter 5*, we consider the origin of fluctuations in the early universe. Inflation is one of the possible mechanisms to produce the initial seeds which are needed for formation of structures in the universe. Most of the inflationary theories lead to a "scale-invariant" spectrum, but generally the amplitude of perturbation is too large. This amplitude can be brought down only if the non-supersymmetric inflationary potential is fine-tuned in a very unnatural way. Correct values for the amplitude may be obtained if the divergent expressions in field theory are regularized using a cutoff at Plank energy. For that, we use the hypothesis of path integral duality. Assuming the path integral amplitude to be invariant under the duality transformation, we evaluate the modified Feynman propagator in a de Sitter inflationary phase.

Conformal fluctuations in the metric can be initiated by the vacuum fluctuations of a scalar field with mass greater than the Plank mass. Flatspace is unstable against such fluctuations. The conservation of energy, however, is violated in the Big Bang cosmology. That is, it is impossible for matter to come into existence without violating energy conservation. If a model should successfully explain creation of positive-energy matter without violating the energy conversation law, then it is necessary to have some degrees of freedom which acts as a negative energy mode. Thus, introducing a negative-energy field, at the classical level itself may provide a natural way for creating matter. The simplest possible choice for a negative-energy field is the one with zero mass and zero spin, usually called "creation field" or C-field. In *chapter 5*, by adding this creation term to the Hamiltonian we investigate the instability of flatspace against small perturbations in the C-field. This makes the quantum scalar field fluctuation in flatspace increases without bounds. The gamma ray bursters (GRBs) may also be explained in this approach.

The last chapter, *chapter 6*, which is somewhat independent of the other chapters, is devoted to statistical mechanics of gravitating systems. The statistical behaviour of N particles interacting through Newtonian gravitational forces is very different from the statistical behaviour of other many body systems such as neutral gases and plasmas. The central feature of gravitating system, in contrast to normal many body systems, is the *unshielded, long range* nature of gravitational force. Because of this feature, one of the fundamental concepts of statistical mechanics, the extensive nature of energy, breaks down. This, in turn, leads to different physical descriptions for the gravitating systems in the microcanonical and canonical distribution.

The statistical behaviour also strongly depends on the spatial dimension. For instance, in $3D$, the available phase volume for the system diverges and one is forced to use short distance cutoff. However, the situation in $2D$ is different. In this case, there is a microcanonical description for all values of energies, through the canonical approach exists only above some critical temperature.

We shall study some properties of these gravitating systems by introducing a toy-model based on a simple Hamiltonian, describing two particles of finite size, confined inside a box. This system shows several important properties of more complicated systems studied earlier. We will study this toy model in both the microcanonical and canonical approach.

We use this toy model to study the behaviour of confined binary systems in $2D$ and compare it with previously known result in $3D$. In the case of $2D$, in which canonical distribution exists only above a critical temperature, we evaluate the exact form of partition function for this system and compare the exact partition function with the mean field partition function for the case of two-particle system. In contrast in $3D$ counterpart, there is no phase transition here. If this system, however, studied in microcanonical ensemble, it shows two different phases of kinetic energy dominated with positive specific heat and potential energy dominated with negative specific heat in presence of short distance cutoff. In absence of short distance cutoff, surprisingly, the negative specific heat region will be replaced by region of large specific heat. This feature is completely new and there is no such a case in $3D$.

The thesis is mainly based on the following publications and preprints:

Gravitational Coupling Constant in Arbitrary Dimension, *Reza Mansouri and Ali Nayeri*, Gravitation & Cosmology, Vol. **4**, 2, 1998.

Statistical Mechanics of Confined Binary System: Comparison of Three and Two Dimensions, *Ali Nayeri* To appear in Mon. Not. R. Astron. Society.

Cosmological Perturbation Theory: A Neo-Newtonian Approach, *Ali Nayeri* Submitted to Phys. Rev. D.

Structure Formation in the Quasi-Steady State Cosmology: A Toy Model, *Ali Nayeri, Sunu Engineer, J. V. Narlikar and F. Hoyle* Submitted to Astrophysical Journal.

The Effect of Dimensional Dependent Gravitational Coupling Constant on Kaluza-Klein Cosmologies, *V. Faraoni and Ali Nayeri* In preparation.

Instability of Flatspace and the Early Quantum Fluctuations by Considering an Unbounded Hamiltonian, *Ali Nayeri* In preparation.

Application of Path Integral Duality in the Inflationary Phase, *Ali Nayeri and T. Padmanabhan* In preparation.

Guide : J.V. Narlikar, IUCAA

Co-guide : T. Padmanabhan, IUCAA

(IV) PUBLICATIONS

by IUCAA Academic Staff

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

a) Journals

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Chassande-Mottin, E. and **S.V. Dhurandhar** (2001) Adaptive filtering techniques for gravitational wave interferometric data: Removing long-term sinusoidal disturbances and oscillatory transients, Phys. Rev. **D63**, 042004.

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b) Proceedings

Bambah, B. (2000) Gauge theoretic chaology, Recent Developments in Non-Linear Dynamics, Eds. P. Panigrahi, V. Srinivasan and A.K. Kapoor, Allied Publishers (2000).(with C.Mukku, S.Lakshmibala and M.S.Sriram).

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Das, M.K., **H.P. Singh,** B. Ramachandran, E. Saikia, P. Narang, B. Biswal, S.K. Gupta and S. Joshi (2001) Auto search for nonlinear behaviour in light curves of variable stars, in Automated Data Analysis in Astronomy, Eds. R. Gupta, H. P. Singh and C.A.L. Bailer-Jones (Narosa, New Delhi), p. 189

c) Books (Authored)

Kaushal, R.S. and D. Parashar, D. (2000) Advanced methods of mathematical physics (a textbook cum research monograph) published jointly by Narosa Publishing House, New Delhi, C.R.C. Press USA, and Alpha-Science International, UK.

d) Popular articles

Biswas, S. (2000) Galaxy — the building block of the universe' in UNIVERSE & BEYOND, 2001

e) Pedagogical Activities

Supervision of Thesis

S.N. Paul and A. Roychowdhury

Md. Khursed Alam
On the nonlinear and linear aspects of magnetized plasma, August 2000, University of Jadavpur, Ph.D. Thesis.

S.K. Pandey

Padmakar Parihar
A photometric study of RS CVn binary stars, January 2001, Ravishankar University, Raipur. Ph.D. thesis.

(V) PEDAGOGICAL ACTIVITIES

a) IUCAA-NCRA Graduate school

N. Dadhich: Mathematical Methods -II

A.K. Kembhavi: Stellar Structure and Evolution

J.V. Narlikar: Statistical Mechanics.

T. Padmanabhan:
(i) Introduction to Astronomy and Astrophysics
(ii) Extragalactic Astronomy and Cosmology - I

A.N. Ramprakash: Astronomical Techniques I - Coherent detection

R. Srianand: Extragalactic Astronomy

Tutorial Assistantship

N. Sambhus: Stellar structure and Evolution

A. Pai: M.Sc. (Physics) course on General Relativity and Cosmology, University of Pune.

T. Roy Choudhury: Extragalactic Astronomy and Cosmology

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

Das Tapas K.: Introductory Cosmology

S.V. Dhurandhar: Astronomy & Astrophysics II

R. Gupta: Astronomy & Astrophysics I, Semester III Paper I theory and laboratory course (semester III and IV)

c) Supervision of Projects

S. V. Dhurandhar

Anand Sengupta (IUCAA-NCRA Graduate School)
Gravitational Waves

Dinesh Raut (VSP)
General relativity and blackholes

R. Gupta

Aravind C. Ranade (M.Sc.)
Observation and analysis of the stellar spectral library

A.K. Kembhavi

M. Azimlu, Iran
Image processing

Cathy Klock, ESPEO, France
Fourier analysis of spiral galaxy images

Kunal Tengase (M.Sc.)
Shape of galaxies.

Kunal Tengase (VSP)
Isophotal Analysis of Galaxies

Savita Mathur, France
Planetary Rings

Deepan A. Choudhary (VJTI, Mumbai),
Atin R. Palekar (VJTI, Mumbai)
Tejas S. Neverekar (VJTI, Mumbai)
Saurabh B. Mahadik (VJTI, Mumbai)
Sunil J. Bhavsar (VJTI, Mumbai)
Fourier analysis in image processing

Maitrayee Bose (Fergusson College, Pune)
Extra Solar Planets.

J.V. Narlikar

Aarti Wagh
Ujjwala Pokharkar
Rujuta Paithankar
Dhanashri Devale
Swanand Gadgil
Makarand Mijar
Ketaki Sahasrabuddhe
Rizwan Shaikh
Shweta Kadaganchi
Rohan Katariya
Neha Naik
Mansi Navare
Jay Vartak
Chetan Totagi
Janhavi Modak
Anjor Kanekar
Alok Kothari
(School Students' Summer Programme)
Rotation of the Earth

Project sponsored by other agnecies

Ratnakar Bhalerao
Malhar Kulkarni
(under support from INSA)
Search for historical references to the sighting of the Crab supernovae of 1054 A.D.

T. Padmanabhan

V. Vijayalakshmi (VSP)
Dynamical Friction

N. Sambhus

Mangesh Kute (B.Sc.)
The Two Body Problem

d) Supervision of dissertation / Thesis

Tapas Das

Devraj Pawar
On Hydrodynamic Spherical Accretion onto Gravitating Astrophysical Objects
M.Sc. Dissertation

A.K. Kembhavi

Habib Khosroshahi (IASBS, Zanjan, Iran)
The Photometric Plane of Galaxies

J.V. Narlikar (Guide)

Ali Nayeri
Gravitational Clustering in Different Scenarios
Ph.D. Thesis

T. Padmanabhan (Co-Guide)

Ali Nayeri
Gravitational Clustering in Different Scenarios
Ph.D. Thesis

(VI) IUCAA COLLOQUIA, SEMINARS, ETC.

a) Colloquia

D. Lynden-Bell: *From Newton to NUT Space via the Quantum N-Body Problem,* April 3.

P.B. Pal: *Pulsar Kicks and Neutrinos*, April 10.

C.V. Vishveshwara: *Leaves from an Unwritten Diary - Subrahmanyan Chandrasekhar - Reminiscenes and Reflections*, April 24.

R. Ramachandran: *Dualities in String Theories*, May 1.

S. Raychaudhury: *The First Results from Chandra and XMM-Newton*, May 22.

J. Ehlers: *General Relativity and its Empirical Foundations*, October 3.

A. Raychaudhuri : *Neutrinos: Probing the Boundaries of Particle Physics*, October 10.

M.R. Das: *Molecular Basis of Life and its Implications*, October 23.

G. Consolmagno: *Meteorite Porosity and Asteroid Structure,* January 8.

P.M. Mathews : *The Earth's Variable Rotation, and What it Revelas about the Earth,* January 29.

S.R. Shetye: *Circulation of the North Indian Ocean,* February 19.

