IUCAA

INTER-UNIVERSITY CENTRE FOR ASTRONOMY AND ASTROPHYSICS

(An Autonomous Institution of the University Grants Commission)

Annual Report

(April 1, 1999 - March 31, 2000)

Editor

T. Padmanabhan
e-mail : **paddy@iucaa.ernet.in**

Design, Typesetting and Layout

Manjiri Mahabal
e-mail : **mam@iucaa.ernet.in**

IUCAA

Postal Address
Post Bag 4, Ganeshkhind, Pune 411 007, India

Location
Megnnad Saha Road, Pune University Campus, Ganeshkhind, Pune 411 007, India

Phone
(91) (20) 565 14 14

Fax
(91) (20) 565 07 60

e-mail
root@iucaa.ernet.in

Universal Resource Locator (URL)
http://www.iucaa.ernet.in/

HIGHLIGHTS OF 1999 - 2000

This annual report covers the activities of IUCAA during its eleventh year, April 1999-March 2000. 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 12 core faculty members, 10 post-doctoral fellows and 13 research scholars (Ph.D. students). The core research programmes by these academics span a variety of areas in astronomy and astrophysics.

These topics include investigations in quantum gravity, exact solutions in GR, gravitational waves, statistical indicators to discriminate cosmological structures, dynamical aspects of gravitational clustering, physics of the cosmological constant, quasi-steady state cosmology, investigations of the QSO host galaxies and radio emission from quasars, models of AGN, IGM and quasar observation systems, study of gravitational lensing, galactic structure and dynamics, properties of interstellar dust, different aspects of neutron star physics and the development of the necessary instrumentation for the IUCAA Telescope. These research activities are summarised in pages 20-57.

The publications of the IUCAA members, numbering to about 100 in the current year are listed in pages 87-92. IUCAA members also take part in pedagogical activities like lectures, seminars, popularisation of science, etc., the details of which are given in pages 96-108 of this Report.

The extended academic family of IUCAA consists of 94 Associates and Senior Associates, who have been active in several different fields of research. Pages 58-73 of this report highlights their research contributions, spanning quantum cosmological models, quantum field theory, exact solutions to Einstein's equations, alternative theories of gravity, cosmology and very early universe, galactic dynamics, interstellar medium and variable stars, X-ray binaries, neutron stars, solar and planetary physics, stellar and galactic photometry and quasar absorption systems. The resulting publications, numbering to about 60 are listed in pages 92 - 95 of this report.

A total of about 1230 man-days were spent by Associates and Senior Associates at IUCAA during this year. In addition, IUCAA was playing host to about 440 visitors through the year.

IUCAA conducts its graduate school jointly with the National Centre for Radio

Astrophysics, Pune. Among the research scholars, two have successfully defended their thesis and obtained Ph.D. degree from the University of Pune during the year 1999-2000. Summary of their theses appears in pages 74-86.

Apart from these activities, IUCAA conducts several workshops, schools and conferences each year, both at IUCAA and at different university campuses. During this year, there were 7 such events in IUCAA and 6 were held at other universities 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 was a major contributor to the Children's Science Congress which was organized at the time of the Science Congress convened in January at the University of Pune.

These activities were ably supported by the scientific and technical, and administrative staff (19 and 36 in number) who should get the lion's share of the credit for successful running of the programmes of the centre. The scientific staff also looks after the major facilities like library, computer centre and instrumentation lab. A brief update on these facilities is given on pages 116-118 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. (see page 118).

CONTENTS

The Council and the Governing Board

The Council

President

Armaity Desai, (till April 1999)
Chairperson,
University Grants Commission, New Delhi.

Hari Gautam, (from July 1999)
Chairperson,
University Grants Commission, New Delhi.

Chairperson, Governing Board

R.P. Bambah,
1275, Sector 19-B,
Chandigarh.

Members

P.C. Agrawal
Director
National Centre for Radio Astrophysics
Pune.

R.N. Basu
Vice-Chancellor
Calcutta University.

A. Bhanumathi
Andhra University, Visakhapatnam.

Arvind Bhatnagar (from October 1999)
Emeritus Scientist
Udaipur Solar Observatory.

Suresh Chandra
Swami Ramanand Teerth Marathwada
University, Nanded.

N.K. Dadhich
IUCAA.

V.K. Dalela (till June 1999)
Vice-Chancellor
Pandit Ravishankar Shukla University
Raipur.

S.H. Devare
Honorary Professor
University of Pune.

R.P. Gangurde, (from August 1999)
Secretary
University Grants Commission
New Delhi.

Ashok K. Goyal
Hans Raj College
University of Delhi.

K. Babu Joseph
Vice-Chancellor
Cochin University of Science and Technology
Kochi.

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

N. Kumar
Director
Raman Research Institute, Bangalore.

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

N. Mukunda
Centre for Theoretical Studies and
Department of Physics
Indian Institute of Science
Bangalore.

A.S. Nigavekar
Vice-Chancellor
University of Pune.

K.M. Pathak
Vice-Chancellor
Tezpur University.

Nirupama Raghavan (till August 1999)
Director
Nehru Planetarium, New Delhi

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

D.C. Reddy
Vice-Chancellor
Osmania University
Hyderabad.

M.I. Savadatti (from May 1999)
Vir Bhadra Kripa, Navodaya Nagar
Dharwar.

G.D. Sharma,(till July 1999)
Secretary,
University Grants Commission, New Delhi.

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

Ranvir Singh Shastri (from July 1999)
Vice-Chancellor
Pandit Ravishankar Shukla University
Raipur.

M.S.V. Valiathan (till May 1999)
Vice-Chancellor
Manipal Academy of Higher Education

Member Secretary

J.V. Narlikar
Director, IUCAA.

The Governing Board

Chairperson

R.P. Bambah

Members

P.C. Agrawal
A. Bhanumathi
Arvind Bhatnagar (from October 1999)
R.N. Basu
N.K. Dadhich
R.P. Gangurde (from August 1999)
N. Kumar
A.S. Nigavekar
Nirupama Raghavan (till August 1999)
D.C. Reddy
M.I. Savadatti (from May 1999)
G.D. Sharma (till June 1999)
M.S.V. Valiathan (till May 25, 1999)

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
Calcutta.

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

P.C. Vaidya
Gujarat University, Ahmedabad.

Statutory Committees

The Scientific Advisory Committee

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, Bhubaneswar

Franco Pacini
Observatorio Astrofisico di Arcetri, Italy

R. Rajaraman
Jawaharlal Nehru University, New Delhi

Ram Sagar
Uttar Pradesh State Observatory, Nainital

S.K. Trehan
146, Sector 9-B, Chandigarh

J.V. Narlikar (Convener)
IUCAA, Pune

The Users' Committee

J.V. Narlikar
IUCAA (Chairperson)

A.K. Kembhavi
IUCAA (Convener)

N.K. Dadhich
IUCAA

H.L. Duorah
Vice-Chancellor
Gauhati University
Guwahati

Asis Datta
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

The Academic Programmes Committee

J.V. Narlikar (Chairperson)
T. Padmanabhan (Convener)
N.K. Dadhich
S.V. Dhurandhar
Ranjan 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)
N.K. Dadhich (Nominee of the Director, IUCAA)
R.P. Gangurde (Ex-officio Member)
J.V. Narlikar (Ex-officio Member)
O.P. Nigam (Ex-officio Member)
A.S. Nigavekar (Nominee of the UGC)
Nirupama Raghavan (Nominee of the Chairperson, Governing Board)
G.D. Sharma (Ex-officio Member) (till July 1999)
T. Sahay (Non-Member Secretary)

Members of IUCAA

Academic

J.V. Narlikar (Director)
T. Padmanabhan (Dean, Core Academic Programmes)
A.K. Kembhavi (Dean, Visitor Academic Programmes)
J. Bagchi
N.K. Dadhich
S.V. Dhurandhar
R. Gupta
S. Raychaudhury
V. Sahni
R. Srianand
S. Sridhar
S.N. Tandon

Scientific and Technical

T.D. Agarkar (from 12.7.99)
N.U. Bawdekar
S. Bhujbal
V. Chellathurai
P.A. Chordia
H.K. Das
S. Engineer
D.V. Gadre
G.B. Gaikwad
S.U. Ingale
A.A. Kohok (from 12.7.99)
P.A. Malegaonkar
V.B. Mestry
A. Paranjpye
S.K. Pathak
S. Ponrathnam
H.K. Sahu
S. Sankara Narayanan
S.K. Vijaianand

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 (from 11.6.99)
R.S. Jadhav
B.B. Jagade
S.M. Jogalekar
S.N. Khadilkar
S.B. Kuriakose
N.S. Magdum
M.A. Mahabal
D.M. Mathew
S.G. Mirkute
E.M. Modak
K.B. Munuswamy
K.C. Nair
R.D. Pardeshi
R.V. Parmar
B.R. Rao
M.A. Raskar
M.S. Sahasrabudhe
V.A. Samak
S.S. Samuel
B.V. Sawant
A.R. Shaik (till 31.5.99)
S. Shankar
D.R. Shinde
V.R. Surve
A.A. Syed
S.R. Tarphe
S.K. Waghole
K.P. Wavhal

Post-Doctoral Fellows

S.K. Banerjee (till 2.9.99)
S. Bose (till 4.10.99)
S. Konar
A. Mangalam (till 13.8.99)
R. Misra (till 1.9.99)
M. Nouri-Zonoz (till 26.8.99))
B.F. Roukema
F. Sutaria
A. Thampan (from 30.9.99)
R.G. Vishwakarma (from 5.2.2000)

Research Scholars

K. Harikrishna (till 16.8.99)

IUCAA MEMBERS AT A GLANCE

A. Nayeri (till 2.9.99)
A. Pai
A. Peyman (from 16.8.99)
T. Roy Choudhury
N.B. Sambhus
T.D. Saini
A.A. Sengupta (from 20.7.99)
S.Shankaranarayanan
J.V. Sheth
P. Singh (from 2.8.99)
K. Srinivasan (till 6.1.2000)
Y.G. Wadadekar

Long Term Visitors

Suketu Bhavsar

Project and Contractual Appointments

A. Chakraborty (till 30.9.99)
(Project Officer, Instrumentation Laboratory)

T. Deoskar
(Trainee Engineer, Instrumentation Laboratory)

K. James (from 1.2.2000)
(Project Officer, ERNET Project)

R.S. Kharoshe
(Trainee Engineer, Instrumentation Laboratory)

V. Kulkarni (from 16.3.2000)
(Science Popularisation)

Meena D'Sa (from 1.3.2000)
(National Astronomical Olympiad)

V.S. Upreti (from 9.8.99)
(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 Professors

Abhay Ashtekar
Centre for Gravitational Physics
and Geometry
Department of Physics
The Pennsylvania State University, USA

C.V. Vishveshwara
Indian Institute of Astrophysics, Bangalore

Senior Associates

F. Ahmed
Department of Physics
Kashmir University, Srinagar

Z. Ahsan
Department of Mathematics
Aligarh Muslim University

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

M.N. Anandaram
Department of Physics
Bangalore University

R. Bali
Department of Mathematics
University of Rajasthan, Jaipur

A. Banerjee
Department of Physics
Jadavpur University

S. Biswas
Departemnt of Physics
University of Kalyani

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

Subenoy Chakraborty
Department of Mathematics
Jadavpur University

Soumya Chakravarty
Department of Physics
Visva Bharati, Santiniketan

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

S. Chatterji
Department of Physics
New Alipore College

S. Chaudhuri
Department of Physics
Gushkara Mahavidyalaya, Burdwan

M.K. Das
Departmentof Physics & Electronics
Sri Venkateswara College, New Delhi

D.P. Datta
Department of Mathematics
NERIST, Nirjuli

R. Datta
Department of Physics
Bethune College, Calcutta

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

A.D. Gangal
Department of Physics
University of Pune

A.K. Goyal
Hans Raj College
University of Delhi

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

Ng. Ibohal
Department of Mathematics
Manipur University, Imphal

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

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

B.A. Kagali
Department of Physics
Bangalore University

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

R.S. Kaushal
Department of Physics & Astrophysics
University of Delhi

M. Khan
Centre for Plasma Studies
Jadavpur University

P. Khare
Department of Physics
Utkal University, Bhubaneswar

V.H. Kulkarni
Department of Physics
University of Bombay

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

D. Lohiya
Department of Physics & Astrophysics
University of Delhi

G.P. Malik
School of Environmental Sciences
Jawaharlal Nehru University, New Delhi

S. Mukherjee
Department of Physics
North Bengal University, Darjeeling

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

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

U. Narain
Astrophysics Research Group
Meerut College

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

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

S. N. Paul
Serampore Girls' College

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

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

R.P. Saxena
Department of Physics & Astrophysics
University of Delhi

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

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

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

K.Y. Singh
Department of Physics
Manipur University, Imphal

D.C. Srivastava
Department of Physics
University of Gorakhpur

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

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

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

...till June 30, 1999

S. Banerji
Department of Physics
Burdwan University

V.B. Johri
Department of Physics
Lucknow University

K.N. Joshipura
Department of Physics
Sardar Patel University, Vallabh Vidyanagar

S.P. Khare
Department of Physics
Ch. Charan Singh University, Meerut

L.K. Pande
School of Environmental Sciences
Jawaharlal Nehru University, New Delhi

L.K.Patel
Department of Mathematics
Gujarat University, Ahmedabad

S.S. Prasad
Department of Physics
UNPG College, Deoria

from July 1, 1999...

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

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

Jishnu Dey
Department of Physics
Maulana Azad College, Calcutta

Mira Dey
Department of Physics
Presidency College, Calcutta

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

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

Usha Malik
Department of Physics
Miranda House, University of Delhi

P. Vivekananda Rao
Department of Astronomy
Osmania University, Hyderabad

Associates

N. Banerjee
Department of Physics
Jadavpur University

S.P. Bhatnagar
Department of Physics
Bhavnagar University

S. Chakrabarty
Department of Physics
University of Kalyani

K. Desikan
M.O.P. Vaishnav College for Women, Chennai

S. Dutta
Department of Physics & Electronics
S.G.T.B. Khalsa College, New Delhi

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

K. Jotania
Department of Physics
S. Xavier's College, Ahmedabad

T.C. Phukon
Department of Physics
Pandu College, Guwahati

S. Rastogi
Department of Physics
D.D.U. Gorakhpur University

G. P. Singh
Department of Mathematics
Visveswarya Regional College of Engineering
Nagpur

S. Singh
Deshbandhu College
University of Delhi

P. K. Srivastava
Department of Physics
DAV PG College, Kanpur

...till June 30, 1999

Indira Bardoloi
Department of Physics
Handique Girls' College, Guwahati

P. Das Gupta
Department of Physics & Astrophysics
University of Delhi

M.K. Gokhroo
Department of Mathematics
Government College, Ajmer

T. Subba Rao
Department of Physics
Sri Venkateswara University P.G. Centre
Kurnool

Sarita Vaishampayan
Department of Mathematics
North Maharashtra University, Jalgaon

C. Venugopal
School of Pure & Applied Physics
Mahatma Gandhi University, Kottayam

from July 1, 1999...