R. Gadagkar on *The Evolution of Cooperation and Altruism in Animals*, March 5.

b) Seminars

D. Malquori: The Role of Interactions in Galaxy and Quasar Evolution, April 6.

P. Saha: Gravitational Lenses: Some Theory, Some Mass Maps, and Some Inferences about H_0, April 19.

C.V. Vishveshwara: Black Holes in Non-Flat Backgrounds, April 20.

S. Datta: Structure of Molecular Clouds : A Fractal Description, April 26.

S. Bhavsar: The Magnitude Distributions of First-Ranked Cluster Galaxies, June 12.

A.S. Sengupta: Simulation of the One Step Search Algorithm for Detection of Gravitational Waves from Inspiralling Compact Binaries, July 28.

Parampreet Singh: Ashtekar Variables, July 28.

H.K. Jassal: Null Strings Near A Higher Dimensional Blackhole, August 21.

A. Rej: Universe as Turbulence and the Model of Structure Formation, September 19.

J. Maharana : Holography and String Cosmology, October 4.

N.N. Rao: Waves in Dusty Plasmas and the Concept of Fugacity, October 20.

K. N. Iyer: Radio Astronomical Studies Using IPS Array at Rajkot, November 10.

K. Bhattacharya: Particle Interactions in Magentic Fields, November 22.

S. Bhattacharyya : General Relativistic Spectrum from Accretion Disk around Neutron Star, November 30.

R. Misra: Timing Properties of X-Ray Binaries, December 6.

G. Date: Isolated Horizons, December 13.

P. Jain: Neutrino-Induced Giant Air Showers in Large Extra Dimension Models, December 14

D.V. Ahluwalia: Spin One: Beyond the Textbook Wisdom, December 18.

J. Rankin: Pulsar Magnetospheric Emission Mapping: Touching The Physics of Pulsar Emission, January 25

J.S. Bagla: Caustics and Singularities in Two Dimensional Gravitational Collapse, February 1.

F.R. Bouchet: Cosmic Microwave Background: Current Status and Perspectives Offered by the Planck Satellite, February 15.

c) MAHFIL (Mid-day Astronomy Hour for Interaction and Lunch)

C.V. Vishveshwara)	
K. Indulekha)	April 26
M.L. Kurtadikar)	
R. Ramachandran)	

S.P. Bhatnagar	)	May 17
Daksh Lohiya	)	
R.V. Saraykar	)	
S. Banerji	)	
P.K. Srivastava	)	June 14
S. Mukherjee	)	
J. Ehlers	)	
G. Date	)	October 18
Lalan Prasad	)	
K.R. Chatterjee	)	
T. Morel	)	November 22
T. Das	)	
T. Padmanabhan	)	December 27
P.S. Joarder	)	
T. Souradeep	)	
J. Anandan	)	
S.K. Banerjee	)	January 24
H. Arp	)	
G. Burbidge	)	

(VII) TALKS AT WORKSHOPS OR AT OTHER INSTITUTIONS

a) Seminars, Colloquia and Lectures

T. Roy Choudhury

Semi analytic modelling of the low density IGM, Young Astronomers' Meet 2001, IUCAA, February 7-10.

Tapas K. Das

Accretion powered spherical wind in general relativity, Third Microquasar Workshop: Granada Workshop on Galactic relativistic jet sources, Granada, Spain, September 13.

Global inflow-outflow solution for extragalactic jet sources, Observatorio Astronsmico Nacional, Alcala de Henares, Alcala, Spain, September 16.

Accretion and winds around compact astrophysical objects, DAEC & UMR 8631 du CNRS, Observatorie de Paris-Meudon, France, September 26.
Outflows from rotating and non-rotating accretion onto black holes and neutron stars, Jodrell Bank Observatory, University of Manchester, UK, October 4.

On the formation of accretion-powered galactic and extra-galactic jets, Institute of Astronomy, University of Cambridge Cambridge, UK, October 10.

High energetic astrophysical processes around accreting supermassive black holes, All Moscow seminar, Sternberg astronomical Institute, Moscow State University, Moscow, October 13.

S.V. Dhurandhar

Proposal of IUCAA joining the LSC, Multi-detector problem in the plenary session, 7th LSC meeting, Hanford, USA, August 15.

Multi-detector coherent search for inspiraling coalescing binaries, VIRGO data analysis meeting, Orsay, France October 9.

A multi-detector search for gravitational waves from inspiraling compact binaries, Group talk, Kip Thorne's meeting: Physics Department, Caltech, USA, August 21.

Detecting gravitational waves from inspiraling compact coalescing binaries with a network of laser interferometric detectors, University of Rome, La Sapienza, Rome, Italy, October 27.

A coherent multi-detector search for gravitational wave signals from inspiraling compact binaries, University of Tokyo, Japan, March 16.

R. Gupta

Stellar spectral classification by artificial neural networks, Department of Astronomy, Univ. of North Carolina, Chapell Hill, USA, June 7.

Astronomy facilities and research in India, Department of Physics and Astronomy, Appalachian State Univ., Boone, North Carolina, USA, June 19.

Small/Automated Telescopes and backend instrumentation for teaching purpose, 20th ASI meeting, Gorakhpur, November 18.

Spectral Classification of unresolved binary stars with artificial neural networks, IDG talk reporting this publication by W.B. Weaver, IUCAA, December 7.

Stellar spectroscopy, IUCAA workshop on Observing with IUCAA Telescope, December 22.

Astronomical spectroscopy, 2 talks at IUCAA sponsored Workshop on Astronomical photometry and spectroscopy, Bangalore University, January 8-12.

Atmospheric effects and observing site and telescopes elsewhere (India and abroad), 2 talks during Second Level, Ist Workshop on Astronomical Photometry, IUCAA, January 17-19.

A.K. Kembhavi

Quasars, 2 talks, Introductory Summer School on Astronomy and Astrophysics and Vacation Students' Programme, IUCAA, Pune, May 22 - June 23 and May 22 - July 7.

Stars, 3 talks, Workshop on Stellar Structure and Evolution, St. Berchmans' College, Changanacherry, October 3-5.

Black holes, St. Berchmans' College, Changanacherry, October 4.

The new planets, St. Thomas College, Kozhencherri, October 5.

Survey of surveys, Workshop on Automated Data Analysis in Astronomy, IUCAA, Pune, October 9-12.

Extra solar planets, Institute of Advanced Studies in Basic Sciences, Zanjan, Iran, November 6.

Extra solar planets, University of Isfahan, Iran, November 9.

Astronomy teaching in universities: The issues and prospects, Astronomical Society of India Meeting, Gorakhpur, November 17.

Black holes - Do they exist?, Physics Department, University of Gorakhpur, November 17.

The new planets - Just gas or new worlds?, Physics Department, University of Gorakhpur, November 18.

Galaxy structure and properties : From our neighbourhood to high redshift, Indo-French School on Star Burst and the Structure and Evolution of Galaxies, IUCAA, Pune, December 11-20.

Galaxy observations with 2m telescope, Workshop on Observing with IUCAA Telescope, IUCAA, Pune, December 21-23

Galaxies, International School for Young Astronomers, Chiang Mai, Thailand, January 7-14.

Evolution of galaxies, Discussion Meeting on Cosmology, CIRI, Nagpur, January 28-29.

Super massive black holes, IAGRG Meeting, CIRI, Nagpur, January 30.

Observation and theory - Either, neither or both, Young Astronomers' Meet, IUCAA, Pune, February 7-10.

Extra terrestrial planets (in Marathi), R.N.C. Arts, J.D.B. Commerce and N.S.C. Science College, Nasik, February 20.

Galaxy correlations, INAOE, Puebla, Mexico, March 14.

Photometric plane of galaxies, North Western University, Evanston, USA, March 22.

Galaxy morphology and the photometric plane, John Hopkins University, Baltimore, USA, March 28.

S. Konar

Neutron star magnetic fields : Recent developments, Workshop on Neutron Stars : Isolated and in Binary, IUCAA, Pune, July 15.

Magnetic fields in astrophysics, VECC, Kolkata, August 11.

Magnetic fields of neutron stars, Young Physicists' Colloquium', Indian Physical Society, Kolkata, August 25.

Magnetic fields of quark stars, Workshop on Nuclear Astrophysics, IUCAA, Pune, September 21.

Magnetic fields of compact objects, IIT Kanpur. September 27.

Photon propagation in magnetised medium, IIT Kanpur, September 27.

T. Morel

A near-infrared [Fe II] line imaging survey of supernova remnants in M33, The Interstellar Medium in M31 and M33 Bad Honnef, Germany, May 23.

J.V. Narlikar

On getting the best value for money, Centre for Cellular and Molecular Biology, Hyderabad, April 9.

Third-world networking, 24th International Astronomical Union General Assembly, Manchester, United Kingdom, August 15.

Matter creation and anomalous redshifts, Keynote address at the VIGIER-2000 Symposium, The Noetic Institute, USA, August 21.

Action at a distance and cosmological boundary conditions, Presentation in Cosmology-II, VIGIER 2000, The Noetic Institute, USA, August 24.

Quasi-steady state cosmology, Physics Department, University of New Mexico, New Mexico, September 1.

Big bang cosmology: Strengths, weakness and alternatives, Library, Arecibo Observatory, USA, September 12.

The evolution of alternative cosmologies, Summer School entitled "Historical Development of Modern Cosmology, University of Valencia, Spain, September 20.

The interaction between physics and astronomy, Two Extension Lectures, Physics Department, Mohanlal Sukhadia University, Udaipur, November 7 and 8.

Why study astronomy, Introductory School in Astronomy and Astrophysics, Swami Ramanand Teerth Marathwada University, Nanded, November 16.

Theories and observations in cosmology, Introductory School in Astronomy and Astrophysics, Swami Ramanand Teerth Marathwada University, Nanded, November 17.

Stochastic creation process and large scale structure in cosmology, Astrostatics session of the Joint Statistical Meeting, New Delhi, January 1.

The microwave background in the quasi-steady state *universe*, Birla Planetarium, Kolkata, January 14.

Observational tests of the quasi-steady state cosmology, Workshop jointly organized by the IIT, Kharagpur and IUCAA, Pune, Contemporary Cosmology, Kolkata, January 16.

MBR in quasi-steady state cosmology, Department of Physics, University of Tokyo, Japan, February 15.

In gravitational waves from mini-creation events, National Astronomical Observatory, Japan, March 9.

The quasi-steady state cosmology : An alternative to the standard cosmology, (i) Department of Physics, Fukui University, March 19, (ii) Department of Earth and Space Science, Graduate School of Science, Osaka University, Japan, March 22, (iii) Yukawa Institute for Theoretical Physics, Kyoto, March 23.

T. Padmanbhan

Survey of astronomy, Astronomy Olympiad students, IUCAA, May 6.

Statistical mechanics of gravitating systems, IIA, Bangalore, October 17.

Interface between quantum theory and gravity, RRI, Bangalore, October 16.

Intergalactic medium: The next frontier, RRI, Bangalore, October 19.

Intergalactic medium, IMSc, Chennai, November 11.

New results from cosmology, XIV DAE symposium on High Energy Physics, Hyderabad, December 21.