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

P.S. Goraya
Department of Astronomy & Space Science
Punjabi University, Patiala

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

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

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

A.C. Kumbharkhane
School of Physical Sciences

Swami Ramanand Teerth Marathwada
University, Nanded

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

Lalan Prasad
Department of Physics
Government P.G. College, Haldwani

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

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

The Tenth batch of Senior Associates and Associates of IUCAA, who were selected for a tenure of three years, beginning July 1, 1999

Bindu A. Bambah

Deepak Chandra

Jishnu Dey

Mira Dey

P. P. Hallan

L. K. Jha

A. C. Kumbharkhane

M.L. Kurtadikar

S. K. Pathak

Lalan Prasad

P. Vivekananda Rao

V. O. Thomas

The photographs of the following Senior Associates and Associates from the tenth batch are not available : Arnab Rai Choudhuri; P.S. Goraya; S. N. Hasan; Usha Mallik; K. Indulekha *and* Amitava Sil.

Appointments of the following Senior Associates and Associates from the seventh batch were extended for three years: Zafar Ahsan, M. N. Anandaram, Asit Banerjee, S.P. Bhatnagar, Somenath Chakrabarty, D.K. Chakraborty, Suresh Chandra, Sujit Chatterjee, M.K. Das, Anil D. Gangal, B.A. Kagali, Pushpa Khare, V.C. Kuriakose, Daksh Lohiya, S. Mukherjee, S.K. Pandey, L.M. Saha, L.P. Singh and Ramesh Tikekar.

Organizational Structure of IUCAA's Academic Programmes

The Director
J.V. Narlikar

Dean, Core Academic Programmes
(T. Padmanabhan)

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

Head, Computer Centre
(A.K. Kembhavi)

Head, Library & Documentation
(T. Padmanabhan)

Head, Publications
(T. Padmanabhan)

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

Head, Instrumentation Laboratory
(S.N. Tandon)

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

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

Head, Recreation Centre
(S.V. Dhurandhar)

Head, Guest Observer Programmes
(Ranjan Gupta)

Head, Workshops & Schools
(Ranjan Gupta)

Head, Science Popularization and Amateur Astronomy
(Somak Raychaudhury)

The Director's Report

I am happy to introduce this year's annual report, reflecting IUCAA's continuing activities on various fronts.

This year's Foundation Day Lecture was delivered by Professor P.C. Vaidya (the 'Bhishmacharya' of IUCAA). The text of his lecture is printed in this report. Coming from a born teacher and researcher, the words of practical wisdom interspersed with humour, were well appreciated by the audience, as I am sure they will be by the readers of this report.

The Foundation Day also saw the inauguration of the extension of the Computer Centre and the Instrumentation Laboratory, by Professor R. P. Bambah, the Chairperson of the Governing Board. The extra rooms added (on top of the existing ground floor wings) in the Brahmagupta Block will considerably ease the burden on office space, especially during the rush periods when we have a large number of university visitors.

The progress of the IUCAA Telescope has picked up again, and all being well, we should have the instrument arriving here during the next financial year. In anticipation of this event, work is already in full swing on the site of the proposed observatory. The road leading to the telescope hill is expected to be completed soon and work on the buildings will start immediately after. The observatory will have two buildings, one housing the telescope plus its essential equipment and the other, a service building separated from it by over fifty metres.

As this annual report will show, the small core group of academics at IUCAA are continuing to achieve national and international recognition for their research contributions, as judged by their awards, participation as peers in important international collaborations and invitations to plenary talks in major conferences. Books written or edited by IUCAA faculty members have also been successful.

It is also encouraging that some associates from universities and colleges are taking up programmes in observational astronomy.

Efforts have been on at IUCAA to get more and more academics from the university sector interested in observational optical astronomy through the use of IUCAA's 40-cm telescope. We hope that when the IUCAA 2-metre telescope gets going, we should have a core group of users from universities and colleges.

IUCAA's academic calendar reflects the spectrum of meetings ranging from high research level to introductory pedagogy, all part of our efforts to create and encourage human resources in astronomy and astrophysics. At the school level, the IUCAA programmes of Saturday lecture demonstrations during term time and projects during summer holidays, continue to attract overwhelming response. IUCAA has also been collaborating with other institutions in India in arranging training of school students for the International Astronomy Olympiads. The response and performance of the students have been extremely rewarding.

As in the previous years, the public response to IUCAA's National Science Day activities including Open House, was excellent. The Science Park has added extra dimension to IUCAA's science communication efforts. There are plans for extending the science park to the south side of the auditorium. The Pune Municipal Corporation recognized this effort through a handsome donation of Rs. 5 lakhs to the Science Park on the National Science Day.

IUCAA's rose garden is considered unique in Pune and has attracted many prizes. We are grateful to have guidance from the renowned rose expert Mr. Vishnu J. Dhurandhar for planning and maintaining the garden.

It is a pleasure to thank all my colleagues at IUCAA for their devoted efforts to enhance the high standard of its academic work, its scientific facilities, its overall ambience and efficient administration. It is not an exaggeration to say that thanks to the sharing of responsibilities, my work as Director is almost redundant.

Professor R. P. Bambah has been a source of strength through his constant encouragement and guidance as Chairperson of the Governing Board. My colleagues and I look forward to his association in this capacity in the years to come.

This year saw the retirement of Professor (Miss) Armaity Desai as Chairperson, UGC. Both in that capacity and as President of the IUCAA Council, we cherished her backing for all our major programmes. We wish her a long, active and intellectually satisfying life ahead.

Last but not the least, I thank Dr. Hari Gautam, Chairman, UGC, the members of the Commission and the staff for helping out whenever the need arose.

Jayant V. Narlikar

Trophies won by IUCAA Gardens

Awards and Distinctions

S.V. Dhurandhar

Principal V. K. Joag best teacher award, University of Pune, 2000.

J.V. Narlikar

Vidnyanmitra Award from Snehavardhan Prakashan, Pune, for literary work, April 24.

Dnyan Vidnyan Award from Jyeshth Nagarik Sansad, Ahmednagar, for academic work, May 2.

Honorary Professor, Banaras Hindu University, Varanasi.

Prof. (Dr.) M.V. Pylee Award for the Distinguished Academician of India, 1998.

Kolhapur Bhushan Award from the Kolhapur Municipal Corporation, Kolhapur.

T. Padmanabhan

The Millennium Medal, awarded by CSIR, India, during the Indian Science Congress held at Pune during January 3-6, 2000.

The essay *Probing the quantum microstructure of spacetime* received an Honourable Mention in Gravity Research Foundation Essay Contest, 1999.

T. Roy Choudhury

Late Deblina Choudhari Award of Indian Physics Association, Pune Chapter, for best oral presentation by a research scholar.

Varun Sahni

Hari Om Ashram Prerit Dr. Vikram Sarabhai Research medal for the year 1999.

Calendar of Events

1999

April 12 - May 21
School Students' Summer Programme
at IUCAA

April 30
IUCAA-NCRA Graduate School
Second Semester ends

May 17 - June 18
Refresher Course in A & A for College / University Teachers
at IUCAA

May 24 - July 9
Vacation Students' Programme
at IUCAA

August 16
IUCAA-NCRA Graduate School
First semester begins

August 17 - 20
Workshop on New Trends in Near Infrared Astronomy
at Physical Research Laboratory
Ahmedabad

August 26 - 28
Mini-workshop on Gamma Ray Bursts: Status and Future
at IUCAA

August 30 -September 3
Mini-school on Computer Astronomy
at St. Thomas College, Kozhencherry

October 7 - 8
Seminar on 1500 years of the Aryabhatiya
at IUCAA

October 25 - 29
Workshop on Observational Programmes with 2m Class Telescopes
at UPSO, Nainital

October 29 - 31
Workshop on Interstellar Molecules
at Sri Krishnadevaraya University, Anantapur

December 9 - 10
Workshop on Observational Astronomy with Planetariums
at IUCAA

December 17
IUCAA-NCRA Graduate School
First semester ends

December 29
Foundation Day

2000

January 3
IUCAA-NCRA Graduate School
Second semester begins

January 17 - 21
3rd, Level 1 Workshop on Astronomical Photometry
at IUCAA

January 21 - 23
Mini-workshop on Quasar Spectroscopy
at IUCAA

January 28 - 30
International Conference for Science Communicators
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 associates/senior 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

Choice of nothing

It is a well known fact that our knowledge about the fundamental laws of physics becomes more and more uncertain, as we proceed to higher and higher energies. In fact, most of the effort in the microscopic physics is directed at understanding the nature of the laws of physics at high energies. An incredible feature about Nature seems to be that the high energy behaviour of the system does not affect the low energy phenomena. For example, the fact that electromagnetism and weak interactions are unified at energies greater than about 100 GeV is fairly irrelevant to normal electromagnetic phenomena at low energies. A more formal way of understanding these issues is based on the theory of renormalisation group, which is *the* paradigm to interpret standard quantum field theoretic phenomena.

There are, however, some features of high energy physics which does seem to leave a trace in the low energy end. For example, the Pauli exclusion principle — which plays a vital role in low energy structure of matter — is a consequence of relativistic field theory which, by itself, is fairly irrelevant in atomic physics. The importance of such relics of high energy theory lies in providing a glimpse of the unknown territory. This prompts one to ask whether the combining of principles of general relativity and quantum theory could be connected to any feature of low energy physics. In a recent work, *T. Padmanabhan* and *T. Roy Choudhury* have speculated that such a possibility might indeed exist. The relic they have obtained seem to be the very choice of the low energy vacuum state and the definition of a particle.

In non-relativistic Newtonian mechanics, the concept of a free particle moving with uniform velocity presupposes the notion of a preferred time coordinate (except for rescaling and shifting of origin). This feature continues in non-relativistic quantum mechanics of point particle. At the next level, when special relativity is brought in, the choice of time coordinate is somewhat extended to cover all inertial frames. Any further extension — for example, to an accelerated frame — will introduce alternative choices of vacuum state and particles, which will not have the correct limiting behaviour in the Newtonian limit. But in the full description, one certainly needs to introduce gravity and curved spacetime, thereby losing any privileged notion of time. *Padmanabhan* and *Roy Choudhury* argue that the ground state of the full quantum gravitational theory should have a sector which determines the ground state of the low energy matter fields and hence, should determine the notion of a particle at low energies. Since one does not know the full quantum gravitational theory, they investigate this feature by taking a quantum cosmological model and determining the kind of vacuum states for matter fields, which can arise in the low energy. Their analysis shows that the boundary condition for the wave functional of the full theory plays a vital role in determining the nature of the low energy vacuum, there by providing a "relic" of the high energy theory. The implications of this result are under investigation.

Hypothesis of path integral duality: Applications to QED

The mathematical divergences of conventional quantum field were always treated with suspicion by the early workers of quantum gravity - who were essentially general relativists. Most particle physicists started taking gravity seriously only from early 80's when supergravity models came into vogue. From perturbative renormalisability, through perturbative cancellations and finally — in the wake of string theories — at non perturbative regularisation due to a cutoff at Planck energies, the divergences had a chequered history in the hands of particle physicists. Assuming that everyone (including even particle physicists !) agree now that divergences are bad news and are regularised in quantum gravity, it will be worthwhile to see whether one could extract this particular feature of the full quantum gravitational model by some general procedure. *Padmanabhan* and collaborators have been involved in such an approach (described in the previous Annual Report) which seems to hold promise. The previous work based on this approach showed that it is possible to introduce a principle by which divergences can be regularised in a covariant manner.

In the third paper in this series, *S. Shankaranarayanan* and *Padmanabhan* have used the modified propagator for quantum field, based on a principle of "path integral duality" to investigate several results in QED. This principle modifies the Feynman propagator by the introduction of a fundamental length scale. They use this modified propagator for the Dirac particles to evaluate the first order radiative corrections in QED and find that the Planck length acts like a regulator, thereby removing the divergences which otherwise appear in the conventional radiative correction calculations of QED. It is found that all the three renormalisation factors Z_1, Z_2, and Z_3 pick up finite corrections and that the modified propagator breaks the gauge invariance at a very small level of $O(10^{-45})$. The implications of this result to generation of the primordial seed magnetic fields in the universe are being studied.

Probes of the vacuum structure of quantum fields

Padmanabhan (along with L. Sriramkumar) has provided a detailed comparison of different approaches which are currently available in literature to probe the vacuum structure of quantum fields in classical electromagnetic and gravitational backgrounds. They compare the results from (i) the Bogolubov transformations and (ii) the effective Lagrangian approach with (iii) the response of monopole detectors in (a) non-inertial frames in flat spacetime and in (b) inertial frames with different types of classical electromagnetic backgrounds. They also carry out such a comparison in inertial and rotating frames when boundaries are present in flat spacetime and find that the results from these different approaches do not, in general, agree with each other. An attempt is made to identify the origin of these differences and to discuss its implications for classical gravitational backgrounds.

A novel approach to particle production in an uniform electric field

Along with *K. Srinivasan*, *Padmanabhan* has outlined a different method for describing scalar field particle production in an uniform electric field. In the standard approach, the (analytically continued) harmonic oscillator paradigm is used for describing the particle production. In the gauges normally considered, in which the four vector potential depends only on either the time or space coordinate, the system reduces to a non-relativistic effective Schrödinger equation with an inverted oscillator potential. The Bogolubov coefficients are determined by tunnelling in this potential. In the Schwinger proper time method for determining the effective Lagrangian, the analytically continued propagator for the usual oscillator system is regarded as the correct propagator for the inverted oscillator system and is used to obtain the gauge invariant result.

There is, however, another gauge in which the particle production process has striking similarities with the one used to describe Hawking radiation in black holes. This gauge, which the authors use to describe the electric field may be called the *lightcone* gauge, so named because the mode functions for a scalar field in this gauge are found to be singular on the lightcone. *Padmanabhan* and *Srinivasan* use these modes in evaluating the effective Lagrangian by the proper time technique. The key feature of this analysis is that these modes can be explicitly normalized by using the criterion that they reduce to the usual flat spacetime modes in the limit of the electric field tending to zero. This normalization procedure allows one to determine the Schwinger proper time kernel without using the analytical continuation of the harmonic oscillator kernel that is resorted to in the standard analysis. They find that the proper time kernel is not the same as the analytically continued oscillator kernel, though the effective Lagrangian is the standard result as it should be.

They also consider an example of a confined electric field system using the lightcone gauge modes and show that the total number of particles (and consequently the effective Lagrangian) is determined by the range of energies for which singularities are present in the system.

Classical Gravity

Electrodynamics from Newton's law of motion and the absence of magnetic charge

In general, the equations of motion of a particle in some field and the dynamics of the field itself are independent. In Einstein's theory of gravitation (general relativity, GR), it is well-known that equations of motion could be derived from the field equation. There is a general feeling that it happens because GR is a non-linear theory. It can be understood by the fact that solution of the Einstein equation determines the geometry of spacetime, which fully imbibes gravitational field in its curvature. Then particle motion under gravity would simply be free (geodesic) motion relative to the curved geometry which is completely determined by the field equation.

This is a very interesting and profound result bringing out one of the key features of gravitational field. Should this be true only for gravitation and not for the other classical field - viz. electromagnetism? This is the question, *Parampreet Singh* and *N. Dadhich* have attempted to address. The background for this is provided by Dyson's paper (Am. J. Phys. **58**, 209, 1990) on Feynman's derivation of the Maxwell equations. Feynman seems to have played with this idea for some time and thought that it may lead to something profound. He considered commutation relation between coordinates and velocities instead of normal conjugate momenta and after some manipulation obtained the Lorentz force law and the two homogeneous Maxwell equations, which imply that the electromagnetic field is curl of a 4-potential. Dyson's paper has given rise to spurt of activity and a number of rederivations and generalizations have been considered. However, all these considerations attempted only to derive the non-dynamical part of the equations.