Precision cosmology: A beginning of a new era, TIFR, Mumbai, December 22.

Future role of the IUCAA Library in web-based astronomy education, IUCAA, December 26.

Understanding the intergalactic medium, Meeting on Contemporary issue in Cosmology, Kolkata, January 16-17.

The new era in cosmology, S.N. Bose National Centre for Basic Sciences Colloquium, Kolkata, January 18.

A. Pai

Gravitational waves: Sources and detectors, YAM-2001, IUCAA, February.

A. Paranjpye

The galaxy and galaxies, Refresher Course for PG teacheres, University of Pune, April 15.

Lure of variable star observing, Introductory Summer School on A & A, IUCAA, June 19.

A.N. Ramprakash

NIPI - Near Infrared PICNIC Imager for the IUCAA Telescope, Workshop on Observing with the IUCAA Telescope, IUCAA, Pune, December 23.

Multiband monitoring and polarimetry of GRB afterglows with IUCAA telescope, International Symposium on "Gamma-ray Astrophysics through Multiwavelength Experiments", Mt. Abu, Rajasthan, March 8.

Varun Sahni

Recent advances in cosmology and astrophysics, Jamia Millia Islamia, New Delhi, February.

The cosmic microwave background and cosmology, Workshop on Contemporary Cosmology, Kolkata, January.

Rediscovering the cosmological constant, 20th Meeting of the Astronomical Society of India, Gorakhpur, November.

The cosmological constant, Workshop on Topics in General Relativity, IUCAA, October.

Constraining Ω *and* Λ *from CMB+supernova observations, Kingston 2000: The CITA reunion meeting, Toronto, Canada, August*

Quintessence models and the equation of state of the universe, *IAU Symposium 201, New Cosmological Data and Fundamental Parameters, Manchester, UK, August.*

The cosmic microwave background after BOOMERanG, IUCAA, May.

Cosmology after the BOOMERanG experiment, TIFR, Mumbai, July.

The case for cosmic repulsion, Canadian Institute for Theoretical Astrophysics, Toronto, Canada, August.

The cosmological constant and the acceleration of the universe, Physical Research Laboratory, Ahmedabad, November.

N. Sambhus

Nucleus of M31, Indo-French Workshop on Starbursts, IUCAA, Pune, December.

Early Planet formation as a trigger for further planet formation, IUCAA-NCRA IDG, January.

Planetary Disks around stars, YAM, IUCAA, February.

T. Souradeep

Exploring the ultra large scale structure of our universe, Workshop on contemporary cosmology, Kolkata, January 16.

A. Thampan

Compact stars; accretion onto compact stars, Introductory Summer Schoo on A & AI, IUCAA, June 19, 20 (2 Lectures).

Luminosities of disk-accreting non-magnetic neutron stars, IX Marcel Grossman Meeting, Rome, Italy, July 5.

Luminosities of disk-accreting rapidly rotating neutron stars: Relevance to equation of state of ultra-high density matter, Dipartimento di Fisica, Univerita di Pisa, Pisa, Italy, July 20.

S. Shankaranarayanan

Covariance of Hawking radiation, Field theoretic aspects of gravity, IUCAA, Pune, October 17.

Vanishing of cosmological constant in Randall-Sundrum model, Raman memorial conference, University of Pune, Pune, January 5.

Localized gravity in large extra dimensions, Young Astronomers Meet, IUCAA, Pune, February 7.

R. Srianand

Chemical enrichment of QSOS, Indo-French school , IUCAA, December.

Chemical enrichment in the Damped systems, Indo-French school, IUCAA, December.

Spectroscopy of QSOs with IUCAA telescope, Mini-workshop on Science with IUCAA telescope, IUCAA, December.

Lyman continuum emission from Lyman break galaxies, Journal club, IAP, Paris, January 23.

Temperature of CMBR at high redshift, European Southern Observatory, Munich, January 24.

Molecular hydrogen in the damped systems, A brief summary given in a meeting on Damped systems, ESO, January 27.

Measuring the CMBR temperature at $z = 2.3$, Cosmo club talk, IAP, Paris, February 1.

QSO absorption lines, BARC, Mumbai, March, 28.

P. Singh

Quadrupole coupling with curvature, Workshop on Gravity - Field theoretic aspects, IUCAA, October 12-20.

Some classical and quantum effects of quadrupole coupling with curvature, 21st meeting of IAGRG, Central India Research Institute, Nagpur, January 31.

Quantum phase shifts in general relativity, YAM, IUCAA, February 7.

S.N. Tandon

Instruments and detectors for photometry, 2 lectures, Introductory School on Astronomy and Astrophysics, SRTM University, Nanded, November.

R. G. Vishwakarma

Cosmology with variable Λ, Workshop on the Contemporary Cosmology, Kolkata, January 16-17, 2001.

Y. Wadadekar

Optical counterparts of radio sources, 2 lectures, IASBS, Iran, May 29, 30.

GNU/Linux operating system, IASBS, Iran, June 5.

Programming in Perl, 2 lectures, IASBS, Iran, June 6, 7.

Bulges of galaxies, Introductory Summer School on A & A IUCAA, June 20.

Photometric plane of galaxies, R.K. Bhalla Award competition, IPA, Pune, August 25.

Stellar photometry, Workshop on Stellar Structure and Evolution, Chenganacherry, Kerala, October 4.

Demo on Astronomical photometry and astrometry using IRAF and extractor, Chenganacherry, Kerala, October 4.

Astrometric techniques in astronomy, Chengancherry Kerala, October 6.

Radio emission from Seyfert galaxies -The starburst connection, Indo-French School on Starburst Galaxies, IUCAA, December 13.

Photometric challenges with small telescopes, 2nd level photometry workshop, IUCAA, January 18.

CCD's in astronomy, National Science Day, IUCAA, February 28.

b) Lecture Courses

A. Thampan

Pulsars, Neutron stars and Black holes, Workshop on Stellar Structure and Evolution, St. Berchman's College, Chengancherry, Kerala, October 3-5 (3 lectures).

S.V. Dhurandhar

Introduction to gravitational waves, VSP, IUCAA, June 27-29 (3 lectures).

J.V. Narlikar

Cosmology, Vacation and Summer School Students, IUCAA, May 26, May 29 and May 30 (3 lectures).

T. Padmanabhan

Special theory of relativity, Indian Institute of Astrophysics Summer School, Kodaikanal, June 11-15, (5 lectures).

Order of magnitude astrophysics, VSP, IUCAA, June 21-26 (4 lectures).

Order of magnitude astrophysics, RRI, Bangalore October 4-12 (5 lectures).

c) Popular Lectures

Tapas K. Das

Expulsive and propulsive; What are they?, Astrophysical Jets , Gujarat University, Ahmedabad, January.

S.V. Dhurandhar

Gravity, Pathare Prabhu Society prize distribution function, Vile Parle, Mumbai, November 26.

The story of gravity, IUCAA, January 27.

R. Gupta

Astronomical telescopes - Eyes of astronomers, IUCAA, August 26.

Vibhinna prakar ke durbeen, (in Hindi) Gorakhpur University, High School students, November 17.

S. Konar

Tara jibon-kahini (Lives of stars) (in Bengali) R.K.S.M. Suster Nivedita Girls' School, Calcutta, August 10.

J.V. Narlikar

Importance of space technology in astronomical observations, ISRO Satellite Centre,, Bangalore, April 19.

Cosmic illusions, Summer Workshop organized by Exploratory, Bharatiya Vidya Bhavan, Pune, April 24.

Khagol vidnyanatil na sutlele prashna (Some unsolved questions in Astronomy) (in Marathi), Pantasachiv Headquarters, Pune, April 26.

Hubble durbinitun vishwache darshan (A view of the universe through Hubble telescope) (in Marathi), IUCAA, Pune, May 3.

Antaralatil drishtikon (Cosmic illusions) (in Marathi), Summer Workshop organized by Exploratory, Bharatiya Vidya Bhavan, Pune, May 5.

The universe as viewed from space, IUCAA, Pune, May 6.

Khagol vidnyanatil na sutlele prashna (Some unsolved questions in Astronomy) (in Marathi), Vasant Vyakhyanmala, Miraj, May 13.

The search for extra-terrestrial intelligence in the universe, Rajiv Gandhi Centre for Biotechnology, Thiruvananthapuram, May 20.

Einstein and revolution in physics, Nehru Planetarium, Mumbai, June 10.

Some tales of how physics and mathematics have helped astronomy, IUCAA, June 24.

Antaralatun vishwache darshan (Views of the universe from space) (in Marathi), IUCAA, July 8.

Views of the universe from space, IUCAA, July 8.

The message of science fiction : Prophetic or trivial?, Sahitya Akademi, Delhi, July 26.

The strange effects of gravity, Visitors Centre Auditorium, Arecibo Observatory, USA, September 13.

Did the universe start with a big bang? Cardiff Astronomical Society, University of Cardiff, UK, September 15.

Vidnyan Kshetratil sandhi ani avahane, (Opportunity and challenges in Science) (in Marathi), Tata Hall, B.M.C.C. College, Pune, organized by the Vidnyan Bharati, Pune, October 1.

The cosmic origin of atomic nuclei, Indian Nuclear Society, Mumbai, October 13.

The origin of chemical elements, M.R. Bhiday Memorial Lecture, Chemistry Department, University of Pune, organized by the Maharashtra Academy of Sciences, Pune, November 3.

New developments in astronomy, Udaipur, November 7.

On setting up a scientific institution, in the Lecture series on Ideas that have worked, New Delhi, November 9.

Vishvachya nirmitibaddalchya vaidnyanik sankalpana (Scientific ideas on the origin of the universe) (in Marathi), Degloor, November 18.

Antaralatun vishwache darshan (Views of the universe from space) (in Marathi), Nanded, November 19.

Prithvi palikade jeevshriticha shodh (Search for extraterrestrial intelligence) (in Marathi), Buldhana, November 20.

Khagol vidnyanachya navya disha (New directions to astronomy) (in Marathi), Chikhli, November 21.

The exciting problems in astronomy, Swami Gandharva Hall, Hubli, November 30.

Are we alone in the universe?, organized by the Rotary Club, Chamber of Commerce and Industries, Hubli, November 30.

The cosmic adventure, P.C. Jain Science College, Hubli, December 1.

Mach's principle: From Newton's bucket to Foucault's pendulum, Ramnarain Ruia College, Mumbai, December 16.

T. Padmanabhan

Scenes in the sky - Excitement of astrophysics, Cochin University Science and Technology, April 25.

Cosmology: Status and future, Cochin University Science and Technology, April 25.

Our universe, University College, Thiruvananthapuram, October 31.

Cosmology today, Nehru Planetarium, Mumbai, November 22.

Journey through the universe, Rotary Club, Pune, December 4.

A. Paranjpye

Observing the night sky, Out Bound Foundation, Pachgani, April 25.

Tarangananche mahatva (in Marathi), Jnana Prabodhini Navanagar Planetarium, Pune, June 22.

A solar system walk, Rotary club of Poona Down Town, Pune, July 5.

DIY - Astronomical photography, AIMO, Pune August 8.

IUCAA Public Outreach Programme, ISRO, Bangalore, August 23.

Aaple vishwa (in Marathi), Sharodostav Vykhyan Mala, Junnar Nagar Vachanalay, Junnar, October 10.

Our colorful universe, Rotary Youth Leadership Award Programme of Rotary Club of Poona Down Town, Pune, January 25.

Some interesting discoveries in astronomy, Senior Citizen's Club, Janaseva Foundation, Pune.

How Foucault showed that the Earth is rotating, Vidya Pratishathan's English Medium School, Baramati.

N. Sambhus

A Cosmic Tour of the Unvierse, The Arts and Science College, Bhilwara, November.

R. Srianand

Measuring cosmic microwave background temperature of the early universe, IUCAA, February 28.

S.N. Tandon

Energy of Sun (in Hindi), IUCAA, February 28.

d) Radio / TV programmes

J.V. Narlikar

Gyan vigyan, Amul Surabhi, DD-I, October 22.

Gyan vigyan, Amul Surabhi, DD-I, January 7.

Scientific programmes in the space series on Balchitravani (Episodes 1 to 8)

A. Paranjpye

Guru ani Mangal yuti (in Marathi), Akashwani, Pune, April 4.

Nate nisargache - Dhumketu (in Marathi), Akashwani, Pune, April 7.

Akashdarshan - Live sky show (in Marathi), Akashwani, Pune, April 7, 24, May 5, December 15, January 15 and February 15.

Sanstha parichay (in Marathi), Akashwani, Pune, April 11.

IUCAA Science Park, Bhatkanti, Alpha TV Marathi, June.

Lunar eclipse, Interview to BBC Hindi service, July 15.

Interviewed Professor Varun Sahni on being bestowed with the Shanti Swaroop Bhatnagar award, Akashwani, Pune, September 26.

150th anniversary of first public demonstration of Foucault's Pendulum, ETV, March 25.

Niranjan Sambhus

Participated as a special invitee *in Akashdarshan - Live sky show* (in Marathi), Akashwani, Pune, March 15.

e) Science Popularisation

J.V. Narlikar

(i) Participation in question-answer programme in Doordarshan Series "Surabhi".

(ii) Occassional talks and interviews on All India Radio and on TV, listed under (d)

(iii) Writing of popular articles in newspapers and magazines, listed under 'Popular Articles'.

(VIII) SCIENTIFIC MEETINGS

Introductory Summer School on Astronomy and Astrophysics

A summer school for students of the B.Sc. final and first year M.Sc. was organized jointly by IUCAA and National Centre for Radio Astrophysics (NCRA) at Pune during May 22 to June 23, 2000. The school is part of an annual series of Summer Schools on Astronomy and Astrophysics, sponsored by the Department of Science and Technology under which, the schools are conducted alternatively at Bangalore and Pune. The school extended over a period of five weeks and lectures covering different theoretical, observational and instrumental aspects of astronomy and astrophysics were given by lecturers from IUCAA, NCRA and TIFR, Mumbai. There were a few problem solving sessions and special discussions including one on careers in astronomy. A few students voluntarily took on projects under the supervision of IUCAA or NCRA faculty. Students of the school visited the GMRT site and also had a day's excursion to Sinhagad fort. Altogether 33 students from throughout India attended this school. Ajit Kembhavi from IUCAA and Vasant Kulkarni from NCRA were the coordinators of the school.

Students and the lecturers of the Introductory Summer School on Astronomy and Astrophysics

Vacation Students' Programme 2000

The 7 weeks long Vacation Students' Programme (VSP) for students in their penultimate year of their M.Sc. (Physics) or Engineering degree course was held during May 22 - July 7, 2000. Seven students participated in this programme. The participants attended about 63 lectures dealing with wide variety of topics in Astronomy and Astrophysics. They also did projects with the faculty members of IUCAA during this period. T. Padmanabhan was the coordinator of this programme.

Neutron Stars: Isolated and in Binary Systems

The workshop on Neutron Stars: Isolated and in Binary Systems was held in IUCAA during July 15-16, 2000. The topics covered in this workshop included - Evolution of Neutron Stars in Binaries, the Magnetar Question, Accretion onto Neutron Stars, Magnetic Fields of the Neutron Stars, Pulsar-Strange Star Connection, Pulsar Observation at GMRT, etc. Talks were given by Sudip Bhattacharya (IIA, Bangalore), S. M. Chitre (TIFR, Mumbai), Pranab Ghosh (TIFR, Mumbai), Yashwant Gupta (NCRA, Pune), E. P. J. van den Heuvel (Univ. of Amsterdam), Sushan Konar (IUCAA), Dipanjan Mitra (RRI, Bangalore), Alak Ray (TIFR, Mumbai), Firoza K. Sutaria (IUCAA) and C. S. Shukre (RRI, Bangalore). A.K. Kembhavi was the coordinator of the workshop.

Participants of the Workshop on Neutron Stars: Isolated and in Binary Systems

Participants of the Vacation Students' Programme 2000

Workshop on Nuclear Astrophysics

The workshop on Nuclear Astrophysics was held at IUCAA during September 20 - 22, 2000. There were twenty four active participants from all over the country. The topics on which lectures were delivered included Neutron Stars, Neutron Rich Nuclei, Neutron Stars and Quark Stars, Cosmic Ray, Quark Matter and White Dwarfs, Neutrino Physics and Nuclear Matter. The speakers were F.K. Sutaria (IUCAA, Pune), Rituparna Kanungo (Japan), Sushan Konar (IUCAA, Pune), Nayantara Gupta (IACS Calcutta) Somenath Chakraborty (Kalyani University, Calcutta), S.K. Singh (Aligarh Muslim University, Aligarh), V.K. Gupta (Delhi University, Delhi) Debades Banerjee (SINP, Calcutta), P.K. Raina (IIT, Kharagpur), and Hiranmaya Mishra (PRL, Ahmedabad). Somenath Chakrabarty and A. Kembhavi were the coordinators of the workshop.

HRD Workshop on Achieving Excellence

A Human Resources Development workshop on Achieving Excellence was conducted at Goa during September 30 - October 1, 2000 for the Adminstrative, and Scientific and Technical staff of IUCAA. The main objective of the workshop was to stimulate the work culture among the members to achieve excellence. Thirty members attended this workshop and eleven members gave talks on various topics, such as, Management of Centre of Excellence, Time Management, Accounts, How to Have Peace Always?, Managing Stress, Effective Purchase System, Personality Development, Income Tax and Investment Opportunities, How to Save Electricity?, 2.0 m. Telescope Project at Giravali, and Information Services in a Networked Environment in India. After each talk, enough time was alotted for discussions. It was generally felt that the workshop was really beneficial and helped people to know about each other and their work. V. Chellathurai and Rajesh Parmar were the coordinators of this workshop.

Workshop on Stellar Structure and Evolution

A workshop on Stellar Structure and Evolution, sponsored by IUCAA, was conducted at St. Berchman's College, Changanacherry during October 3-6, 2000. Topics covered by the workshop included solar physics, stellar photometry, stellar structure and evolution, binary stars and compact objects. The lecturers included Harish Bhatt and C. Sivaram from IIA, Bangalore, S.R. Prabhakaran Nayar from University of Kerala, Ajit Kembhavi, Yogesh Wadadekar and Arun Thampan from IUCAA and teachers from some of the surrounding colleges. The organization of the workshop was managed by O.S. Sebastian and George Varghese of St. Berchman's College with the help of their colleagues. The coordinator from IUCAA was Ajit Kembhavi.

Participants of the Workshop on Nuclear Astrophysics

Workshop on Automated Data Analysis in Astronomy

A workshop on Automated Data Analysis in Astronomy was held at IUCAA during October 9-12, 2000. This was first of this kind of workshop organized in India in this field and it was attended by about 40 participants from India and abroad including representatives from USA, Germany, Russia, Argentina and Greece. Invited speakers were from these countries, institutes in India (IIA, PRL, UPSO, NCRA, BARC and IUCAA) and Indian Universities like Delhi, Osmania and Assam. The major topics included discussions/talks on large astronomical data bases, data reduction techniques, artificial neural networks and astrophysical goals achievable from such data bases. The workshop was funded by IUCAA, ISRO, DST and CSIR. The coordinator of this workshop was Ranjan Gupta.

Participants of the Workshop on
Automated Data Analysis in Astronomy

Workshop on Topics in General Relativity

About 20 active workers interested in field theoretic aspects of gravity got together at IUCAA for over a week (October 12-20, 2000) to discuss the current problems they were working on. The format of the workshop was very informal and helped free discussions. The topics included both classical and quantum aspects.

It started with an overview of classical GR and was followed by discussion on electrogravity duality, gravitational collapse, isolated horizons, naked singularity, Kalb-Rammond field and optical activity, 2+1 gravity, black hole entropy and entropy bounds, horizon states in AdS black holes, quantum creation of open universe, role of negative energy field in gravitational collapse and the Boomerang observations and their implications to cosmology. The speakers were N. Dadhich, G. Date, J. Ehlers, T. R. Govindarajan, P.S. Joshi, S. Kar, R. Kaul, P. Majumdar, S. Mukherjee, J.V. Narlikar and V. Sahni. The coordinator of this workshop was N. Dadhich.

Introductory School on Astronomy and Astrophysics

The School of Physical Sciences (SPS), Swami Ramanand Teerth Marathwada University (SRTMU), Nanded organised an Introductory School on Astronomy and Astrophysics, sponsored by IUCAA, during November 16-20, 2000. Thirty two students of graduate and post-graduate classes from various colleges in Maharashtra and Andhra Pradesh and twenty local students of the SPS participated in the school.

Lectures were delivered by J.V. Narlikar, S.N. Tandon, U.C. Joshi, V.B. Bhatia, M.L. Kurtadikar and the faculty members of the SPS, including Suresh Chandra, A.L. Choudhari, M.K. Patil and A.C. Kumbharkhane. The topics covered in the school were (i) Coordinates and time, (ii) Photometric studies, (iii) Radio astronomy and molecules, (iv) Stellar structure and evolution, (v) Cosmology and (vi) Astronomy in India.

Besides the lectures, there were extensive programmes for night observations, with two 8" Meade telescopes. The night observations were supervised by J.V. Narlikar, S.N. Tandon, U.C. Joshi, V.B. Bhatia, Suresh Chandra, A.L. Choudhari, M.K. Patil and A.C. Kumbharkhane.

On November 17 evening, on the demand of the participants, a special question-answer session was organised, in which the questions were answered by J.V. Narlikar, S.N. Tandon, U.C. Joshi, Suresh Chandra and M.K. Patil. S.N. Tandon, IUCAA and Suresh Chandra, SRTMU, Nanded, were the coordinators of the school.

Workshop on Solar Physics

A workshop on Solar Physics was organised at IUCAA during December 4 - 8, 2000. It brought together several people working on this area in India and lectures were pedagogical reviews of the respective fields of interest. There were lectures on Overview of Solar Physics, Instrumentation and Observational Techniques related to Solar Astrophysics, Solar Activity, Solar Magnetic Field, Solar Interior and Seismology, The Physics of Chromospheres and Coronae, Solar Chromosphere and Corona and Aspects of Solar Wind and the Radio Sun.