In contrast, *Singh* and *Dadhich* attempt to derive the entire set of the Maxwell equations. They begin by demanding that the force in Newton's law be linear in velocity and derivable from a velocity dependent potential. This determines that force is of the form of Lorentz force involving a polar and an axial vector, and these vector fields satisfy the homogeneous Maxwell equations.

Now, what remains is to obtain the other two dynamical equations. That they do as follows: First they introduce a scalar and pseudo scalar charge on a test particle and write each vector field in terms a polar and an axial vector, giving rise to four vector fields. The two homogeneous equations, now split into four equations in four vectors, is a highly under determined system and hence cannot be solved. So they assume linear relations between the pairs of polar and axial vectors, reducing the system back to two vector fields satisfying the four equations. These equations turn out to be the entire set of the Maxwell equations. Further, the fact that a test particle should not be able to distinguish between (i) the field produced by a scalar/pseudoscalar charge and (ii) that of a moving pseudoscalar/scalar charge leads to an important result that the two kinds of charges cannot be independent and they must bear a universal chiral relation between them.

Thus, they have obtained the equation of motion for the field corresponding to Newton's law of motion under some natural conditions. Further, it demands that there could exist only one kind of charge; calling it electric is simply a matter of convention.

This is a very satisfying exercise in the overall context of synthesis and unity of physics. What is true for gravity is also true for electromagnetism and so it opens up the road to probe this question for other fields.

Empty space in GR

In the Newtonian theory, empty space is characterized by vanishing of matter density. Its analogue in GR is vanishing of the Ricci curvature tensor. *Dadhich* asks the question: Could we not characterize empty space at least for the simplest case of an isolated body in terms of some "densities"? He looks for the analogue of the density in the Newtonian theory which would be the energy ρ measured by a static observer. As regards massless particles, which can never be static, the density felt by them would be different - say ρ_n. Another density is what a stream of ordinary particles feel which brings them together; this is also different in GR from ρ and is denoted by ρ_t.

The empty space surrounding an isolated body is then characterized by $\rho = 0 = \rho_n$. That is, this condition is sufficient to make all Ricci curvatures zero and it solves to give the unique Schwarzschild solution. Naturally, one would ask what happens when $\rho_t = 0 = \rho_n$ and $\rho = 0 = \rho_t$?

The former leads to the Barriola - Vilenkin solution for a black hole with a global monopole. This was shown by *Dadhich* (see last year's Annual Report) that it is electrogravity dual of the Schwarzschild solution. Under the electrogravity duality transformation, active and passive electric parts of the Riemann curvature interchange, while magnetic part remains unaltered. Under this transformation, $\rho \leftrightarrow \rho_t, \rho_n \rightarrow \rho_n$ which shows that the first and the second conditions are dual of each-other. The dual solution differs only from the Schwarzschild solution by addition of a constant in the potential, which is trivial for the Newtonian theory but not so for GR.

The third possibility also integrates to give the general solution which approximates to the Schwarzschild spacetime at large distance. However, in the near zone, its behaviour is very different as it does not admit a horizon. Thus it is not a black hole though $R = 2M$ is a critical surface, indicating a throat of a traversable wormhole. Further investigation is needed to understand the spacetime fully.

It may be mentioned that, for spherically symmetric spacetimes, all the stresses could be written in terms of these three densities and three momentum densities. For instance, a charged black hole is characterized by the condition, $\rho = \rho_t, \rho_n = 0$ while the de Sitter space by $\rho = const., \rho_n = 0$.

This is a physically illuminating way of looking at the empty as well as the non-empty space. It also leads to a new class of black hole solution in the lower 2+1 dimensional gravity.

The brane new world

Inspired by the work in the string theory, the 4-dimensional world we live in is considered as a (mem) brane embedded in the higher dimensional space. The extra space dimensions were generally taken to be finite in extension and compact. Recently, Randall and Sundrum have considered a 5-dimensional warped space models in which the extra dimension need not be compact. They have shown that it is possible to localize gravity on the brane when there is one infinite extra dimension. In this framework, the matter fields are supposed to remain confined to the brane while free gravitational degrees of freedom could propagate in the extra dimension and back react on the brane to produce extra stresses in the effective Einstein equation to be solved on the brane. The matter distribution in the bulk includes negative cosmological constant and the usual matter fields are confined to the brane.

If matter (without rotation) on the brane collapses under gravity to form a black hole, it should approximate to the Schwarzschild solution in the weak field limit. It should, however, differ significantly in the near zone. The back reaction introduces a trace free stress tensor on the right hand side of the Einstein equation on the brane. *Dadhich*, Maartens, Papadopoulos and Rezania have attempted to find an analogue of the Schwarzschild solution in the brane world.

They have argued that the tracelessness is one condition and only one more condition is needed to completely determine the solution with spherical symmetry. The second, natural, condition could be that the solution admits a horizon to incorporate essential aspects of the black hole. These two conditions interestingly lead uniquely to the solution which has the same mathematical description as the charged black hole in 4-D. Of course, the new parameter here has nothing to do with the "tidal" charge produced by the free gravitational field. It is well-known that this kind of modification of the Schwarzschild solution would add a term which goes as $1/r^2$. The sign of the tidal charge could be positive or negative. In the former case, it would oppose normal gravity while in the latter case it would reinforce it. It could be argued that since gravitational field energy is always negative, tidal charge would be negative and thus reinforce gravity.

This opens up a whole new world for probing. For instance, with enhanced gravity, what would happen to the cosmic censorship hypothesis, black hole thermodynamics, singularity free cosmological models, and so on? Intuitively one would expect the results to favour censorship and disfavour occurrence of non-singular models. It would be interesting to find what exactly happens.

New black holes in 2+1 gravity

In 4-dimensional usual gravity, it has been shown by *Dadhich* earlier that electrogravity dual solutions to the well-known black hole solutions could be constructed by solving the equation dual to the effective empty space equation in terms of densities. These were, however, all either known or similar to the known solutions. In the case of 2+1 dimensional gravity, this method leads to a new class of black hole solutions, which are dual to empty space which is flat. *S. Bose*, *Dadhich* and S. Kar have solved the equation dual to the empty space equation given above and obtained a new multi-parameter families of black hole solutions. Electrogravity duality transformation has thus led to a new class of interesting solutions that includes the well-known Banados - Teitelboim - Zanelli (BTZ) black hole as a special case.

The 2+1 gravity provides an excellent arena for studying quantum effects of gravity in a simplified framework. The gravitational field in 3 dimensions has no dynamics and this is why it implements quantum considerations. The results obtained in this simplified framework would at best be indicative of what one should expect in the full theory of quantum gravity. In the absence of that, it is worth while studying gravity in the lower dimensions so as to gain some useful insight and direction. The famous BTZ solution corresponds to the negative cosmological constant in 3-D. Some other spacetimes have also been constructed but there exist fewer non-trivial solutions in 3-D as compared to 4-D. The reason is the absence of gravitational interaction in 3-D. In here, a spacetime is generally constructed with some physical property in view, say, occurrence of a horizon. It is not obtained by solving any equation, instead one tries to find physical interpretation of the stresses it produces. For instance, note that the equatorial projection of the Schwarzschild black hole is also a black hole in 3-D.

For the new black hole solution, matter distribution that supports the black hole turns out to be a string dust, characterized by its energy density being equal to the radial tension. It would be interesting to study its thermodynamics and quantum emission of particles which would be easier in 3-D than 4-D. In future, they plan to study the particle emission from the new black hole solution and compare it with the well studied case of the BTZ black hole.

Gravitational Waves

The construction of several large-scale interferometric gravitational wave detectors, with optimal sensitivity in the frequency window ~ 10 Hz $-$ 1 kHz is close to completion. For a period extending upto a year, starting from the end of year 2000, engineering data runs will be carried out in order to test and debug the detector components. Finally, between 2002 and 2004, the interferometers will carry out the first set of science data runs with the realistic goal of directly observing gravitational waves (GW). This initial phase will be followed by substantial upgrades in most of the instruments aimed at reaching a better sensitivity and larger bandwidths. The worldwide effort includes the following projects: (i) The Laser Interferometer Gravitational-wave Observatory (LIGO) in the USA consists of two facilities, one at Hanford (WA) and the other at Livingstone (LA), hosting two 4 km and one 2 km interferometers. (ii) The French/Italian project VIRGO, is located at Cascina, near Pisa, Italy, and consists of a 3 km detector. (iii) The German/British GEO600 is a 0.6 km interferometer under construction at Ruthe, near Hannover, Germany. (iv) In Japan, the TAMA project is *currently running* a medium scale interferometric detector of arm length 300 metres, and is planning to extend the baseline to 3 km and to carry out other substantial improvements on the instruments within the next few years. (v) Finally, the ACIGA consortium will build, if funding is approved, a 500 metre interferometer (AIGO500) near Perth, Australia. In the meantime, a number of existing resonant bar detectors are steadily increasing their sensitivity with bandwidths of (~ 1 Hz) in a kHz spectral window. Besides these efforts involving groundbased instruments, there is a mission to fly – possibly by 2010 – a space-borne laser interferometer LISA (the Laser Interferometer Space Antenna) that could open the low frequency window 10^{-5} Hz - 10^{-2} Hz, currently accessible only through the (low-sensitive) technique of Doppler tracking of interplanetary spacecraft.

Building and running such powerful machines represents an enormous enterprise, which has started over 30 years ago. However, analyzing the large amount of data – several Mb per second – and digging out with high confidence astrophysical signals from the noise which severely corrupts the data, present its own challenges. In fact, over the past decade, a new field, that of GW data analysis has emerged and it is now regarded as one of the key aspects for the successful detection of GWs.

Several types of GW sources have been envisaged which could be directly observed by Earth-based detectors: (i) Burst sources – such as binary systems of neutron stars and/or black holes in their inspiral phase, black hole/black hole mergers and supernovae explosions, whose signals last for a time, typically between a few milli-seconds to a few minutes, which is much shorter than the observation period, (ii) stochastic backgrounds of radiation, either of primordial or astrophysical origin, and (iii) continuous wave sources – GWs emitted by rapidly rotating neutron stars – where a weak deterministic signal is present at all times in the data stream.

In this worldwide effort, IUCAA has contributed handsomely in the theoretical aspects of the experiment, especially, in gravitational wave data analysis. This work is of two kinds:

(i) The gravitational wave data analysis of two important astrophysical sources namely that of coalescing binaries and continuous wave sources. The emphasis has been on algorithm development and the aim has been to present strategies which optimally extract the GW signal out of the noise. This not only means extracting the signal with the maximum possible signal-to-noise-ratio (SNR) with minimum errors in the parameters of the signal, but also involves estimating the computational cost and evolving data analysis strategies towards minimising this cost.

(ii) Developing 'data cleaning' methods to remove/identify non-Gaussian noise in the raw data of the detector. The non-Gaussian noise in the data gives rise to major problems for matched filtering methods used for data analysis. An adaptive algorithm has been developed which 'learns' to recognise this noise and then if so desired, remove it.

Also, an IFCPAR (Indo-French Centre for the Promotion of Advanced Research) project has been approved which addresses the data analysis issues concerning the LISA project mentioned above.

(a) Detecting coalescing binaries with a network of detectors: The paucity of gravitational wave sources and the relative difficulty in detecting such waves, as compared to those in the electromagnetic domain, necessitate the development of optimal data analysis techniques to detect the signal, as well as to extract the maximum possible information from the detected signals. Coalescing binary systems are promising sources of gravitational waves, because the inspiral of the binary is easy to model and detection strategies can be developed - matched filtering for instance - which can optimally extract the signal from the noise. As mentioned in the beginning, several large scale interferometers will come on line. The interferometric network at present consists of the two LIGO detectors in the US, the VIRGO in Italy, the GEO600 in Germany, the TAMA300 in Japan and the AIGO500 in Australia. The data analysis problem of extracting signals using a network, is therefore of major importance to the gravitational wave community. *S.*

Bose, A. Pai and *S. V. Dhurandhar* have formulated a strategy based on the maximum likelihood method, which optimally extracts the coalescing binary signal from the network data. Further, using clever techniques, the strategy also saves substantially on the computational cost. In the past, a sizable amount of research has been done on the problem of detecting gravitational waves using a single detector. However, very little work has been devoted towards developing techniques which analyse data from a network. Searching for burst signals using a network is important because of (i) its superior sensitivity as compared to a single detector (ii)extracting more and accurate information about the source, such as its location in the sky, etc. and (iii) discriminating against non-Gaussian noise events which plague the detector. A single likelihood ratio is deduced for the entire network, which is now a function of eight parameters of the signal, namely, the distance to the binary, the initial phase, the polarisation angle, the inclination angle of the orbit, the time-of-arrival at a fiducial detector, the direction angles to the source and the chirp time which depends on the masses of the stars. The formalism developed allows for the analytic maximisation over the first four parameters mentioned above and moreover the Fast Fourier Transform (FFT) can be applied to maximise over the time-of-arrival. The analytic maximisation and the FFT allow not only the continuous scanning of the parameter space over the first five parameters but also save enormously on the computational costs. For the rest of the parameters, a bank of filters is needed. In the simple examples that have been considered so far, the number of filters for a hypothetical network of three detectors widely spaced around the globe is about 10^8 for the Newtonian signal. This number may be deemed to be typical for the real network, say, of the two LIGO detectors and the VIRGO detector.

(b) Continuous wave sources: Continuous wave (CW) sources pose one of the most intensive problems in GW data analysis computationally. A rapidly rotating asymmetrical neutron star is a source of continuous gravitational waves. For the known pulsars in our galaxy, the maximum gravitational wave amplitude can be estimated from the spindown luminosity, which turns out to be three or four orders of magnitude below the broadband sensitivity of the detectors. A long integration time (typically of the order of a few months or years) is needed to build up sufficient signal power before it can stand above the noise. The long integration time in turn implies that Earth's motion is important and modulates the signal, introducing Doppler shifts which depend on the direction to the source. If one desires to coherently extract the signal, the detection problem is complicated by the Doppler effect, which must be first corrected for. For instance, a monochromatic signal with a frequency of 1 kHz from an isolated source can spread into a million Fourier bins if no Doppler correction is applied. However, if one knows the direction of the CW source, but say, not its exact frequency, then the data can be Doppler corrected and a FFT performed to extract the signal. On the other hand, if one does not know the direction and frequency of the source, the computational burden is enormous as one must search over all the directions. In this case, Schutz has estimated that one must search over 10^{13} directions. The problem is made worse, if the intrinsic frequency of the source changes, say, due to spin down, because one would then need to search over the spindown parameters as well. On this background, the problem of the 'blind' search for a CW source orbiting a companion star is simply considered as computationally intractable as the total parameter space would be the product of the individual parameter spaces, which would be extremely large. We can, however, considerably reduce the computational burden,

if the direction to the source is taken to be known, or approximately known (only a few directions to be searched for). Such a situation astrophysically manifests itself in the case of globular clusters in our galaxy some of which contain several binaries $\sim 10^6$, but whose directions in the sky are known. Perhaps a few filters may be needed for a direction search to scan over the cross-section of the cluster. *Dhurandhar* and A. Vecchio (from AEI, Max Planck, Potsdam) have investigated this problem for an intrinsically monochromatic CW source and have estimated the computational costs (a) for the case of circular orbits and (b) for elliptical Keplerian orbits. They find that the costs are comparable to the blind search for isolated neutron stars requiring about 10^{16} filters for the circular case and 10^{21} filters for the elliptic case. For this calculation, the maximum CW frequency to be searched for is taken to be 1 kHz and the maximum radius of the binary orbit to be one million km. They also considered targeted searches for known radio pulsars. For most pulsars, radio observations place tight error bars on some of the parameters. This considerably reduces the volume of the parameter space to be searched over and the cost reduces dramatically. Using the data from the Princeton catalogue for pulsars in binaries, they have made a detailed analysis. For the pulsars that have been discovered long ago, the parameters, such as say, the orbital period, are known very accurately and a search with just a few filters is sufficient. However, for the recently discovered pulsars, the error bars are not very tight and thus the number of filters needed goes up to $\sim 10^{10}$.