Participants of the Workshop on Solar Physics

The lectures were delivered by S.M. Chitre (TIFR, Mumbai), Arvind Bhatnagar (USO, Udaipur), S.S. Hasan (IIA, Bangalore), P. Venkatakrishnan (USO, Udaipur), H.M. Antia (TIFR, Mumbai), A. Ambastha (USO, Udaipur), Peter Ulmschneider (University of Heidleberg, Germany), B.N. Dwivedi (BHU, Varanasi) and P.K. Manoharan (RAC, TIFR, Ooty). There were about 12 participants from universities besides the lecturers.

The workshop was organised by T. Padmanabhan, IUCAA in consultation with H.M. Antia, TIFR, and Arvind Bhatnagar, USO.

Indo-French School on Star Bursts and the Structure and Evolution of Galaxies

An Indo-French school on Star Bursts and the Structure and Evolution of Galaxies was organized at IUCAA during December 12 - 20, 2000. The school was sponsored by the Indo-French Centre and was part of the activity to build collaborations between astronomers in the two countries. Senior scientists and research students from France and India participated in the workshop. There were a number of lectures on observational and theoretical aspects of the influence of star bursts on the formation and nature of galaxies. The school included lecture

Participants of the Indo-French School on Star Bursts and the Structure and Evolution of Galaxies courses and seminars by senior French and Indian astronomers. There were a number of discussions and short presentations by research students. The coordinators of the school were A.K. Kembhavi from IUCAA and Bruno Guiderdoni from Institut d'Astrophysique, Paris.

Observing with IUCAA Telescope

A workshop on Observing with IUCAA telescope was held in IUCAA during December 21-23, 2000. The main purpose of this workshop was to (1) discuss various observing programmes to be undertaken with IUCAA telescope, (2) introduce the details of Telescope/site/first light instrument/software for observing, etc., to the potential users from the university sector, (3) review the potential research problems that could be addressed with a 2m class telescope and (4) to plan for the next set of instruments. The workshop was attended by 30 participants from universities, research institutes and IUCAA. Visits to the instrumentation laboratory and IUCAA telescope site at Girawali were arranged as a part of this workshop. R. Srianand was the coordinator of the workshop.

Seminar on The Information Age: Challenges and Opportunities for the Library Profession

A one day seminar on The Information Age: Challenges and Opportunities for the Library Profession was organized at IUCAA on December 26, 2000. Kindly refer the Facilities section in this Annual Report for further details of this seminar.

Second Level, 1st Workshop on Astronomical Photometry

A second level workshop on astronomical photometry was organized in IUCAA during January 7-19, 2001, for those who participated and made their own photometers in the first level workshop.

The aim was to refresh the knowledge of the participants and to check out if their photometers were working to the satisfaction. Hands on experience on taking observations were also planned during this period.

S.N. Tandon, R. Gupta and Y. Wadadekar addressed the participants. Vilas Mistry checked the photometers and carried out repair works when necessary. The participants were also taken to a small town, called Wai, about 100 kilometers south of Pune, for extinction measurement exercise.

The workshop was organized by R. Gupta and A. Paranjpye.

Workshop on Astronomical Photometry and Spectroscopy

A five-day workshop on Astronomical Photometry and Spectroscopy was held in the Department of Physics, Bangalore University during January 8 - 12, 2001. Around forty college and university teachers and research scholars participated in the workshop. While the major sponsor was IUCAA, Bangalore University also provided funds and infrastructural facilities for the workshop.

The workshop was inaugurated by K. Siddappa, the Vice-Chancellor of Bangalore University. Resource persons drawn from IIA, IUCAA, Delhi University and Bangalore University delivered lectures on various theoretical and observational aspects, such as radiation fundamentals, time scales and coordinate systems, stellar photometry, variable stars, interstellar medium, star formation, stellar evolution, spectral classification, spectral widths, solar spectroscopy, spectrophotometry space-based astronomy, etc. Practical sessions in the use of photometers and telescopes were held during three nights. A special lecture on "Particles and the Universe" was delivered by P.I.P. Kalmus, visiting professor from Queen Mary College, London University on 11th January.

A booklet containing the abstracts of the lectures was distributed to the participants before the commencement of the workshop. Photocopies of lecture transparencies were also handed over to all the participants for further studies.

Ranjan Gupta was the IUCAA coordinator and B.A. Kagali was the workshop convener at Bangalore University.

Participants of the workshop on Astronomical Photometry and Spectroscopy

Young Astronomers' Meet 2001

The seventh Young Astronomers' Meet (YAM) was held in IUCAA during February 7-10, 2001. YAM serves as a unique forum for research students in the country, working in Astronomy, Astrophysics, and related fields, to interact and present their work. YAM activity was initiated in 1992, and the first YAM was held at NCRA. To create facilities for interaction amongst students working in similar fields, and initiation of possible research collaborations are the prime aims behind holding YAM.

This YAM was co-sponsered by DST, IUCAA, and NCRA, and was organised by the research students of IUCAA. The schedule included talk and poster presentations by participants, and special lectures by A.K. Kembhavi on "Observations and Theory: Either, Neither or Both", and by R. Nityananda titled "Lies, Damn Lies, and Statistics". On the last day, a trip to GMRT was arranged, where G. Swarup introduced the telescope/radio astronomy to the participants.

Following topics were covered in this YAM: Astronomical instrumentation, Astroparticle physics, Cosmology, Compact objects/Accretion phenomena, Galactic and extragalactic astronomy, General relativity and gravitation, High energy astrophysics, Interstellar medium, Solar astronomy and Stellar astronomy. YAM was organised by the research students of IUCAA.

Participants of the Young Astronomers' Meet

Public Outreach Programme

(I) National Science Day

On the first National Science Day of this millennium, February 28, 2001, IUCAA buildings and facilities were kept open to the public, with special added attractions. As always the event drew huge crowds, and participation by students and public was very enthusiastic and gratifying.

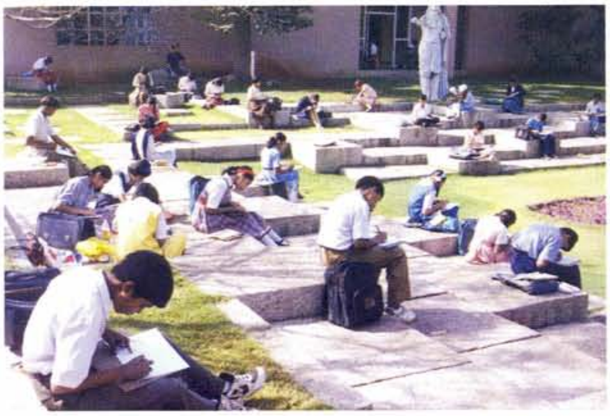
Following the pattern set over the last several years, this year too the events comprised of three main activities:

Competitions for school students: Quiz, essay and drawing competitions were organized for high school students. Seventy-five schools sent teams of five students each for entry to the competitions. The star attraction was the quiz, in which a team of three students from each school participated.

After the elementary round in the morning, the finals were held in the afternoon. The quiz had questions from different scientific fields with some emphasis on astronomy. In the essay competition one student from each school was asked to write on one of several exciting topics selected by a panel. The drawing competition too was similarly conducted. It was very interesting to watch students giving free rein to their imagination, drawing while seated here and there on the IUCAA lawns. The prizes were given away by T. Padmanabhan.

Arvind Gupta, freelance science educator from Delhi, gave a talk to school teachers on his techniques of teaching science to students through very simple, low cost demonstrations. His demonstrations to the teachers and later to students proved to be very popular. Arvind Gupta continued his demonstrations when the public in large numbers came in during the afternoon. V. G. Gambhir and his team from Homi Bhabha Centre for Science Eductaion (HBCSE) in Mumbai trained, on February 27, large team of 8th standard students from Jnana Prabodhini Prashala

Having fun with Science!



Mixture of academic and natural surroundings adds to their imagination

to provide scientific demonstrations using equipment brought by the HBSCE. These forty young ladies were very confident, accurate and efficient in explaining the experiments to students as well as other visitors to the open day. This speaks highly of the teaching methods being propagated by the HBCSE. The Focault pendulum was explained to visitors with the help of a simple demonstration by Dilip Sathe.

An history teacher, who substituted for a science teacher who took ill, commented that she found the lectures, demonstrations, exhibits and the overall programme very understandable. She said that she was glad that she had come, in spite of her initial reluctance to accompany her team of students to a science event.

Programmes for the general public: General Public were invited to visit the IUCAA premises on the National Science Day between 3 p.m and 7 p.m. The visitors were able to move through the IUCAA campus and become acquainted with the state-of-the-art astronomical work being done there. A highlight of this programme was an exhibition of astronomical photographs by David Malin, given to IUCAA by the British Council. These photographs were exhibited along with some additions from IUCAA's own collection. Guided tours of the exhibits were provided to visitors.

The research and developmental work going on at IUCAA was presented through two thematic displays, one on the IUCAA Optical Telescope and the other on the Universe on Different Scales. The displays provided brief exposures to the importance of these areas and pointed out the contributions being made by astronomers at IUCAA. The displays were explained to the public by students and postdocs from IUCAA.

Two public talks were organized in the Chandrasekhar Auditorium. S.N. Tandon spoke (in Hindi) on Energy from Sun, while R. Srianand talked (in English) on Temperature of our Universe - A few Billion Years Ago. Later, A.K.

Kembhavi answered questions on astronomy, posed by students and other visitors, in Marathi and English.

Sky Watch: A major attraction of the National Science Day was the night sky observation with small telescopes, all of which were actually built by amateur astronomers using IUCAA facilities. Each observing session was preceded by talks on telescopes and observing techniques. Vineet Kulkarni gave two talks on meteor showers, Prakash Tupe conducted a slide show based on Power of Ten and Yogesh Wadekar talked on Astronomy with CCD.

Ajit Kembhavi, Arvind Paranjpye and Vinaya Kulkarni provided the overall organization of the National Science Day.

Award winners

Essay Competition (Marathi language):
1st: Mukta M. Gundi, N.M.V, .Girls' High School.
Honorable mention: Shruti S. Joshi, Ahilyadevi High School for Girls & Varada Dandekar, Garaware High School & Jr. College

Essay Competition (English language)

Looking at the beautiful planet with a ring. This three year old is hardly likely to believe that the planet will have a bad effect on him.

The proud winners with their mentors and T. Padmanabhan (IUCAA)

1st: Niranjan Khaire, St. Ursula High School
2nd: Ruch Karkarey, Symbiosis Secondary School.
3rd: Samir S. Patil, Vikhe Patil Memorial School.
Honorable mention:
Shustri Date, S.P.M. English School;
Trushna Krishna, St.Joseph's High School,
Dhruva Chandran, Loyola High School & Jr. College
Yamini Naik, Vidya Bhavan.High School

Drawing competition
1st: Sanket Dhanorkar, Abhinav Vidyalaya High School. (English medium)
Neha Ravikiran Gugari, Jnana Prabodhini Prashala.