(c) Adaptive filtering techniques for the removal of non-Gaussian noise: Gravitational wave detectors produce an enormous volume of output consisting mainly of noise from a host of sources, both environmental and intrinsic to the apparatus. Buried in this noise will be the gravitational wave signature. Sophisticated data analysis techniques have been developed to optimally extract astrophysical data. Many of the techniques developed so far are based on matched filtering and assume stationary Gaussian noise. However, the real data stream from the detectors is not expected to satisfy the stationary and Gaussian assumptions. In fact, the data from the Caltech 40 metre proto-type interferometer has the expected broadband noise spectrum, but superposed on this are several other noise features, such as long-term sinusoidal disturbances emanating from suspensions and electric main harmonics and also transients occurring occasionally, typically due to servo-controls instabilities or mechanical relaxation in suspension system. While no precise *a priori* model can be given for this noise until the detector is completed and fully tested, matched filtering techniques cannot be used to locate/remove these noisy signals. This disparity between standard Gaussian assumptions and real data characteristics poses a major problem for directly applying matched filtering techniques. This is the case when searching for burst sources such as blackhole binary quasinormal ringings and also for inspiral searches in Caltech 40 metre data. One must then introduce a veto on the decision taken. It is possible that in the future, improved experimental techniques and greater experience will reduce or even completely eliminate some of these nonstationary and non-Gaussian features. Nevertheless, it will take probably some time to reach such high quality of data. So at this juncture, it is necessary and desirable to somehow combat this noise. Since such noise features defy modelling, a novel approach to the problem is called for. E. Chassande-Mottin (from AEI, Max Planck, Potsdam) and *Dhurandhar* have proposed a denoising method based on *LMS adaptive linear prediction* techniques which do not require any precise *a priori* information about the noise characteristics. An algorithm is given which separates and ex-

tracts the non-Gaussian noise components from the stationary and Gaussian background noise. The adaptive filter 'learns' to recognise the non-Gaussian features and then if one so desires, remove them from the data. The data is thus 'cleaned' of the non-Gaussian noise, after which standard filtering techniques may be applied to extract the GW signal. The strength of the method is that it does not require any precise model on the observed data: the signals are distinguished on the basis of their autocorrelation time. The robustness and simplicity of this method make it useful for data preparation and for the understanding of the first interferometric data. This method has been successfully tested on the Caltech 40 metre data.

(d) GW data analysis for LISA: The LISA (Laser Interferometric Space Antenna) has now been selected as a corner-stone mission in the ESA Horizon 2000-plus programme. 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 blackhole binaries and coalescences, stochastic GW background from the early universe. The LISA and the ground based detectors complement each other in an essential way. Since both types of detectors have similar energy sensitivities, their different observing frequency bands will provide crucial spectral information about the source. This is as important as complementing the optical and radio observations from the ground with observations in space at submillimetre, infra red, ultra violet, X-ray and gamma-ray frequencies. Under the sponsorship of IFCPAR, *Dhurandhar* and J-Y. Vinet and P. Hello from France will address the following data analysis issues concerning LISA. The first part of the project will be to arrive at a satisfactory model for the laser frequency noise given the various stabilisation schemes. The second part will be to use these results to extract monochromatic and chirping GW signals. The signals will be both amplitude and phase modulated relative to the barycentric frame, while the laser noise will be random as there are no modulation effects. This difference will be used to devise optimal signal extraction strategies.

Cosmology and Structure Formation

Geometrical analysis of large scale structure in the universe

One of the most intriguing features of the galaxy distribution on scales larger than 10 Megaparsec is the organization of matter into geometrically complex structures which have frequently been described as being cellular, honeycomb-like, sheet-like, filament-like, etc. The number of adjectives used to describe the large scale structure of the universe underscores both its richness as well as the difficulty in trying to quantify its geometrical properties. It is, for instance, well known that although the presence of clustering can be described by the two point correlation function, the latter does not provide any information concerning the geometrical patterns that one usually sees both in N-body simulations and in three dimensional redshift surveys of galaxies. To describe the three dimensional clustering pattern of galaxies adequately one must, therefore, complement the correlation function by statistics which are sensitive to the 'connectedness' of the galaxy distribution and hence to the overall geometrical pattern of clustering. In order to come to grips with the rich textural possibilities of large scale structure, a number of geometrical indicators of clustering have been proposed in the past, including minimal spanning trees, the genus curve, percolation theory, etc. A major recent advance in our understanding of gravitational clustering has been associated with the application of Minkowski functionals (MF's) to cosmology. MF's are very versatile and can be applied both to a collection of point objects such as galaxies, as well as to continuous distributions such as density fields in large scale structure or brightness contours in the Cosmic Microwave Background (CMB). For a three dimensional surface (such as an isodensity contour), one can define four Minkowski functionals, which are: the volume V_0, the surface area V_1, the integrated mean curvature V_2 and the integrated Gaussian curvature (or genus) V_3. A significant feature of MF's is that both percolation analysis and the genus curve are members of this family. In addition, as demonstrated by *V. Sahni*, B. S. Sathyaprakash and S. F. Shandarin in 1998, ratio's of MF's provide us with an excellent 'Shapefinder' statistic which can be used to quantify the shape of the supercluster-void network including the shapes and sizes of individual superclusters and voids. The Shapefinder statistic can be applied both to catalogues of galaxies as well as to realistic three dimensional numerical simulations of large scale structure. *Sahni* in a collaboration with Schmalzing, Buchert, Shandarin, Sathyaprakash and Melott has applied the MF's and the Shapefinder statistic to large N-body simulations of gravitational clustering. Individual objects are identified at different threshold levels of the density and their properties are studied using partial MF's. The morphological information contained in the four MF's can be reduced in a simple and intuitive way by defining two dimensionless shape descriptors: the *filamentarity* $\mathcal{F}$ and the *planarity* $\mathcal{P}$ where $0 \leq \mathcal{F}, \mathcal{P} \leq 1$. Thus a supercluster with $\mathcal{F} \ll \mathcal{P}$ is *sheet-like*, whereas one with $\mathcal{P} \ll \mathcal{F}$ is *filamentary*. On the other hand a void with $\mathcal{P} \simeq \mathcal{F} \simeq 0$ is quite spherical.

It is clearly important to study both N-body simulations and real galaxy catalogues in parallel which has been achieved by Somnath Bhardwaj, *Sahni*, Capp Yess, Sathyaprakash and Shandarin who have applied Minkowski functionals to the study of superclusters and voids in the Las Campanas Redshift Survey (LCRS). The LCRS is the largest three dimensional galaxy survey at present and contains approximately 25,000 galaxies. The survey region is divided into six slices, three each in the northern and southern galactic hemispheres. The slices are strips of the sky 1.5° thick and 80° wide that are separated by 3° and probe a distance of upto 600 h^{-1} Megaparsec (where h is the value of the Hubble parameter in units of 100 km/sec/Mpc). The survey is complete to a limiting magnitude $m = 17.75$. Since the geometry of LCRS is quasi two-dimensional, *Sahni*, et al. applied a two dimensional version of the Minkowski functionals to examine the 'connectedness' of large scale structure in LCRS. The results of their analysis was unambiguous and showed that LCRS displayed a high degree of *filamentarity* in both Northern and Southern sky sections (in general agreement with the visual appearance of the catalogue). In order to ascertain the physical significance of these results, an identical analysis was performed on a mock Poisson catalogue with the same number of galaxies, selection function and geometry as the survey. It was thereby discovered that the Poisson catalogue had fewer large superclusters (at a given value of the filling factor) than LCRS. The Poisson catalogue also exhibited far less filamentarity and percolated at higher values of the filling factor when compared with LCRS.

These results confirmed that the clustering of galaxies in the universe exhibited strong filamentary features which could not be accounted for in a purely random distribution of matter. Furthermore, it has been convincingly demonstrated that galaxies clustering gravitationally from an initially random Gaussian distribution, build up pronounced filamentary features on supercluster scales (this result follows from earlier work by *Sahni*, Sathyaprakash and Shandarin and also from the more recent analysis of *Sahni*, Schmalzing and collaborators). Consequently, the fact that the LCRS survey when smoothed on very large scales shows properties consistent with those of a Gaussian random field whereas, the unsmoothed catalogue demonstrates strong filamentary features, lends strong support to the conjecture that the large scale clustering of galaxies is driven by gravitational instability from Gaussian initial conditions.

Jatush Seth and *Suketu Bhavsar* are looking at the Las Campanas wedges to determine the statistics of filaments. The idea follows from the work of *Bhavsar* and Ling where an objective technique has been used to identify and quantify filamentary structure in the LCRS redshift slices. To determine their significance, fake catalogs are generated from the original in such a way that structures smaller than some determined scale are kept intact but structure on scales larger than this are broken by shuffling around regions within the catalog. This keeps small scale structure intact, destroying the longer filaments. Filaments are identified in these fake catalogs using the original filament identifying technique to determine the statistical significance and physical lengths of the true filamentary structure in the original LCRS wedges.

Using the void statistics to determine Ω and Λ

Boudewin Roukema, Jatush Sheth and *Suketu Bhavsar* are investigating how the void distribution can be identified and quantified so that it can be compared between galaxies at low redshift in the LCRS and quasars in a high redshift survey. This is hoped to result in a characteristic distribution function of voids which is independent of redshift at large ($\sim 100h^{-1}$ Mpc) comoving length scales, i.e., at scales above those of galaxy formation. This should enable tighter constraints in the Omega-Lambda plane than those presently found by *Roukema* and Mamon.

The cosmological constant

Recent years have witnessed a resurgence of interest in the possibility that a positive cosmological constant (or Λ-term) may dominate the total energy density of the universe and *Varun Sahni* has been trying to gain an understanding of this important issue. The cosmological Λ-term has had a chequered history. Introduced by Einstein in 1917 and discarded by him soon after, Λ has made many comebacks, the most recent having to do with measurements of high redshift Type Ia supernovae. Type Ia supernovae are widely regarded as being explosions which arise when a white dwarf star has accreted enough matter from its binary companion to cross the Chandrasekhar limit. The high absolute luminosity ($M_B \simeq -19.5$ mag) of this class of objects combined with the fact that the variability of their intrinsic luminosity is small makes Type Ia supernovae excellent standard candles with which to probe the geometry of the universe and its matter content. Observations of over two dozen high redshift supernovae by the Supernova Cosmology Project team and the High-Z Supernovae Search Team have established that high redshift supernovae are *fainter* than expected in a standard matter dominated FRW universe. Such an effect can be explained if, in addition to 'normal' matter, there is a dominant contribution arising from a positive cosmological constant. (The presence of Λ has the effect of *increasing* the luminosity distance to a given object which causes distant objects to appear fainter.) Combining supernovae observations with those of the Cosmic Microwave Background leads to the best fit values $\Omega_m \simeq 0.3, \Omega_\Lambda \simeq 0.7$ for the dimensionless energy density in matter and Λ respectively. These results clearly favour a total density in matter which is close to critical ($\Omega_{total} = 1$) in good agreement with predictions made by the inflationary scenario almost two decades ago.

In an invited review article on the cosmological constant *Varun Sahni* and Alexei Starobinsky review the latest developments concerning Λ, emphasising both observational as well as theoretical issues. Perhaps the most puzzling aspect of a cosmological constant is related to its energy density which must be of order $\rho_\Lambda = \Lambda/8\pi G \simeq 10^{-47}$ GeV^4 in order to satisfy the supernovae observations. However, as originally pointed out by Zeldovich, the contribution to Λ from zero-point vacuum fluctuations is much larger (formally infinite) since, assuming an ultraviolet cutoff at the Planck scale, $\rho_{Pl} = \langle T_{00} \rangle \sim 10^{76}$GeV^4, which is 123 orders of magnitude larger than ρ_Λ. This discrepancy is well known as the *cosmological constant problem.* Any attempt to generate a small Λ at the present epoch must, therefore, address the following issues which plague a cosmological *constant*: (i) a degree of fine tuning of parameters may be required to explain the exceedingly small numbers $\rho_\Lambda/\rho_{Pl} \sim 10^{-123}$ or even $\rho_\Lambda/\rho_{EW} \sim 10^{-53}$; (ii) For $\Omega_m \simeq 0.3, \Omega_\Lambda \simeq 0.7$, $\rho_m/\rho_\Lambda \simeq 1$ at a redshift $z_\star \simeq 0.37$, which could be interpreted to mean that we are living at a preferred epoch when the energy densities in matter and Λ are almost equal. (This is sometimes referred to as the 'coincidence problem'.)

Some of these problems can be alleviated if we consider the energy density in Λ to be a function of time. (A time dependent Λ-term could arise if the final vacuum energy is zero, but the universe takes a long time in relaxing to that state.) The concept of a cosmological constant is, therefore, more conveniently replaced by the more general concept of a Λ-field. The simplest Λ-field models borrow heavily from inflationary model building and are based on scalar fields which are assumed to couple weakly to gravity. In such models, the value of Λ is directly related to the value of the scalar field potential $V(\phi) \simeq \rho_\Lambda = \Lambda/8\pi G$. In an important class of scalar field models, the energy density decays *faster* at early times and more slowly during late times. As a result, the ratio ρ_Λ/ρ_r between the density in a time dependent $\Lambda-$term and that in matter is of order unity and one can conceive of the Λ-field being produced by mechanisms similar to those giving rise to radiation shortly after inflation (preheating, etc.). A time-dependent Λ-term can, therefore, significantly ameliorate the fine-tuning problem which plagues the cosmological *constant.*

It is, however, fair to say that although several promising models of a time dependent Λ-term exist, none is singled out uniquely on the basis of a fundamental theory of particle physics such as supergravity or M-theory. In this context it is important that one can *reconstruct* the scalar (Λ-field) potential solely on the basis of observational data and in a completely model-independent manner as demonstrated by *T. D. Saini, S. Raychaudhury, Sahni* and Starobinsky.