Quiz competition
1st
Tejas Kulkarni, Sudeep Pradhan, Mohini Rahalkar
Pandit Rao Agashe School;

2nd
Devendra Damle, Anirban Gupta, Alok Paranjape
Symbiosis Secondary School

3rd
Saurav Swapan Chandra, Pooja Arvind Patel, Pranav V. Soman
Vidya Pratisthan's English Medium School.

N.C.Rana Memorial Trophy for All Round Performance - Symbiosis School.

(II) Programmes for School Students

(a) School Students' Summer Programme 2000

The School Students' Summer Programme was held from April 10 to May 19, 2000. Invitation for participation tothis programme was sent to all the schools in Greater Pune and the schools were requested to nominate two students from 8th or 9th standard. Seventy five schools responded to our invitation. A batch of 28 students was invited to work at IUCAA from Monday to Friday each week for 6 weeks. Sub-groups of 4 to 6 students were

Some of the participants of the School Students' Summer Programme 2000

formed from this batch and each sub-group worked under the guidance of a member of IUCAA. No set syllabus or course guideline was made for this programme. The students and the guide worked out the schedule for each week. The students also had a free access to the IUCAA library. In addition to their programme with the guides, some common activities were also planned for them. They were shown scientific films, a lecture was arranged and they were taken to the Science Park. A question and answer session was also conducted for the students with Jayant Narlikar answering their questions.

On Thursday, May 4, at 2 p.m., a 14" telescope and a CCD camera which is halfway across the world in California, was operated through the Internet in the presence of that week's school students and several members of IUCAA. This innovative telescope was made by a group called TIE (Telescope in Education) at Mt. Wilson. Using an interface supplied by the Mt. Wilson group, it was possible to move the telescope to several targets, take exposures with a CCD camera, and download and display the images in real time. The objects observed were M87, M83, M51, M101, etc.

This was the beginning of a collaboration between IUCAA and the Outreach group at Mount Wilson to use telescopes at each others' institutions for "daytime observing". The terminology arises from the fact that when it is daytime (2 p.m.) here, it is about 1 a.m. at Mt. Wilson, California, USA.

On Fridays, the students were asked to give an oral presentation of their work, in addition to submitting a report of their work. Based on last year's experience, the students were given instructions on how to present their work.

Those who contributed to this programme by guiding students were Tarun Saini, Yogesh Wadadekar and S. Shankarnarayanan (Research Scholars); Subhash Karbelkar (Associate); Firoza Sutaria, Arun Thampan, Sushan Konar (Post-Docs); Ranjan Gupta, Somak Raychaudhury, S.N. Tandon, Jayant Narlikar (Faculty); V. Chellathurai, Dhananjay V. Gadre (Scientific staff) and Vinaya Kulkarni (Science Popularization Laboratory). Arvind Paranjpye was the co-ordinator of this programme.

Some of the projects undertaken by the students were - Rotation of the Earth : Foucault's pendulum, Measuring time: Samrat Yantra, the sun dial, Solar system, Astronomy and Astrophysics: Kepler's laws, calculating masses of planets, law of gravitation, scale model of the solar system, Doppler effect, luminosity and temperature, Hubble's law, Understanding paradoxes : Olber's, Achilles and a tortoise, Mathematics: Non - Euclidean geometry, Combinotrics, works of Fermat, Pascal, Gauss, Riemann, discovery of calculus - Newton and Leipeniz, Computer Programming : understanding and writing computer programme, Evolution of life: Darwin's theory. Most of the students also read introductory books in astronomy.

Gilber Clark, Director of the TIE project, is the brain behind the "web-driven" telescope. He has received many awards in the last three years, including the NASA Exceptional Achievement Medal and the Rolex Award for Enterprise for Applied Science and Invention. We acknowledge his kind cooperation in giving us the telescope time. We also thank Steve Goldent, Mary Cragg and Gary Creason of TIE, and Sarah Ponrathnam, Vijay Upreti, Sunu Engineer and Vinaya Kulkarni at IUCAA for their help in remote viewing through telescope possible.

(b) Lecture Demonstration

Since 1993, IUCAA has been organizing lecture demonstration programme for the students of standards VIII to X. This programme has been very popular and successful. Since 1998 there has also been a similar programme for students of class XI and XII. Normally the topics of the lectures are related to astronomy and astrophysics but occasionally we have invited speakers from other branches of science. When there is a major scientific discovery or event, some speaker is invited to address the issue. Accompanied by their teacher, the students are allowed to visit our Science Park and Devayani complex to see the Focault's pendulum.

Lectures are given separately in English and Marathi for students upto the X standard while lectures for the senior students are only in English. During the period of the report, 11 lectures were given in English, 5 lectures in Marathi and about 7400 students have attended the programmes. The list of lectures were:

For High School Students (Classes VIII - X)
[Every speaker delivered lecture in Marathi and then in English]

J.V. Narlikar (IUCAA)
A view of the universe from space, July 8.

D. Deobagkar (Biology Department, University of Pune)
Human genome mapping, August 21.

S. Padhye (Department of Chemistry, University of Pune)
Magic of chemistry - From chocolates to fullerenes, September 9.

P. Gothoskar (NCRA)
History of longitude, December 9.

A. Paranjpye (IUCAA)
Kitchen scientist, February 10.

For Students of Jr. College (Class XI - XII)
[These lectures were only in English]

J.V. Narlikar (IUCAA)
Some tales of how physics and mathematics have helped astronomy, June 24.

S. Raychaudhury (IUCAA)
Science in space - The next generation, July 22.

R. Gupta (IUCAA)
Astronomical telescopes - Eyes of astronomers, August 26.

S. Karbelkar (IUCAA - Visiting Scientist)
The proton (In search of democritus's atmos), September 23.

R. Nityananda (NCRA)
Clocks and timekeeping - Yesterday, today, tomorrow, October 21.

S.V. Dhurandhar (IUCAA)
The story of gravity, January 27.

(III) Other Programmes

(a) Public Lecture

A special public lecture by Jean-Pierre LUMINET on "The Shape of the Universe" was organized on October 11, 2000. This was jointly organized with Alliance Francaise de Poona .

(b) Live Introduction to the Night Sky

IUCAA in association with All India Radio (AIR), Pune had introduced last year, a live radio programme 'Akashdarshan - An introduction to the Starry Heavens". This has become a very popular programme. It reaches listeners within a radius of about 150 kilometers with centre at Pune. During this programme, listeners were invited to get acquainted with the stars with Arvind Paranjpye giving a live commentary. IUCAA also distributed free star maps made for that night's programme. The first programme of the season was broadcast on December 14, 2000 and the last one on March 15th (this was conducted by Vinaya Kulkarni).

(c) 150th Anniversary of First Public Demonstration of Foucault's Pendulum

On March 26, 1851, Leon Foucault, a physicist and 'machanician' (as was called) gave the first public demonstration at Pantheon dome, Paris that the earth rotates. To commemorate the 150th anniversary of that occasion, IUCAA gave free access to the public on March 26, 2001 to see the Foucault's Pendulum that was in its premises. About 800 people turned up to get a feel of the motion of the earth without looking at the heavenly bodies.

This pendulum was 'set to motion' by eminent astrophysicist and Noble Laureate Professor S. Chandrasekhar on 28th of December 1992 as a symbolic gesture of dedication of IUCAA to the nation.

(d) Programme for Amateur Astronomers

The making of small telescope (6 inch aperture) by amateur astronomers in the science laboratory continues. One engineering student Amit Chaphalkar has undertaken making the job of 8 inch telescope with equatorial mount with fine motion corrections. Vinaya Kulkarni is guiding him.

(e) Observing Meteor Showers

Regular meteor shower observing activities continue with amateur astronomers participating in observing Leonids and Geminides. This year had been bad for meteor shower observations as most nights got clouded out. But the predictions of better Leonids activity for November 2001 and 2002 have drawn more amateurs to this activity.

(f) Occultations

After successfully inducing amateur astronomers in taking the meteor shower observations, Arvind Paranjpye has now started training amateur astronomers in taking occultation observations. Amateurs were encouraged to time lunar occultations using their small home made telescopes. He also made attachment for using a simple PC based CCD (movie) camera for recording occultations.

On the night of March 15, 2001, occultation of 8.7 magnitude star HIP 66446 (SAO 120035) by asteroid 423 Diotima was successfully recorded. The event was particularly favourable, as it had relatively wide path (about 200 km), the event took place (for the location of observer) at small zenith distance and about 60% illuminated moon was about 55 degrees from the star and the minor planet. A Compustar C14 (14 inch Shmidt-Cassigrain) telescope with web camera (Logitech QuickCam) attached to PIII computer was used for recording the event. One C8 telescope and one 6 inch home made telescope was used for visually timing the event.

The team consisting of amateur astronomers Hrishikesh Kulkarni, Prakash Nitsure, Mayuresh Prabhune, Tushar Purohit and Kiran Shah was lead by Arvind Paranjpye. Vinaya Kulkarni was the contact person for control and information exchange.

The team who carried out successful Asteroid Occultation

Facilities

(I) Computer Centre

The IUCAA Computer Centre continued to extend state of the art computing facilities to the members of IUCAA, as well as its visitors from the universities and institutions within India and abroad.

During 2000-2001, a high end compute server DS20E from Compaq with dual processors, 2.8 GB RAM and 152 GB hard disk was acquired to meet the high end computational requirements of our users. We have also procured the mathematical package MATLAB and upgraded MATHTENSOR software.

Recently, a mirror site of Astrophysics Data System (ADS) has been set up at IUCAA in collaboration with Harvard-Smithsonian Center for Astrophysics, Cambridge, Massachusetts, USA. IUCAA is one of the nine worldwide mirrors of the original site ADS. IUCAA's ADS site can be accessed from http://ads.iucaa.ernet.in.The main resource of ADS is its collection of abstracts of papers in the fields of astronomy, astrophysics, instrumentation, physics and geophysics.The service also provides links to scanned images of over 160,000 journal articles. This is the second mirror site after VizieR.

The infrastructure of ERNET Network Operation Centre (NOC) at IUCAA has been recently upgraded to meet the ISP (Internet Service Provider) standard. The new upgraded setup includes two ES40 high-end alpha servers with alpha RAID storage system; Cisco routers 7507, 7206 with redundant CPU and power supply for WAN and leased line connectivity; Cisco RAS 3660 for dial-up PPP and UUCP connections; two Cisco PIX firewall (hardware) for security and 10 KVA redundant UPS (Uninterrupted Power Supply).

The IUCAA computer centre continues to provide support to university departments and colleges for configuring networks, obtaining hardware and software, setting up applications and training personnel.

(II) Library and Publications

The IUCAA library added 246 books and 200 bound volumes in the period under review. The total collection amounts to approximately 16,800. The library caters to the needs of the inhouse academic community, as well as visitors coming to IUCAA.