The reconstruction method of *Saini, Raychaudhury, Sahni* and Starobinsky is based on two important considerations: (i) the value of the Hubble parameter is *directly related* to the luminosity distance so that knowing the latter one can determine the former; (ii) the Einstein equations governing the behaviour of a scalar field in an expanding universe permit us to express the scalar field potential entirely in terms of the Hubble parameter and its first derivative. Therefore, knowing the luminosity distance amounts to knowing the form of the scalar field potential and the equation of state of the time-dependent Λ-term. *Saini, Raychaudhury, Sahni* and Starobinsky propose a simple yet powerful three parameter ansatz for the luminosity distance. The values of the three parameters are determined by comparing with Supernovae data and using a maximum likelyhood method to determine the luminosity distance. Using the published data of 42 Type Ia high

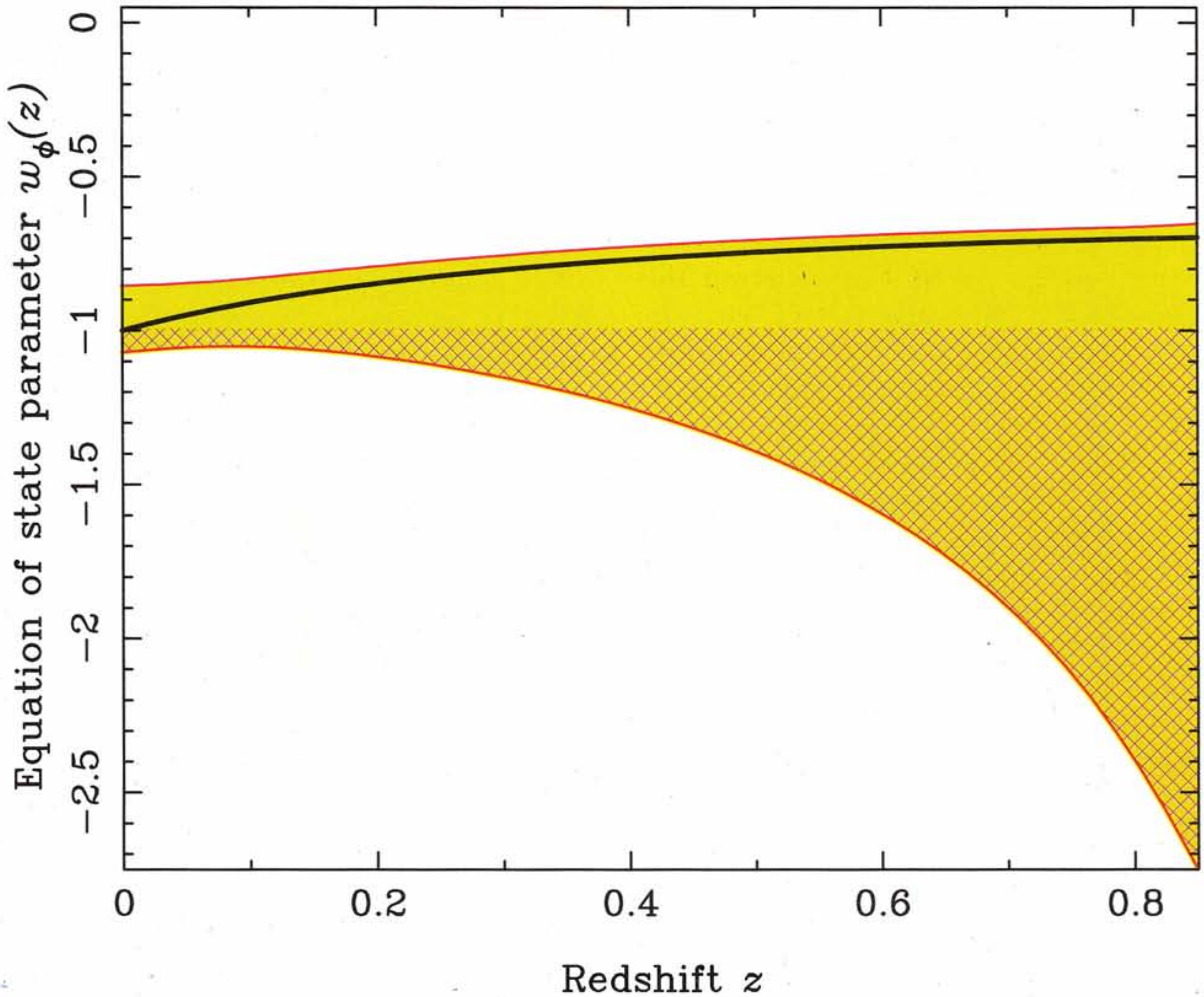


Figure 1: The reconstructed (model independent) cosmic equation of state is shown as a function of cosmological redshift z. The solid line corresponds to the best-fit values of parameters in the ansatz for the luminosity distance. The shaded area covers the range of 68% errors. A small evolution in w_ϕ is supported by observations; however, a cosmological constant ($w_\phi = -1$) also agrees with the data. The hatched region corresponds to $w_\phi < -1$ which is unphysical for a minimally coupled scalar field.

redshift supernovae compiled by the Supernova Cosmology Project, *Saini, Raychaudhury, Sahni* and Starobinsky find that there is some evidence for evolution of the cosmological Λ-term between a redshift of $z = 0$ and $z = 0.83$ ($z = 0.83$ is the redshift of the most distant supernova in their sample). The best-fit equation of state varies between $P/\rho = -1$ at the present epoch to $P/\rho = -0.7$ at the redshift $z = 0.83$. However, an unevolving cosmological *constant* with equation of state held fixed at $P/\rho = -1$ is also consistent with current supernovae data. The conclusion reached by this work is that a cosmological Λ-term which is either constant or weakly time-dependent agrees well with the high redshift supernova data. The reconstruction method promises to yield excellent results as the data improve and more high redshift objects are added to the supernova inventory. Another promising approach being explored is to use weak gravitational lensing in conjunction with supernovae observations to place constraints on the cosmic equation of state.

Effect of anticorrelation on gravitational clustering

One of the simplest descriptors of gravitational clustering is the two point correlation function and considerable effort has been spent by *Padmanabhan* and collaborators in the previous years to understand this theoretically. The existence of nonlinear scaling relations (NSR) allows significant amount of progress to be made in this task. The NSR, however, has so far been studied only for those cases in which the correlation function is everywhere positive. This is unsatisfactory for two reasons. First, in order to understand the transfer of power in gravitational clustering, it is necessary to study the evolution of model input power spectra, which are sharply peaked and hence, possess negative correlations at some scale. Second, it is not possible to rule out observationally the existence of negative correlation at — say — (300-500) Mpc. Because of these reasons, *Padmanabhan*, along with Nissim Kanekar, have taken up the generalisation of NSR for negative correlation regimes and related issues. Indeed, they arrive at very surprising results.

It turns out that the existence of such regions have important dynamical effects on *all* scales. In particular, the mere existence of negative correlation in the linear correlation function at some scale l, implies that the true nonlinear correlation function at *all* scales $x < l$ is bounded from above. Such a result has important implications for the transfer and saturation of power during gravitational clustering. The authors also obtain the modifications to nonlinear scaling relations due to the existence of negative correlation at some scale.

Analytic description of power transfer

In the last few years, *Padmanabhan* has been involved in the study of power transfer between different scales during the process of gravitational clustering. He has now obtained a simple formalism which describes this phenomena. This formalism allows — among other things — re-derivation of several standard results in gravitational clustering in a very simple and illuminating manner. Some of these results were first presented in his lectures given at IPM School on Cosmology 1999 (Large Scale Structure Formation), Iran (January 23 - February 5).

ARFUS

Boudewin Roukema was involved in the development of the galaxy formation software package ARFUS continued in 1999/2000, with help from *Padmanabhan, Sunu Engineer* and Jasjeet Bagla. A local copy of this software is available at IUCAA.

This package was used by *Roukema*, et al to show that the loss of matter into a 'debris' phase should only affect the values of typical global galaxy formation statistics by about 10-30%.

Gravitational lensing

The light from distant galaxies and quasars is affected by the gravitational field of the intervening matter between us and the source, resulting in magnified or multiple images. To probe the distribution of matter in the universe, which is overwhelmingly dark, one needs to directly map this gravitational field. The study of gravitational lensing, therefore, has recently become one of the most valued tools in surveying the universe and understanding its constituents and its evolutionary history.

The most direct way of measuring the distribution of matter in a cluster of galaxies is to study gravitationally lensed images of galaxies lying behind the cluster. *Tarun Deep Saini* and *Somak Raychaudhury* have developed an algorithm for the reconstruction of the two-dimensional mass distribution of a cluster of galaxies from the observ-

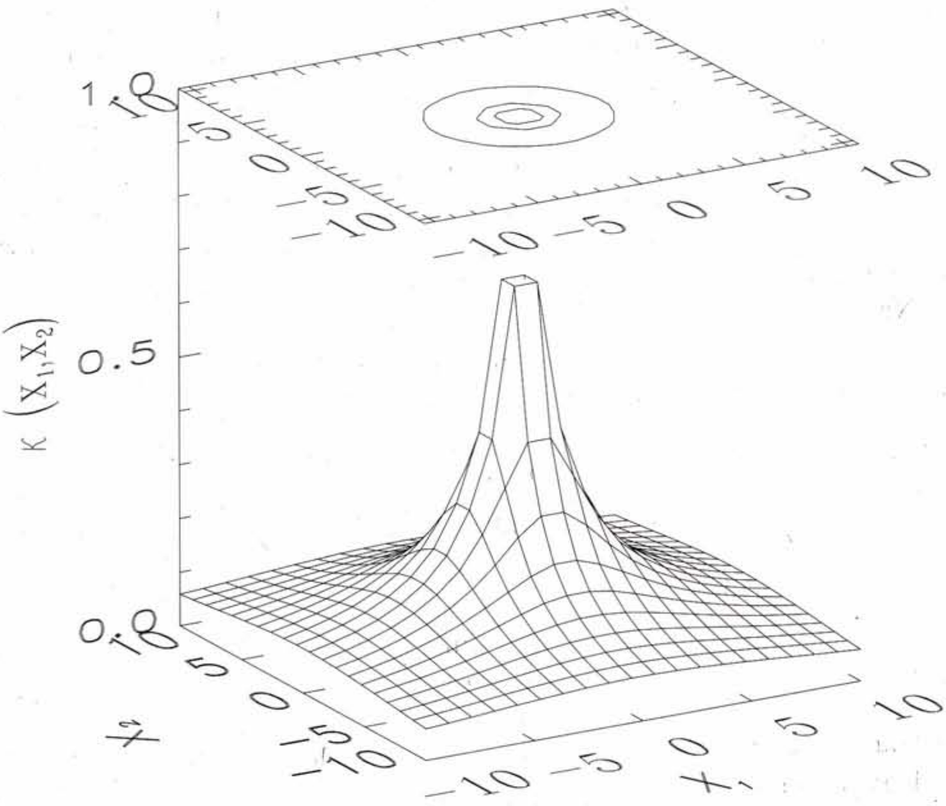


Figure 2: An equally-spaced Cartesian grid (in the source plane) is lensed by a two-component mass model, both pseudo-isothermal elliptical mass distributions with zero ellipticity and $k_0 = 0.8$ and 0.5 respectively. The axes are marked in units of the core radius r_c, assumed to be same for both the models. The separation between the centres of the two distributions is $10\,r_c$ (from Saini and Raychaudhury, astro-ph/0002416).

able distortion of background galaxies (see Figure 2). From the measured (reduced) shear the lens mapping is directly obtained, from which a mass distribution is derived. This is unlike other methods, where the convergence (κ) is obtained first. They have shown that this method works best for sub-critical lenses but can be applied to a critical lens away from the critical lines, on the reasonable assumption that the mean excess surface density in the lens vanishes at large distances. The strength of this method is that for finite fields, the usual mass-sheet degeneracy and similar boundary problems can be eliminated by an iterative scheme, in the absence of a substantial external shear.

Saini and *Raychaudhury*, together with Yuri Shchekinov have estimated the enhanced probability of finding supernovae in gravitationally lensed arc images. Distant supernovae will be more easily detectable since foreground cluster lenses would magnify such supernovae by up to 3-4 magnitudes. They have shown that the magnification in these arcs significantly enhances the S/N ratio and detectability of SNe Ia, and recommend systems that could be monitored with medium to large telescopes. As an example, they show that in the case of the well-known lens cluster Abell 2218, the detectability of high-redshift supernovae is significantly enhanced due to the lensing effects of the cluster. Since lensed supernovae will remain point images even when their host galaxies are stretched into arcs, the signal-to-noise ratio for their observation will be further enhanced, typically by an order of magnitude. They recommend monitoring well-modelled clusters with several known arclets for the detection of cosmologically useful SNe around $z = 1$ and beyond.

The quasi-steady state cosmology

Work on the quasi-steady state cosmology (QSSC) continues with emphasis on the observable aspects of the theory. Thus, one major issue to be discussed was how the theory explains the redshift-magnitude relation for data on extragalactic supernovae. The standard cosmology does not provide a good fit as the distant supernovae are systematically fainter than expected, and to get a good fit one has to introduce the cosmological constant. This has led to the notion that the universe is currently accelerating.

In the QSSC, however, two effects appear. The first is of expansion produced by the creation process which changes from acceleration to deceleration during a typical cycle. The other is the extinction of light produced by the intergalactic dust in the form of metallic whiskers. *S.K. Banerjee, J.V. Narlikar*, N.C. Wickramasinghe, F. Hoyle and G. Burbidge have carried out the analysis and have found that the fit to the observed data is very good, and the optimum value of the whisker density agrees very well with that required to understand the Planckian spectrum of the microwave background. In addition, the observed inhomogeneity of data (requiring a few supernovae to be anomalously dim) can be understood here in terms of local pockets of concentrations of whiskers which condense from the metallic vapour ejected by the supernovae.

The work on structure formation in the QSSC continues after the publication of the toy model which successfully explained the observed filament-void picture of large scale structure with a two-point correlation function with power law index of -1.8. *Sunu Engineer, S. Bhavsar and Narlikar* are now examining a few other statistics of the cluster-void distribution, such as the minimal spanning tree, to understand how structure formation evolves in the QSSC.

Banerjee, R.G. Vishwakarma, Narlikar and P. K. Das are examining the variable mass hypothesis to understand the recent findings of high redshift X-ray quasars near low redshift galaxies. Extraordinary alignments suggest ejection of quasars from the disturbed galactic nuclei. The variable mass hypothesis first proposed by *Narlikar* in 1977 and explored for ejection- candidate quasars by Das and *Narlikar* in 1980, is being invoked. The ejected quasar starts with zero mass and acquires inertia with time through a Machian interaction. This work is in collaboration with H. C. Arp.

Observational Cosmology

Estimate of galaxy clustering

The clustering of galaxies, as represented by the two-point auto-correlation function, was estimated for galaxies at high redshift ($z \sim 2$) in the Hubble Deep Field (North) by *B. Roukema*, Valls-Gabaud, Mobasher and Bajtlik. Correction for the integral constraint was done in a way which avoids the usual assumption that the angular correlation function should be a power law with a given slope. The low value of the correlation length found suggests that the epochs of high bias in the correlation function expected at high redshift is over.

Peculiar velocities

There is strong observational evidence for the existence of large-scale gravity-induced flows in the local universe. The dipole anisotropy of the cosmic microwave background (CMB) radiation provides a natural velocity reference frame for the analysis of galaxy motions. The dipole anisotropy, determined from COBE, implies that the Local Group (LG) moves with respect to the CMB rest frame at $\sim$600 km/s. If this has a kinematic origin, then sufficiently far away, the peculiar velocities should converge to the CMB frame. Indeed, the observed LG motion relative to the rest frame defined by galaxies within 6000 km/s points toward the Hydra-Centaurus-Great Attractor region, which is close to the direction of the CMB dipole.

To investigate the reality of large-scale streaming motion on scales of up to 150 Mpc, *Somak Raychaudhury*, together with K. R. Müller, G. Wegner and W. Freudling has measured radial velocities and central velocity dispersions for 238 E/S0 galaxies using medium-resolution spectroscopic data obtained at the MDM and MMT observatories. The galaxies are selected from the ACCESS Catalogue of galaxies (*Raychaudhury* and Lynden-Bell, described below).

The spectra obtained have a median S/N (per $\AA$) of 23, an instrumental resolution (FWHM) of ~ 4 $\AA$, and the spectrograph resolution (dispersion) is ~ 100 km s^{-1}. The Fourier cross-correlation method was used to derive the radial velocities and velocity dispersions. The velocity dispersions have been corrected for the size of the aperture and for the galaxy effective radius. These parameters are being used to map the peculiar velocity field in three directions far away from the Supergalactic Plane which includes both the observer and the Great Attractor.

The ACCESS catalogue in the southern equatorial sky

At present, there is no homogeneous catalogue of bright galaxies in the Equatorial strip ($-17^\circ.5 <$ Declination $< +2^\circ.5$) of the sky, a region that was missed by the two most frequently-used sources of $> 1'$ galaxies, the ESO and UGC catalogues. This "missing strip" has always been a problem for all-sky surveys like estimates of Ω_0 from the optical dipole, designing peculiar velocity surveys, etc.

Somak Raychaudhury and D Lynden-Bell have compiled the APM-Cambridge Catalogue of the Equatorial Southern Strip (ACCESS), which concludes a decade-long project. They have used a method of semi-automatically finding and measuring the brighter galaxies, on APM scans of (IIIa-J/UKSTU) photographic Schmidt plates, and a new method of reliably matching the plates using overlaps.

This is the first photometrically calibrated catalogue of bright galaxies in the "missing strip", as well as being the first automated catalogue of galaxies to be published (the galaxies were found and measured using the APM). It is constructed in such a manner that both diameter-limited and magnitude-limited samples can be extracted from it.

A Catalogue of super clusters

Suketu Bhavsar and *Somak Raychaudhury* are in the process of constructing an objective catalogue of Superclusters, i.e., clusters of clusters of galaxies. They are using a volume-limited subset of the catalogue of Abell clusters, for which redshifts have been measured in collaboration with John Huchra, Harold Corwin and Ron Olowin. This enables them to use the clustering technique of the minimal spanning tree to objectively identify the superclusters along with their hierarchical sub-structure, with a view to studying their statistical properties.

Thermal and non-thermal emission in rich galaxy cluster Abell 85

The cluster of galaxies Abell 85 is thought to be the prototypical of a highly symmetrical, dynamically evolved and virialized cluster harbouring a giant cD galaxy of elliptical morphology at its centre. However, the images produced by radio telescopes operating at metre wavelengths have revealed a very large (≈ 500 *kpc*), diffuse and ultra steep spectrum radio source 0038-096, projected at ~ 700 *kpc* from cluster centre. This radio emission appears to be a part of the relativistic particles and magnetic field inherent to the intra-cluster medium, as (unlike in normal radio galaxies), the progenitor optical galaxy is not identifiable at all. The presence of this and a handful of few other similar radio sources in clusters of galaxies present a great theoretical challenge. In the last couple of years, the understanding has developed that these so called 'radio relics' and 'radio halos' are actually the manifestations of violent dynamical processes in which collision and merger of large scale gravitating mass components serve to liberate large amounts of energy - a small part of which could energize the charged particles to relativistic energies and amplify the intra-cluster magnetic fields to micro Gauss strengths. This broad theoretical picture is yet to be fully confirmed. The latest generation of highly sensitive radio and x-ray telescopes are essential to provide useful data in this area. *J. Bagchi* and his collaborators have started such a programme involving both observational and theoretical efforts.

Recently, *Bagchi*, Lema Neto and Pislar have extensively studied the Abell 85, employing x-ray data from ROSAT satellite and radio data from VLA and Ooty Synthesis Radio Telescope (OSRT). They detected the non-thermal x-ray emission cospatial with the radio source 0038-096, and interpreted it as due to inverse Compton radiation from the interaction of relativistic electrons/positrons with the Cosmic Microwave Background. Employing this first detected signal of its kind in clusters, they were able to derive a value of $0.95 \pm 0.10\ \mu$ G for the cluster-scale magnetic field strength. *Bagchi*, Lema Neto and Pislar also found a new 'radio relic' in this cluster which is also associated with an excess x-ray emission at ≈ 1 Mpc south of the cluster centre. With an aim to further understand the nature of thermal and non-thermal x-ray emission in this cluster, they have used the BeppoSAX satellite. BeppoSAX, with its superior spectroscopic capabilities, was targeted on Abell 85 for about 100 k seconds duration. The spectroscopic data from the low-energy concentrator spectrometer (LECS, sensitive in the 0.1-10 keV range) and medium-energy concentrator spectrometer (MECS, sensitive in the 1.3-10.5 keV range), were used by them to show that the average cluster temperature is 6.6 ± 0.3 keV and the average metal content is 0.38 ± 0.06 times the solar abundance. They have also found strong indications in the cluster centre, for an excess of soft x-ray photons due to a cooling flow, and a higher metallicity (0.48 ± 0.1 times solar) in the intra-cluster medium. They found that in the southern region, containing the excess x-ray emission and diffuse radio plasma, the gas temperature is higher and the metal abundance is lower than the central region. Durret, Forman, Gerbal, Jones and Vikhlinin have detected a filament of low level x-rays and optical galaxies connecting this region of Abell 85 to another nearby cluster Abell 87. Therefore, the BeppoSAX data of *Bagchi*, Lema Neto and Pislar supports the scenario in which the cluster is undergoing a merger with Abell 87 to the south, and the ensuing accretion shock serves to accelerate the relativistic particles and amplifies the magnetic field. These in turn produce radio emission by synchrotron process and the nonthermal x-ray emission by inverse Compton scattering on Cosmic Microwave Back-

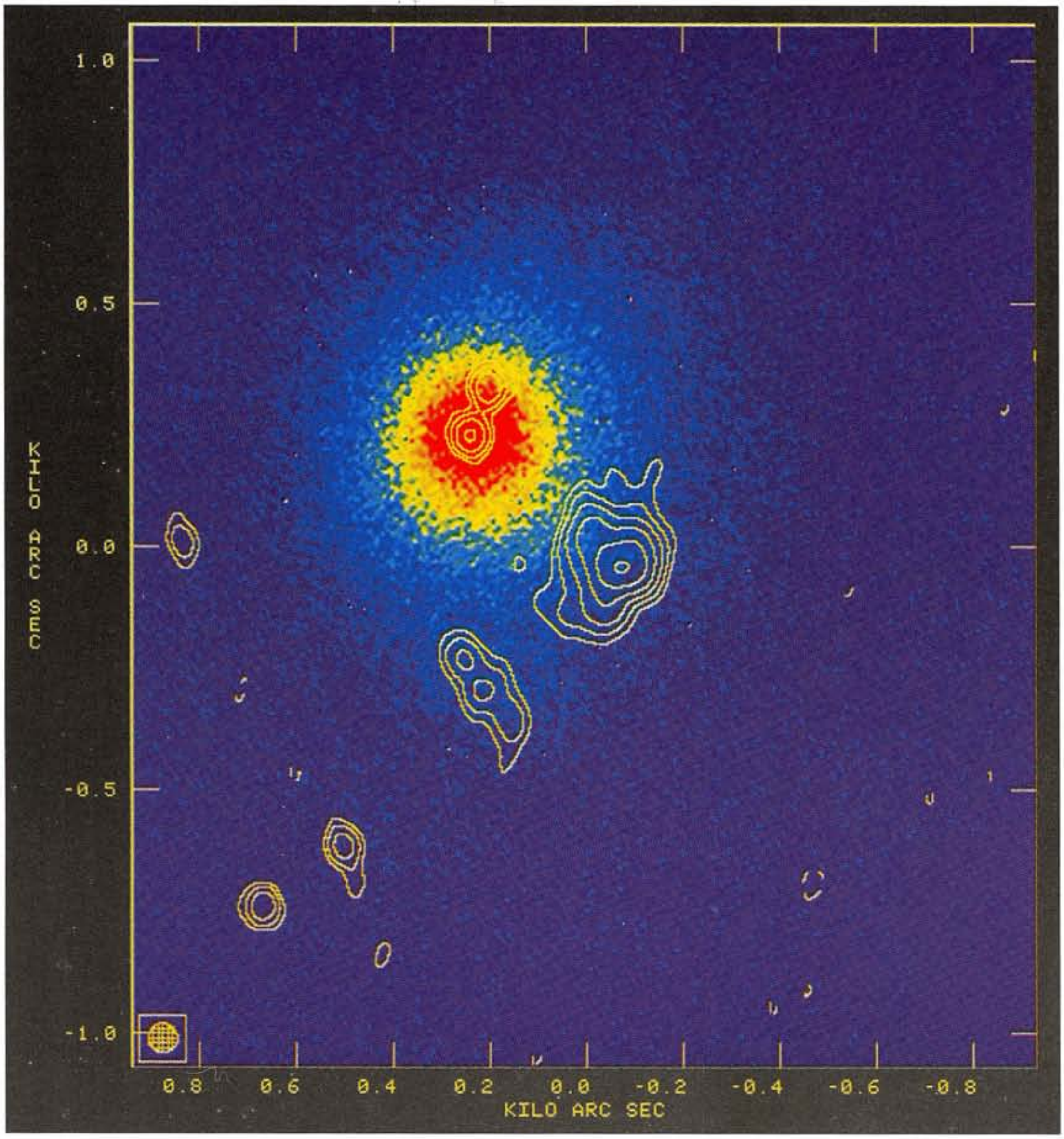


Figure 3: The X-ray and radio emission from the rich cluster of galaxies Abell 85 at redshift z = 0.055. The colour image shows the thermal bremsstrahlung X-ray radiation extending over 1 Mpc, observed by the Italian-Dutch BeppoSAX satellite (*J. Bagchi* et al.). This image is from the Medium Energy Concentrator Spectrometer (MECS) data in the photon energy range 1.3-10.5 keV and 100 kilo seconds exposure. The contours depict the radio sources detected by the Ooty Synthesis Radio Telescope (OSRT) at the frequency of 327 MHz and at 1 arcmin angular resolution. Radio emission emnating from cluster centre and at the cluster periphery, from two large diffuse sources (south and south-west) which have extremely steep spectral index, can be seen. The east is to the left and north at the top.

ground photons.

Detection of a very large scale ($\sim 3\ h_{50}^{-1}\ Mpc$) magnetic field structure in a distant filament of galaxies

The origin of magnetic field and its evolution in cosmic bodies is one of the least understood of astrophysical problems. Magnetic field appears ubiquitous, wherever modern methods allow for its detection. Planets and stars, the diffuse gas in galaxies, and the hot and teneous gas in clusters, all appear to be magnetized to different degrees. Amongst the largest systems, the magnetic field strength in galactic disks is estimated to be $1 - 10\ \mu$ G, and the clusters of galaxies appear to have fields of order $0.1 - 10\ \mu$G. Beyond the scale of great clusters ($\sim 1\ Mpc$), the existence and the magnitude of magnetic fields is largely unknown. In the last couple of years, employing advanced supercomputers, the MHD evolution of magnetic fields, along with the baryonic and dark matter components, could be followed through since very early epochs. These simulations show that, at present, the field can reach strengths of order $10^{-9} - 10^{-7}$ G in large scale ($\sim 10 - 100\ Mpc$) web-like network of filaments and sheets. The magnetic field in structures of dimension like clusters ($\sim 1\ Mpc$), is obtained to be about $10^{-7} - 10^{-6}$ G. To check for the validity of these ideas, it is first required to detect and estimate the field strength in largest scale cosmic structures and then determine, by observations, how much of it correlates with baryonic matter.

J. Bagchi has found evidence for cosmological scale magnetic field and high energy particles in a hitherto unknown large-scale filamentry formation of faint galaxies; 2343+0018. Employing radio data from VLA telescope at 20 cm wavelength, a giant radio structure of quite unusual morphology, extending over 10 arcminutes of angular scale was discovered. To uncover the nature of optical structure of galaxies underlying this formation, *Bagchi*, T.A. Ensslin, C.S. Stalin, and M. Singh made multiband, deep CCD observations with the UPSO (Nainital) 1-m telescope. They found an enormous filamentry formation of mostly elliptical galaxies, extending over 12 arcminutes in angular scale, with several smaller side chains of galaxies joined with the main structure. Due to quite good photometric conditions during the observing run, they could obtain a redshift of $z = 0.3 \pm 0.05$ from the photometric data alone. It was also realized that the entire radio structure is actually aligned roughly across this filament of galaxies and is quite diffuse and having low surface brightness. The cause of the radio emission seems almost certain to be the diffuse synchrotron emission from relativistic electrons/positrons in a magnetic field. They have estimated the linear size of the entire radio and optical structure, and have put it at $\sim 3h_{50}^{-1}\ Mpc$, far larger than even the giant radio galaxies ($\sim$ 1 Mpc), thereby putting it in the realm of cosmological sized structures. Invoking the 'minimum energy' condition, they have estimated the magnetic field in the filament to be $\approx 5 \times 10^{-7}$ G. It was also shown by them that at two places on the filamentry structure, there is enhancement of radio energy and elliptical galaxies can be seen at both these spots. Although, in terms of its morphology or linear dimension, the source 2343+0018 does not resemble a bipolar radio galaxy, it seems possible that these galaxies are injecting the necessary energetic particles and magnetic fields in the cluster medium to power the radio emission. It was realized by them that such large scale distribution of cosmic ray particles and magnetic fields can act as excellent probes for the study of structure formation and associated large scale shocks that form at the intersection of filaments and sheets due to gravity driven supersonic flows of intergalactic matter. More investigations are being planned with GMRT in radio domain, and using large optical and X-ray telescopes, to fully understand the cosmological implications of this structure.

GMRT observations of two galaxy clusters containing peculiar radio sources

J. Bagchi, in collaboration with Gopal-Krishna and V.K. Kulkarni, have used the recently operational GMRT array to map the clusters of galaxies 0116+111 (at z = 0.131) and 2126-121 (at z = 0.176). The radio source 0116+111 was first found by Joshi and Singal (1980) in Ooty Lunar Occultation Survey. They detected an extremely steep spectrum (spectral index $\alpha \sim -1.3$) and highly diffuse object. Recently, Gopal-Krishna, *Bagchi*, and Kulkarni, based on their R-band New Technology Telescope (NTT) data, identified it with a $\sim$ 17 - mag centrally dominant cD galaxy in a medium distant galaxy cluster. A slit spectrum taken with the grism-3 optics of NTT gave a redshift of z = 0.1316, based on number of absorption lines in the spectrum. The bright elliptical galaxy $\sim$ 15" to south of cD was found to have z = 0.1309. The VLA radio maps (at 1.4 and 4.9 GHz frequencies) showed two warm spots straddling the cD along P.A. $\sim$ 50 deg, due to a jet-like outflow. The amorphous radio structure underlying these peaks has the size of 2 arcmin in the GMRT map at 610 MHz (i.e., $\sim$ 0.3 Mpc for $H_0 = 65$). Much of this diffuse emission to north-west of cD has no detected optical counterpart. Thus, it probably represents parts of a radio-halo in this distant cluster. If so, its luminosity ($\sim 10^{25}$ $W.Hz^{-1}$ at 610 MHz) would place it among the most luminous radio halos known. Interestingly, they found that the possible radio outflow from the cD galaxy, instead of being linear, assumes the form of a huge radio 'barred spiral'. A somewhat similar spiral morphology is known to occur in the radio source Virgo-A (M87). The exact cause behind such distortions is not known. The interesting question, arising out of GMRT data is, if the relativistic particles and magnetic field are diffusing away from the centre, filling the giant radio halo, and their energy being re-amplified due to energetics of mergers in this cluster ? More investigations are being carried out to fully understand these issues.