In the period under review, duplicate issues of books and journals received by the IUCAA library from K. Krishnaswamy, TIFR, Mumbai were transferred to IRC, North Bengal University as well as School of Studies in Physics, Pandit Ravishankar Shukla University, Raipur, with a view to strengthening the collection there. The IUCAA library has also initiated a proposal with the American Institute of Physics to avail online access to the journals being published by American Insitute of Physics as well as the American Physical Society for the IRCs through the dial-up connection. These titles include: Astronomy Letters, Astronomy Reports, Journal of Experimental and Theoretical Physics, Journal of Mathematical Physics, Physical Review D, Physical Review Letters and Reviews of Modern Physics

The IUCAA library is a member of the Forum for Resource Sharing in Astronomy (FORSA), which has been established by astronomy librarians in 1979. The participating libraries are eight scientific institutions in India (IIA, Bangalore; IUCAA, Pune; NCRA, Pune; CASA, Hyderabad; PRL, Ahmedabad; RRI, Bangalore; TIFR, Mumbai and UPSO, Nainital), in which astronomy is a major research area. It was decided to merge the databases of each library into an integrated catalogue. For this purpose, the IUCAA library has recently acquired the SLIM MARC export utility for the purpose of exporting its data and the work is in progress.

A one day seminar on "The Information Age : Challenges and Opportunities for the Library Profession" was organized at IUCAA on Tuesday, December 26, 2000. The seminar was inaugurated by J.V. Narlikar, Director, IUCAA. The various topics covered were as follows: Library profession in the new millennium: Meeting the challenge (Maya Avasia, TIFR, Mumbai); Impact of the INTERNET on the organization and the services of Library and Information Centres (A.C. Tikekar, Mumbai), Impact of information technology and the changing roles of the library professions in the world of information in India (S.N. Singh, NIV, Pune); Future role of the IUCAA library in web-based astronomy education (T. Padmanabhan, IUCAA); Libraries for the Universities : Help from the INTERNET) (A.K. Kembhavi, IUCAA); Need for continuing professional/technology related education (M.B. Konnur, Pune). A total of 50 librarians attended the seminar.

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 laboratory has facilities for the design, construction, and testing of the instruments for optical observations. During this year, the following accessories were developed for the IUCAA Telescope:

a) Dome Position Controller: In order to keep slit of the dome (through which telescope sees the sky) along axis of the telescope, a azimuth-position controller has been developed by S. Engineer, D.V. Gadre, R. Kharoshe, A. Kohok and S.N. Tandon. This controller receives the desired azimuth-angle from the telescope, and rotates the dome to this position.

In this controller, position of the dome is measured by a multi-turn angular encoder coupled to shaft of one of the twelve wheels on which the dome rotates, the current position is compared to the desired position, and based on this comparison the motors (which rotate the dome) are energised for an appropriate duration of time; this cycle, of comparing the positions and energising the motors, is repeated till the current position matches the desired position within a specified error-band; the error-band is specified as a space angle, and therefore, a larger error-band is allowed in azimuthal angle for small zenith angles of the telescope.

b) A Multi-motor Controller: As most of the instruments require motions of components, e.g. placing a particular filter in the beam, a motion controller has been developed by D.V. Gadre and R. Kharoshe, which can control up to six stepper motors. This controller can be placed on the telescope and linked to a computer through a serial link.

Observation with the IUCAA 16" Telescope

Small aperture telescopes can effectively be used for training projects for the graduate and under-graduate students as well as to carry out serious research on relatively bright variable stars.

IUCAA has acquired a few small telescopes to server these purposes, of which one with the largest aperture is a computer controlled 16" Meade telescope equipped with an SSP-3A photometer, ST-7 CCD camera, SLR camera and a simple spectrograph. The telescope is installed on a terrace in IUCAA, and in spite of the bright night sky in Pune, can be put to good use. It is used by project students, M.Sc. students from various univerisities, as well as by graduate students from universities working on variable stars.

During the period covered by this report, the telescope has been extensively used by Sudhanshu Barway, a research student from Pt. Ravishankar Shukla University, Raipur, for photometric observations of some chromospherically active stars which form an important part of his Ph.D. programme. He has discovered three relatively long period and one moderate period chromospherically active stars during the course of the observations. He has also carried out observations to study the sky conditions at IUCAA. Biman Jyoti Medhi, a Ph.D. student from Guwahati University, has monitored some RS CVn and W Uma type variable stars using the 16" telescope.

A group of five M.Sc. (Physics) students from Mumbai university have used the 16" telescope as part of the observational programme associated with their special papers in astronomy. The telescope has also been used by several amateur astronomers.

(IV) The IUCAA Telescope

As reported in earlier annual reports, IUCAA is setting up a 2 m telescope for observations in the optical and near infrared bands. The telescope is being supplied by the Particle Physics and Astronomy Research Council of UK. The telescope has an alt. - azimuth mount, and a f/10 Cassegrain focus. A corrector provides a large field of 40 arcmin. diameter with sub arcsecond images in the optical band, whereas the uncorrected field gives sub arcsec. images up to a radius of 10 arcmin.

The telescope has been assembled at the factory in Liverpool, UK and is undergoing the final performance tests; it is expected that the telescope would be ready for shipping by July, 2001.

The observatory, at a site about 80 km from IUCAA, has two main buildings: a telescope enclosure and a service building. In order to minimise thermal perturbations of the telescope enclosure, ambient air is sucked through it and let out in the service building which is located about 80 metres away. The buildings are ready and the dome is being installed.

It is expected that the telescope would be installed soon after the monsoon and would be ready for observations before end of the year 2001.

A brief description of the instruments being developed for observations with the telescope can be found under the head Instrumentation in the section on Research at IUCAA.

IUCAA Reference Centres (IRC)

1. North Bengal University (Coordinator: S. Mukherjee)

The IRC at North Bengal University, which started functioning at the end of the year 1999 underwent some significant developments during the year 2000-2001. The library of IRC received some books and Journals from IUCAA, as well as from some individuals. Internet facilities were made available to the users, mostly college and university teachers. The centre acted as the nucleus of a number of collaborative research work covering several fields. A brief summary is given below:

Some recent techniques of quantum cosmology were used to calculate the probabilities of the creation of an open universe and also of the production of primordial black holes in 3+1 as well as in higher dimensions. A major part of the results have already been published. A detailed study of very compact stars like Her X-1 and SAX1808.4-3658 have been made making use of the general Relativistic solution of Mukherjee, Paul and Dadhich. It has been shown that the model describes realistic stars when equations of states relevant for strange stars and quark-diquark stars are used. The problem of the radiative collapse of a star has also been studied in collaboration with a group of scientists of Natal University. The possibility of constructing a traversable wormhole with the help of a self-interacting scalar field has been studied in collaboration with N. Dadhich (IUCAA) and S. Kar (IIT, Kharagpur). Some experimental work on muon anomaly in ultrahigh gamma ray astronomy has also been completed. Work on Delbruck scattering was continued in collaboration with some faculty members of the University of Pittsburgh.

IRC organised a number of lectures and group discussions and was also a co-organiser of a National Symposium on 'Conceptual Issues in Relativity, Cosmology and Astrophysics' held in the Physics Department of North Bengal University on March 28- 30. The programme included presentation of research papers on conceptual issues, intensive discussions and a special session for post-graduate students.

2. Pt. Ravishankar Shukla University, Raipur (Coordinator : S K Pandey)

The facilities available at the centre have helped the faculty members and research scholars in the University in keeping their research activities alive. The INTERNET facility that has been provided by IUCAA at the centre is used extensively by the researchers here in browsing through important web sites around the globe that helps them in scanning/downloading the articles of their research interest.

D.K. Chakraborty and his research students investigated the projected properties of a family of mass models, which are triaxial generalizations of the modified Hubble model, to gain further insight into the structure and dynamics of elliptical galaxies. This work was published in Monthly Notices (D.K. Chakraborty and P. Thakur, 2000, 318, 1273), and another article has been submitted to MNRAS after revision. Research activities of A.K. Sapre and his group was mainly focussed in the study of QSO-galaxy pairs to examine whether these pairs are physically associated or not. S.K. Pandey along with his students were involved in (a) studying properties of dust in extragalactic environment to examine the nature, origin and evolution of dust in early-type galaxies, and (b) photometric monitoring of chromospherically active stars using small telescopes to investigate short term as well as long term variations of activity in them in the framework star-spot models.

Facilities at IRC were also used by researchers in the department for paper presentation in oral/poster sessions in various national and international conferences. In particular, D.K. Chakraborty and his students presented one paper at the XXIVth General Assembly of IAU held at Manchester during August 7-18, 2000, and two papers at the XXth Meeting of ASI held at Gorakhpur during November 15-18, 2000. S.K. Pandey gave an invited talk on teaching of Astronomy at Pt. Ravishankar Shukla University, Raipur, and he along with his students also presented four papers in the poster session at the XXth meeting of ASI held at Gorakhpur during November 15-18, 2000.

Padmakar Parihar used the facilities to complete his thesis work and was awarded Ph.D. degree by Pt. Ravishankar Shukla University in January 2001. He also made his thesis presentation at the ASI meeting at Gorakhpur and bagged the best thesis award at the meeting.

The centre has been able to attract a few visitors who have shown keen interest in pursuing research work in A&A. Avinash Jadhav, Lecturer in the physics department of Government College Neemuch, Madhya Pradesh, visited the centre a couple of times and has applied for his Ph.D. registration to the University to carry out research work in A&A. Likewise, a couple of past students of the department plan to make use of the facilities at the centre to pursue research work in A&A. A research project entitled "A study of stellar activity in chromospherically active stars" was submitted by S.K. Pandey to CSIR, New Delhi for financial support with the provision of a few research fellowships in order to attract young bright students of the region who for want of financial support are unable to engage themselves in research work.

The centre also made use of visitors to the University (for examination work, etc.) for delivering lectures at the centre. During the year R.V. Gavai (TIFR) gave a series of two lectures on (i) An introduction to particle physics, and (ii) The little bangs of our Universe, during November 8-9, 2000. P. Vivekanand Rao (Osmania University) gave a lecture on "Photometric Observing facilities at Japal-Rangapur Observatory" on January 12, 2001. G.S.D. Babu (IIA) delivered a lecture on "Astronomical observations by the Indian Astronomers in the IXth Indian Expedition to Antarctica" on February 28, 2001 on the occasion of National Science Day. He also gave a popular lecture on "IXth Indian Expedition to Antarctica" at the Media centre of a local press on February 28, 2001.

In short, IRC at Raipur has become a life-line for sustaining the research and other academic activities in the area of A&A in the University, and thus has been able to show some progress in meeting the objectives with which the IRC was established at Raipur.

3. Cochin University of Science and Technology (Coordinator: V.C. Kuriakose)

The library and computational facilities at IRC are being used by the students (P.G. and M.Phil), research scholars and teachers of this department. Teachers and students of neighbouring colleges and universities frequently visit the centre for reference work. The library facilities in the centre have encouraged PG students to give seminars and to do dissertation work in topics related to Astronomy and Astrophysics.