The cluster of galaxies Abell 2345 (2126-121) is an X-ray bright cluster at z = 0.176. It is of considerable interest as it was recently reported to be an example of rare class of clusters having two candidate radio relics, as inferred from 1.4 GHz VLA-NVSS radio survey with 45" beam. Several radio sources of peculiar morphology were detected in the central $\sim$ 3 Mpc region. But due to poor resolution, their nature was not understood. To clarify the nature of this peculiar system, Gopal-Krishna, Kulkarni and *Bagchi* have mapped the cluster at 616 MHz using 15 antennas of the GMRT array, yielding the HPBW resolution of $\sim$ 10". With the GMRT data, it was shown by them that the central region of this cluster is an interesting place as it harbours at least three the so-called 'head-tail' radio sources in which the bipolar radio outflow from the parent galaxy is sharply bent backwards, forming a comet-like 'tail' of diffuse radio emission behind. It is rare to find so many bent-radio-jet sources in a cluster and these can be used as tracers of 'cluster weather', providing information on the dynamics of intra-cluster medium. Apart from this, the new GMRT map has also provided higher resolution information on the two potential diffuse radio relics in this cluster. More observations with GMRT are being carried out by them to uncover the true nature of this cluster of galaxies.

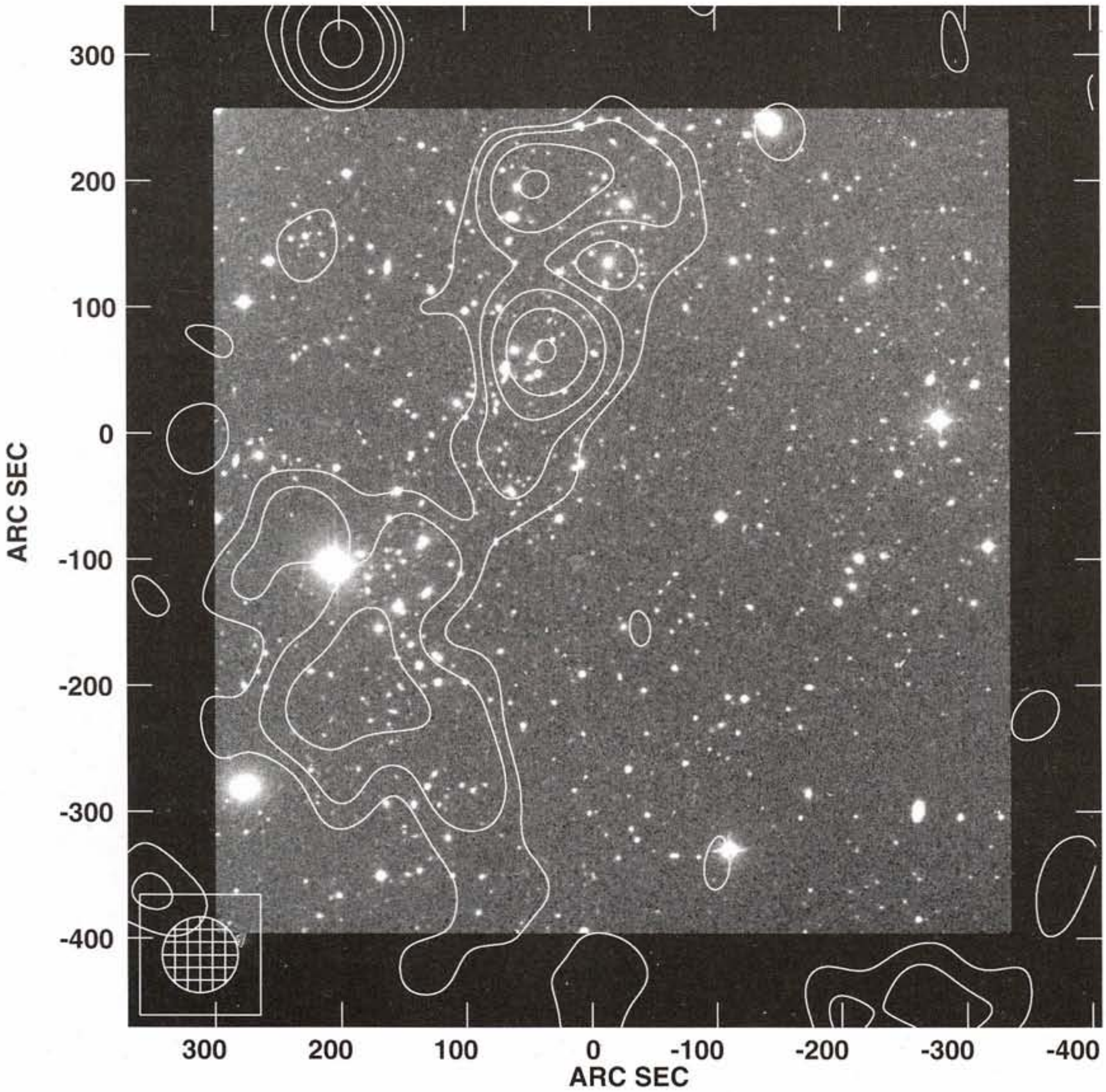


Figure 4: The large scale diffuse radio emission from the filamentry network of galaxies 2343+0018 (redshift z =0.30). The image shown is a deep Johnson R filter optical image (λ_R = 5505Å) obtained by the U.P. State Observatory (UPSO) 1-m Sampurnanand reflector (*J. Bagchi* et al.). Johnson V, R, and I filter data was acquired using a SITE 2K X 2K CCD camera, giving a plate scale of 0.375"/pixel, and a field of view of 12 arcmin at the f/13 Cassegrain focus. A multi-Mpc scale optical structure composed of several filaments of galaxies can be seen. The associated synchrotron radio emission morphology shown here using contours, is from the NRAO VLA Sky Survey (NVSS) at the frequency of 1.4 GHz. The contour levels shown are 0.7,1.4,2.8,5.6 and 11.0 m Jansky per beam area (0.785 arcmin^2) respectively. This image was generated from the NVSS data, by smoothening the original map having FWHM resolution of $45'' \times 45''$, to a final resolution of $60'' \times 60''$ FWHM, improving the detection of diffuse radio emission features. The resolution of the map (beam shape) is shown inside a small box in the lower left corner. The image has the east to the left and north at the top.

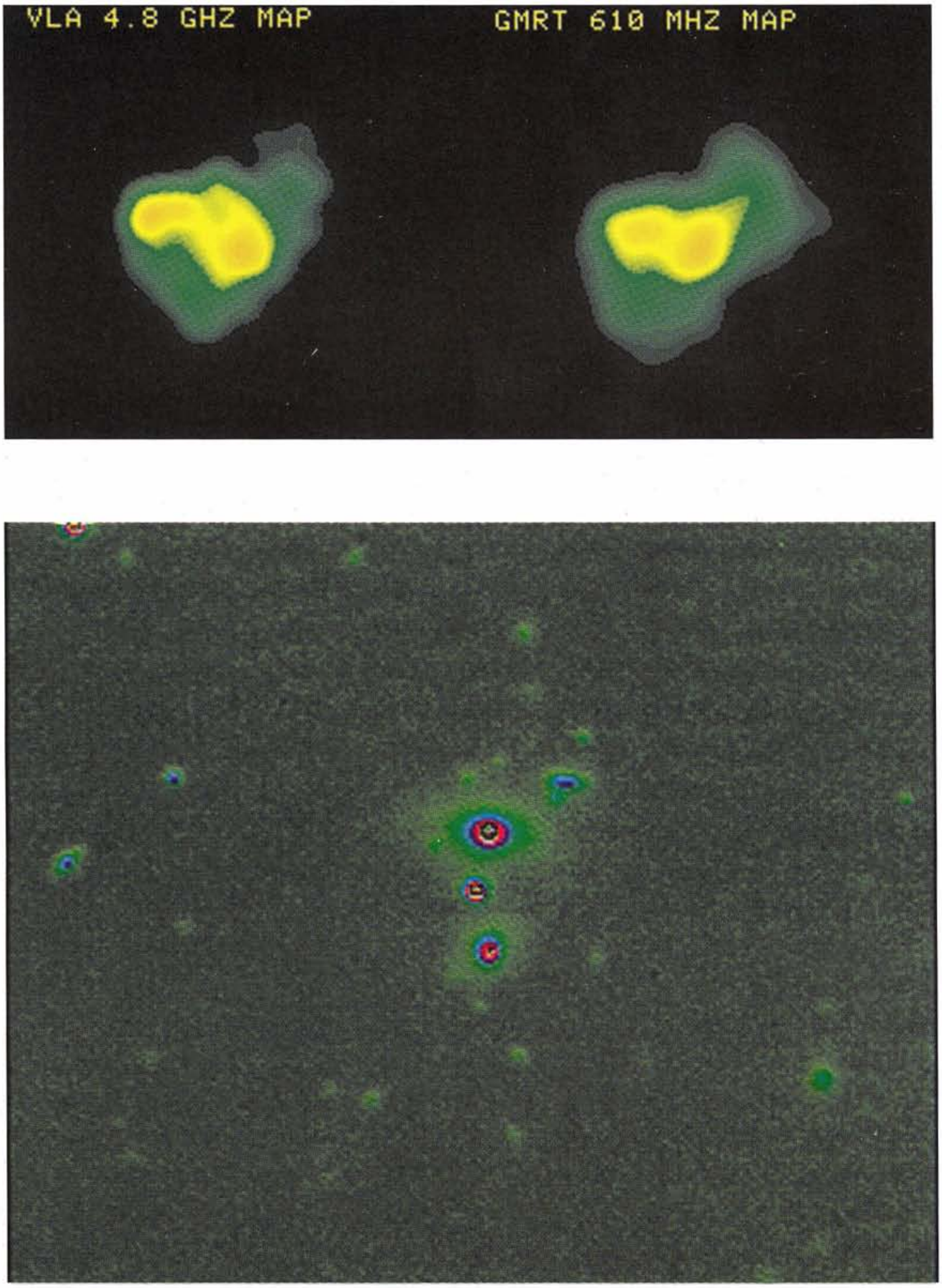


Figure 5: The extended, diffuse radio-halo type emission discovered in the central region of cluster of galaxies 0116+111 (at redshift 0.13). In the upper panel shown is the 0.3 Mpc scale radio structure at two different frequencies: the Very Large Array (VLA) 4.8 GHz image to the left and the Giant Meter Wave Radio Telescope (GMRT) 610 MHz image to right, both with an angular resolution of 12 seconds of arc. In the lower panel, the optical R-filter CCD image of the central region of the cluster is shown. This image was obtained by the European Southern Observatory 3.6-m New Technology Telescope (ESO NTT) (Gopal-Krishna, V.K. Kulkarni and *J. Bagchi*). All images have east to the left and north at the top.

Observing the geometry and topology of the universe

Boudewin Roukema is continuing his investigations related to the observational methods for detecting or constraining the global topology of the universe. These include:

(i) Comparison of an observational based hypothesis for the topology of the universe with COBE observations of the cosmic microwave background.

(ii) Observational proof that small flat universe models of size a tenth of the horizon diameter are *not* excluded by COBE observations.

(iii) Speculation on a relation between global topology and large scale structure which could lead to some constraints on global topology even if the universe is larger than the horizon.

(iv) A technique of measuring galaxy velocities transversal to the line-of-sight.

(v) A method of constraining topological multiple images of astrophysical objects.

Roukema and Mamon also measured the density parameter of the universe by a new technique, that of using the empirical peak in the density perturbation power spectrum as a tangential, comoving standard ruler on observational cosmological scales. The result is that the matter density of the universe is $\Omega_m \approx 0.3 \pm 0.15$, independently of the value of the cosmological constant.

Combination of this result with the results of the supernovae type Ia method implies that the observable Universe is nearly flat, independently of microwave background analyses, under the assumption of a standard, perturbed, Friedmann-Lemaître cosmological model.

Brightest galaxies in rich clusters

Joseph Bernstein and *Suketu Bhavsar* have looked at the data of Postman and Lauer on first ranked galaxies and concluded that the best explanation for the distribution in their luminosities is if these galaxies were composed of two populations of objects. These galaxies consist of a special population of galaxies competing for first rank with the extremes of normal galaxies.

QSO, AGN and Absorption Systems

The appearance of AGN host galaxies

Galaxies change their appearance with redshift, due to many reasons. Firstly, cosmological dimming tends to reduce their surface brightness at higher redshifts. Secondly, their observed size changes with redshift and thirdly, their own evolution can affect their appearance. An additional complication is introduced when a bright nucleus is present as in active galactic nuclei, because it can easily swamp out the light of its host galaxy under conditions. The effects of the earth's atmosphere that tends to smear out the light from galaxies adds to the difficulties.

Ajit Kembhavi, *Ranjeev Misra* and *Yogesh Wadadekar* have recently completed a study of the appearance of AGN host galaxies at different redshifts. They carefully constructed models that take into account all the influences mentioned above, using the best available data. This study will enable observational astronomers to predict the possibility of detection of quasar hosts, thereby increasing the efficiency of such detections.

Radio emission from AGN

Over the last couple of decades, faint radio sources have been identified with quasars, Seyfert galaxies, radio galaxies and even a few normal galaxies that are close to us. A very large and sensitive radio survey called the Faint Images of the Radio Sky at Twenty centimetres (FIRST) survey is currently being carried out using the Very Large Array (VLA) telescope in the USA.

Wadadekar and *Kembhavi* have been involved with studies of the optical properties of different populations of extragalactic radio sources having radio emission detected by the FIRST survey. In a recent study, they have looked for radio emission from all known Seyfert galaxies lying in that part of the sky observed by the FIRST survey. Their work has resulted in radio detections of over 500 AGN, of which over 200 have been detected in the radio band for the first time. They have examined several statistical correlations in the data. They have shown that radio emission from Seyfert 1 and Seyfert 2 galaxies is very similar, as expected by the standard unification schemes for Seyfert galaxies.

Are Seyfert galaxies extremes of a normal population?

Yogesh Wadadekar and *Suketu Bhavsar* are investigating the fit of a Gumbel distribution to the radio luminosity distribution of Seyfert 1 and Seyfert 2 galaxies. The radio luminosities were obtained from a cross-correlation of known Seyfert galaxies with radio data from the ongoing VLA Faint Images of the Radio Sky (FIRST) survey by *Wadadekar* and *Ajit Kembhavi*. If Seyferts are the extremes of a stochastic phenomena occuring among normal galaxies, then when the Seyferts are treated as a collection of a class of objects, properties like their radio luminosity distribution should exhibit characteristic distributions. The visual appearance strongly suggests that it is a Gumbel distribution and they are investigating this possibility.

Probing the nuclear regions of the QSOs with associated absorption systems

The associated absorption systems are the absorption systems with redshift, z_{abs}, close to the redshift, z_{em}, of the QSOs. Associated absorption systems are seen in $\sim (10-20)\%$ of the QSOs. Based on the absorption line profiles the associated systems are classified as: (i) Broad absorption systems (or BALs) with widths $\Delta v \sim$ a few 1000 kms^{-1}; (ii) mini-BALs with $\Delta v \sim$ a few 100 kms^{-1} and (iii) Narrow associated systems (or NALs) with $\Delta v \sim$ a few 10 kms^{-1}. Even though low-ionization species such as Mg II and Fe II are seen in a few cases (see e.g. Wampler, Chugai & Petitjean 1995, ApJ 443, 586), the BALs are characterized by the presence of very highly ionized gas. The column density ratios $N(\mathrm{OVI})/N(\mathrm{HI})$, $N(\mathrm{NV})/N(\mathrm{HI})$ and $N(\mathrm{CIV})/N(\mathrm{HI})$ are much larger than unity indicative of metallicities of the order or larger than solar. Based on the energetic arguments and large heavy element enrichment BALs and mini-BALs are believed to be associated with the outflowing gas from the central regions of the QSO.