Research studies in different areas are being carried out in this centre. K.G.Arun (M.Sc. Student), Minu Joy and Kuriakose are involved in the studies on Quantun Field Theory in curved spacetime. In collaboration with A.K. Kembhavi (IUCAA), Ravikumar and Kuriakose have started studying galactic image processing. C. Sivakumar, Moncy V. John and K.Babu Joseph are applying stochastic method to study evolution of the universe and related problems. Extensive studies on neural network and its applications to astrophysical problems have been carried out by Ninan Sajith Philip and K. Babu Joseph. Nonlinear Dynamics is another area of research work. P.D. Shaju and Kuriakose are studying fluxon dynamics in Josephosn Junctions. R.Ganapathy, M.N. Vinoj and Kuriakose are studying optical solitons. A.P Jayadevan, Taji Joseph and Ramesh Babu T. have studied meson spectroscopy using relativistic quark model and also studied multiphoton processes in atomic systems. V.Sheeja, K.G. Sandhya, T. Manju and M. Sabir are studying chaotic systems.

IRC is conducting monthly seminars regularly. PG students, research scholars and teachers of various disciplines (both experiments and theory) participate in seminars. This gives an opportunity of fruitful interactions of research workers working in different areas. Seminars were given by T. Padmanabhan (IUCAA): "Cosmology: Status and Future"; J.V. .Narlikar (IUCAA): "The present interesting problems in Astrophysics"; S. Shaji : "Nonlinear optics"; R. Ganapathy : "Role of Stokes parameters in optical fibres"; S.Ramkumar: "Adaptive optics in Astronomy"; T. Manju : "Fractal image coding"; C. Sivakumar: "The standard model and a stochastic approach to cosmology"; C.D. Ravikumar: "Introduction to isophotal analysis of elliptical galaxies"; M.N. Vinoj: "An introduction to nonlinear science and solitons"; K. Bindu.: "Introduction to thin films". On December 14th, in collaboration with Department of Physics, the IRC celebrated "100 years of Quantum theory" by having a one day seminar on "Quantum Mechanics".

T. Padmanbhan and J.V. Narlikar visited this centre in April 2000 and May 2000 respectively. Moncy V. John, Department of Physics, St. Thomas College, Kozhencherri and K. P. Satheesh of Department of Physics, Government College, Kottayam, visited this Centre during March 23-26, 2001 for reference work.

The Twelfth IUCAA Foundation Day Lecture

Democracy and Right to Information

by

Ms. Aruna Roy
(Member, Mazdoor Kisan Shakti Sangathan,
Devdoongri, Barar, Rajasthan)

(Extended Abstract of the talk)

One of the most outstanding collective achievements of post-independent India has been its practice of Democracy. Despite the numerous problems, the obvious shortcomings in practice, and the odds staked against it, India has continued in its general structures, to be a functioning Democracy. The primary reason for this has been the commitment of the people of India, including the poor and the disadvantaged to protecting and widening the scope of democratic practice. With independence, India adopted (without even properly adapting) the Westminster model. Over fifty years of experience, India has not only exposed its weaknesses, but also subjected this model of Parliamentary Democracy to a range of contrary socio-political forces that have endeavoured to manipulate and capture its controls to further their own ends. At the same time, there has been an ongoing effort by groups of poor and disadvantaged people to mould democratic institutions and their mechanisms, so that ordinary citizens have a more meaningful voice in decision-making. The Right to Information campaign in Rajasthan has been one such outstanding illustration of poor and marginalized sections of society creating democratic alternatives, which would be meaningful, not just to themselves, but to Indian conditions as a whole. It is a movement that has offered opportunities to control corruption and the arbitrary exercise of power. More significant, however, has been the formulation of the parameters of the movement as being a first step towards practical and functioning modes of participatory democracy. This lecture will attempt to outline the story and significance of this ongoing people's struggle.

Ever since the formation of the Mazdoor Kisan Shakti Sangathian (MKSS) in 1990 in Central Rajasthan, its members had been struggling to procure for themselves the statutory minimum wage. This was being denied even to workers employed on Government works under the pretext of the workers being lazy and not turning out the requisite quantum of work. The minimum wage struggle inevitably led to two contrary versions of the truth facing one another - one, of the Government and its functionaries, and the other, of wage workers. The collective realization amongst the wage workers that their version would always be considered false until they could access the documents that gave legitimacy to the official version. The specific demand to get photocopies of bills, vouchers and muster rolls of construction works was made in 1994. The official response was that these documents could not be given as they constituted accounts and were, therefore, secret. The members of the MKSS formulated a slogan: Our Money - Our Accounts; made a demand for a legal entitlement to access these records as part of their right to survive and express themselves; and the Right to Information movement was born in Rajasthan.

Continuous frustration with seeking redress from colonial bureaucratic redressal mechanisms also led to a search for platforms of redressal, where modes of participation like the Right to Information could be practiced. Beginning in late 1994, the MKSS organized a series of village based public hearing, where records of development works were read out in public, and people sat together to verify and wherever necessary force corrective action. Very sharp reactions followed from both the bureaucracy and elected representatives, and it became clear that the people's Right to Information could only be obtained with a legal entitlement. Beginning with a day's dharna in the town of Beawar in May 1996, followed by a wide range of groups expressing support to the struggle, the movement spread to the other parts of Rajasthan and India. In late 1996, the national campaign for the people's Right to Information was formed with the twin purpose of advocating legislation for the people's Right to Information, and supporting grass root level initiatives for its use.

In 1997, the State of Tamil Nadu became the first State to pass a Right to Information Law. In the same year, after a 56 days' dharna outside the State Secretariat, the Government of Rajasthan conceded the demand for photocopies of records of development works. In May 2000, the Rajasthan State Legislature passed a comprehensive Right to Information Law. The States of Goa, Karnataka and Maharashtra have also passed legislation, and a Bill has been tabled in Parliament for a central law, which has been referred to a joint select committee of Parliament.

The campaign for effective legislation is important and significant. It is true that most of the laws that have been passed are weak, ineffective, and full of loopholes. However, of equal if not greater importance is the use of Right to Information by citizen groups and the recognition of its potential implications. The continued struggle in Rajasthan has shown, how it is an important first step in convincing citizens that their democratic rights and responsibilities do not end with the vote cast once in five years. Decision making is not the exclusive preserve of elected representatives and the bureaucracy. To convert the loosely used catchwords of Transparency and Accountability into the effective concepts they could be, citizens need to ask questions and demand answers. We need to establish our right to participate in decision making, not just once in five years, but from day to day. It is only when unfettered and informed democratic debate takes place based on open facts and figures, that we can hope to resolve with norms of justice, some of the contentious issues that face us as a nation.

However, participatory democracy will also become an empty slogan unless it is backed by a popular effort to work out its details. The mechanisms and modes of participatory decision making are still to be worked out and institutionalized. In Rajasthan, the platform of public hearings have now been institutionalized with changes in the law and the provision for social audits of all development works in ward sabhas (neighbourhood groups). The Panchayati Raj structure offers possibilities for working out modes of participatory decision making. However, there is no reason to limit such decision making to local self government bodies. A democratic framework requires a continuous process of consultation and debate. Such participation will never be in the interest of the coteries who rule. It is our duty, and in fact, in our best interests as citizens and as a nation to translate it into a working reality. Amongst, the poorest and the most disadvantaged people in Rajasthan have shown us through their struggles that there is much that is possible if we make governance our common concern. They have made it clear that they will not be mute spectators to manipulations in their name. What about the rest of us?

ACRONYMS

ACIGA	:	Australian Consortium for Interferometric Gravitational Astronomy
AIGO 500	:	Australian International Gravitational Observatory
AGN :		Active Galactic Nuclei
BARC	:	Bhabha Atomic Research Centre
BCS	:	Bardeen, Cooper, Schrieffer Theory
BH	:	Black Hole
BHU	:	Banares Hindu University
CASA	:	Centre for Advanced Study in Astronomy
CASS	:	Centre for Astrophysics and Space Sciences
CASPEC	:	Cassegrain Spectrograph
CBI	:	Cosmic Background Imager
CCD	:	Charge Coupled Device
CERN	:	Centre Europeen pour la Recherche Nucleaire
CFA	:	The Centre for Astrophysics (Redshift Survey)
CIRI	:	Central India Research Institute
CMB	:	Cosmic Microwave Background
COBE	:	Cosmic Background Explorer
CSIO	:	Central Science Instruments Organisation
CSIR	:	Council for Scientific and Industrial Research
CWKB	:	Complex Wentzel-Kramers-Brillouin
DD	:	Door Darshan
DSY	:	Department of Science and Technology
EFOSC	:	ESO Faint Object Spectrograph and Camera
ERNET	:	Educational Research Network
ESO	:	European Southern Observatory
ESPEO	:	Ecole Superieure des Procedes Electroniques at Optiques
FRW	:	Friedmann - Robertson - Walker
GMRT	:	Giant Metrewave Radio Telescope
GR	:	General Relativity
HRI	:	Harish Chandra Research Institute of Mathematics and Mathematical Physics
IACS	:	Indian Assocaition for Cultivation of Science
IAGRG	:	Indian Association for General Relativity and Gravitation
IAP	:	Instittue of Astrophysics
IASBS	:	Instittute for Advanced Studies in Basic Sciences
IAU	:	International Astronomy Union
ICGC	:	International Conference on Gravitational and Cosmology
IGM	:	Inter galactic Medium
IIA	:	Indian Institute of Astrophysics
IISc	:	Indian Institute of Science
IIT	:	Indian Institute of Technology
IOA	:	Institute of Astronomy
IRAS	:	Infra-Red Astronomy Satellite
JSPS	:	Japan Society for the Promotion of Science
ISO	:	Infrared Space Observatory
ISRO	:	Indian Space Research Organisation
LIGO	:	Laser Interferometric Gravitational Wave Observatory
LISA	:	Laser Interferometric Space Antenna

LMXB	:	Low Mass X-ray Binaries
MACHOS	:	Massive Compact Halo Objects
NCRA	:	National Centre for Radio Astrophysics
NERIST	:	North Eastern Regional Institute of Science and Technology
NIV	:	National Institute of Virology
NS	:	Naked Singularities
PRL	:	Physical Research Laboratory
QCD	:	Quantum Chromo Dynamics
QED	:	Quantum Electrodynamics
QSO	:	Quasi Stellar Object
QSSC	:	Quasi - Steady State Cosmology
RAC	:	Radio Astronomy Centre
RHIC	:	Relativistic Heavy Ion Collider
RRI	:	Raman Research Institute
SNR	:	Signal to Noise Ratio, Supernova Remnant
TIFR	:	Tata Institute of Fundamental Research
UPSO	:	Uttar Pradesh State Observatory
USO	:	Udaipur Solar Observatory
UVES	:	UV-Visual Echelle Spectrograph
VECC	:	Variable Energy Cyclotron Centre
VJTI	:	Veermata Jijabai Technological Institute
VLT	:	Very large telescope
VSP	:	Vacation Students' Programme
VST	:	Very Large-Survey Telescope
WKB	:	Wentzel-Kramers-Brillouin