However, NALs can be produced by gas ejected from the central engine or due to gas belonging to the host-galaxy or even to members of a galaxy cluster surrounding the QSO. However, it has been shown that it is possible to distinguish between these different populations as the gas associated with the AGN is of higher metallicity (most of the time, much larger than solar), has high values of ionization parameter (the dimensionless ratio number density of ionizing photons and number density of hydrogen atom) and the corresponding clouds have dimensions so small that they often cover the continuum and broad line region only partially (e.g., Petitjean, et al. 1994 A&A 291, 29; Hamann 1997 ApJS 109, 279; Barlow & Sargent 1997 AJ 113, 136). In addition, it is possible to detect absorption due to excited fine-structure lines; a few lines have been shown to vary and signatures of radiative acceleration (line-locking) have been claimed (e.g., Hamann 1998 astro-ph/9806101; Petitjean & *Srianand* 1999 A&A 345, 73). Thus, in general, associated absorption lines provide a powerful tool to approach the complexity of the quasar environment.

R. Srianand is involved in a long term programme to study the nature of associated absorption system using the high resolution *echelle* spectra of AGNs and high redshift QSOs. Using HST GHRS data, he has investigated the velocity structure in the C IV associated absorption system observed along the line of sight to NGC 5548. The absorption line profiles suggest that most of the narrow components in the associated systems, identified using the narrow unsaturated lines in Lyα and C IV, show signatures of line-locking with velocity separation equal to that of C IV doublet splitting. The estimated probability of occurrence of 8 pairs with velocity splitting equal to that of C IV doublet splitting (within 10 kms^{-1}) among 18 clouds randomly distributed in the velocity range 0-1500 kms^{-1} is 6×10^{-3}. This suggests that the line locking seen is most probably true. The existing high resolution spectra of NGC 5548 in the HST archive showed no change in the velocity centroid of the individual absorption components over a time scale of 2 years. This has been used to get an a upper limit on the change in the velocity of the components to be $\sim 2 \times 10^{-2}$ $cm\ s^{-2}$.

Line-locking is a process in which the velocity separation between two absorption minima are equal to the velocity separation between some allowed resonance transitions. Line-locking signatures are usually expected in the gas flow dominated by the radiative acceleration due to resonance lines. Grids of photo-ionization models were constructed and the radiative acceleration due to line absorption in various transitions were estimated. Observed column densities of different transitions, condition imposed by the line-locking signatures and the maximum limit on the acceleration were used as a constraint to get self-consistent models for the absorbing region. In the framework of these models it has been shown that the (i) number density in the clouds is less than 10^9 cm^{-3}, (ii) the cloud is situated well outside the broad line region and (iii) the clouds cannot produce sufficient amount of O VII and O VIII and they are not responsible for the "warm absorbers" seen toward NGC 5548 in X-rays. This study also suggested a possible connection between the associated systems and the optically thin line emitting clouds in the outer parts of the broad emission line region.

The gravitationally lensed high-redshift BAL quasar APM 08279+5255 ($z_{em} = 3.9114$) is one of the most luminous objects in the universe. Imaging of the field reveals two main components (Irwin, et al. 1998, ApJ 505, 529, Ledoux, et al. 1998, A&A 339, L77) separated by 0.378±0.001 arcsec as measured on HST/NICMOS data (Ibata, et al. 1999, astro-ph/9908052) and of relative brightness $f_B/f_A = 0.773 \pm 0.007$. The HST images reveal the presence of a third object C with $f_C/f_A = 0.175 \pm 0.008$, located in between A and B and almost aligned with them. A high-resolution high signal-to-noise ratio spectrum of APM 08279+5255, covering the wavelength range 4400–10000Å was obtained using the Keck telescope and made available to the Astronomy community for analysis (Ellison, et al. 1999, PASP 111, 946).

All three types of associated systems discussed above were seen along the line of sight toward APM 08279+525 and were investigated in greater detail by *Srianand* and Patrick Petitjean. Two of the narrow-line systems, at $z_{abs} = 3.8931$ and $z_{abs} = 3.9135$, show absorption due to singly ionized species with weak or no

N V and O VI absorption at the same redshift. Absorption due to fine structure transitions of C II and Si II (excitation energies corresponding to, respectively, 156μm and 34μm) are detected at z_{abs} = 3.8931. Excitation by IR radiation is favoured as the column density ratios are consistent with the shape of APM 08279+5255 IR spectrum. The low-ionization state of the system favours a picture where the cloud is closer to the IR source than to the UV source, supporting the idea that the extension of the IR source is larger than $\sim$200 pc. The absence of fine structure lines at z_{abs} = 3.9135 suggests that the gas responsible for this system is farther away from the IR source. Abundances are $\sim$0.01 and 1 $Z_{\odot}$ at z_{abs} = 3.913 and 3.8931 and aluminium could be over-abundant with respect to silicon and carbon by at least a factor of two and five. All this suggests that whereas the z_{abs} = 3.8931 system is probably located within 200 pc from the QSO and ejected at a velocity larger than 1000 km s^{-1}, the z_{abs} = 3.9135 system is farther away and part of the host-galaxy. Several narrow-line systems, with $z_{abs} \geq z_{em}$, have strong absorption lines due to C IV, O VI and N V and very low neutral hydrogen optical depths. Absorption due to low ionization species are absent. This probably implies very high ionization and high metallicities $Z \geq Z_{\odot}$. However, firm conclusion cannot be drawn as the exact values depend strongly on the shape of the ionizing spectrum.

The profile of the C IV broad absorption shows very complex structure with mini-BALs (width $\leq$ 1000 kms^{-1}) and narrow components superposed on a continuous absorption of smaller optical depth. The continuous absorption is much stronger in O VI indicating that the corresponding gas-component is of higher ionization than the other components in the flow. Unlike what is usually assumed in the model of the BAL flow, it is more likely that the observed structures in the BAL flow are mainly due to density inhomogeneities. There is a tendency for mini-BALs to have different covering factors for different species. This could either be due to ionization inhomogeneities in the absorbing gas or the ionization structure in the broad emission line region. It has been shown that a few of the absorbing clouds do not cover all the three QSO images, especially it is concluded that the mini-BAL at z_{abs} = 3.712 covers only image C. *Narrow* components within the BAL flow show signatures of line-locking with velocity separations within 5 km s^{-1} of the O VI, N V and S IV doublet splittings. This strongly suggest the line driven radiative acceleration as an important process to explain the out-flow.

Structure of intermediate redshift Mg II and damped Lyα systems

It is known that the low-z ($<$ 1.0) Mg II absorption systems detected along the line of sight to high z QSOs are associated with extended gaseous halos of luminous galaxies (Bergeron & Boisse, 1991, A&A, 243, 344). The spectrum of the QSO APM 08279+5255 has revealed 9 Mg II systems in the redshift range $z \sim 1/2 - 2.1$. As APM 08279+5255 is a multiply imaged system, the spectra can be used to probe the structure of the Mg II systems. *Srianand* with Patrick Petitjean, Bastien Aracil, and Rodrigo Ibata has investigated the nature of the Mg II systems along this QSO.

Most of the detected Mg II systems though saturated, show large residuals at the bottom of the lines. The most likely interpretation is that the individual clouds within the Mg II halos do cover only one of the two brightest QSO images. The separation between the two lines of sight decreases from 1.7 to 0.7 h_{75}^{-1} kpc (Ω = 1, z_{lens} = 1) between z = 1.22 and z = 2.07. This reveals that the Mg II halos are made of a collection of clouds of radius smaller than about 1 h_{75}^{-1} kpc.

Two of the Mg II systems at z_{abs} = 1.062 and 1.181 are studied in detail. For the first time, absorption due to Na I doublet, that is usually seen in our interstellar medium, is detected in these two absorption systems. The presence of Na I and other neutral species provided good constraints on the models of the absorbing cloud. The column density ratio of Na I to Mg I is found to be larger than unity. This implied that the gas responsible for the absorption is neutral and cold. The Doppler parameter measured in individual and well detached components is as small as 1 kms^{-1}. The column densities of Na I, Ca II, Mg I, Ti II Mn II and Fe II observed at z_{abs} = 1.1801 are very close to that observed along the line of sight toward 23 Ori in our galaxy.

The shape of the QSO continuum is consistent with attenuation by dust at z = 1.0 ($A_V \sim 0.5$ mag). Altogether, it is found that the H I column density at z = 1 is of the order of (1 to 5) x 10^{21} cm^{-2}, the corresponding metallicity is in the range (1 - 0.3) $Z_\odot$, the overall dust-to-metal ratio is about half that in our galaxy and the relative depletion of iron, titanium, manganese and calcium is similar to what is observed in cool gas in the disk of our galaxy. The objects associated with these two systems could both contribute to the lens together with another possible strong system z_{abs} = 1.1727.

There is a possible damped Lyα system detected at z_{abs} = 2.974. The Ly α absorption line has a dark core, this means the transverse dimensions of the absorbing gas is larger than 200 h_{75}^{-1} kpc. Column densities of Al II, Fe II, Si II, C II and O I indicated abundances relative to solar of -2.31, -2.26, -2.10, -2.35 and -2.37 for Fe, Al, Si, C and O respectively. These surprisingly similar values indicate that the amount of dust in the cloud is very small as are any deviations from relative solar abundances. It seems likely that the upper limits for the zinc metallicity of several damped Ly α systems at $z > 3$ in previous studies is indicative of true cosmological evolution of the metallicity in individual systems.

Understanding the distribution of neutral hydrogen in the universe

As a part of the Indo-French project on "Semi-analytic Modelling of Structure Formation" *T. Padmanabhan, R. Srianand* and *Tirthankar Roy Choudhury* have started on a detailed investigation of the distribution of neutral hydrogen in the universe.

As a first part, they have obtained a semi-analytic procedure for evaluating the correlation function of neutral hydrogen along the line of sight to a quasar or in the transverse sky-plane. This result clarifies several issues related to the distribution of quasar absorption systems and the semi-analytic expression agrees well with observations. They have also indicated how this result could be of use in probing the power spectrum at the scales of (100-400) Mpc.

In a related work, the authors have made a series of line-of-sight numerical simulations of the neutral hydrogen in the universe and are using it to study different properties of quasar absorption systems. Preliminary results show that this approach is very useful in constraining different parameters of the IGM and detailed comparison with observation are possible.

Galactic Dynamics

Self–gravitating eccentric discs around black holes

The double nuclei observed in some galaxies, such as M31 and NGC4486B, could consist of an eccentric disc of stars orbiting the central black hole. Employing averaging techniques appropriate to dynamics within the radius of influence of the black hole, *S. Sridhar*, D. Syer, and J. Touma derive equations governing the structure of a cold, $m = 1$ eccentric disc that precesses steadily. Noting the connection with the Laplace–Lagrange discs of planetary dynamics, they formulate an eigenvalue problem, and present numerical solutions.

The pattern speed of the nuclear disk of M31 using a variant of the Tremaine–Weinberg method

The twin peaks in the nucleus of M31 have been interpreted by Tremaine as a thick, eccentric, disk of stars orbiting a supermassive black hole. A special feature of the eccentric disk model is that the brighter peak is thought to arise from the increased densities of stars in the vicinity of their apoapsides which are all postulated to be oriented in nearly the same direction. The dynamical alignment of the apoapsides of the stellar orbits could be maintained by self–gravity, and the whole structure might be a discrete, nonlinear eigenmode. The pattern speed of this mode could, in principle, be determined by the Tremaine–Weinberg (TW) method, which requires measurements of the surface brightness, and radial velocity along a strip parallel to the line of nodes. However, spectroscopic observations along the line of nodes are not available. *Niranjan Sambhus* and *S. Sridhar* have proposed a variant of the TW method, which exploits a basic feature of the eccentric disk model, to extract estimates of the pattern speed from *Hubble Space Telescope* spectroscopic data, taken along the line joining the two peaks. Within limitations imposed by the data, they estimate that the pattern corotates, with a period of more than $200,000$ years.

Kinetic theory of stellar systems in galactic nuclei

In the centres of galaxies reside dense stellar systems around massive, dark objects (MDO), which could be supermassive black hole. *S. Sridhar* has formulated the gravitational dynamics of this many–body system. The techniques of celestial mechanics enable the elimination of the coordinates of the MDO, resulting in a modification of the standard kinetic equation that governs time evolution of the stellar system; a new self–consistent term appears that allows for exchange of momentum between the MDO and the stellar system. When the mass of the MDO far exceeds the mass of the stellar system, the principle of averaging promotes a conserved quantity, thereby reducing the degrees of freedom. The kinetic equation now describes the slow evolution of an averaged distribution function, together with fast damping of fluctuations due to phase mixing; the back–reaction of the MDO contributes only indirectly, at the lowest order in the mass ratio. The kinetic equation could provide a new basis for analyses of familiar physical problems concerning stellar systems in galactic nuclei.

The bulges of galaxies

Amongst the most important issues in the research on formation of galaxies, are the epoch and physical mechanism of formation of the bulge. There are two competing models for the formation of bulges. One model assumes that the bulge and disk form independently, with the bulge preceding the disk while the other suggests that the disk forms first and the bulge emerges later from it.

These models can be compared using measurements of global photometric parameters that characterize the galaxy. The photometric parameters are determined using a technique of bulge disk decomposition developed by *Yogesh Wadadekar*

Figure 6: A 3-D view of the shape of the dust grain with host sphere of 7208 Silicate dipoles with an inclusion of three Graphite inclusions.

and *Ajit Kembhavi.* Habib Khosroshahi, *Wadadekar*, and *Kembhavi* have been involved in a project to study the bulges of early type disk galaxies and ellipticals in the near infrared band. Their analysis of a complete sample of early type disk galaxies has indicated that more than one mechanism of bulge formation may be at work. Bulges in early type disk galaxies may have formed at early epochs like in ellipticals, while the bulges in late type disk galaxies may be much younger. Their findings are corroborated by recent HST observations, which show that distinct bulge formation mechanisms operate for large and small bulges. The data on ellipticals was provided by Bahram Mobasher of the Space Telescope Science Institute.

The existence of a single mechanism of bulge formation for ellipticals and early type disk galaxy bulges, is indicated by the fact that both these kinds of 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 has indicated that they too lie on the photometric plane. Attempts to obtain a theoretical foundation for the photometric plane are on.

Galaxy and ISM

Interstellar dust and extinction by composite porous grains

Following the ongoing work on modeling of interstellar dust grains, *Ranjan Gupta*, along with D.B. Vaidya has initiated a new direction in the dust composition by attempting inclusions of graphite dipoles into the main silicate host sphere. Figure 6, shows such a typical dust grain with the host sphere consisting of 7208 silicate dipoles and three graphite inclusions.

Further investigations are in progress to obtain a satisfactory composition which can reproduce the observed interstellar extinction curve.

A proposal submitted by *Ranjan Gupta* and Asoke K. Sen, to India-Japan Cooperative Research Programme operated by DST, New Delhi and JSPS, Japan entitled "Light scattering by irregularly shaped particles" has now been approved. This proposal envisages collaboration with Tadashi Mukai of Kobe University, Japan and would lead to fruitful advances in the ongoing work.

Fluid Mechanics

Parity symmetry in magnetohydrodynamics and the geodynamo

The earth's magnetic field has existed for at least 3.5 billion years. Over most of this period, it has been predominantly dipolar, with polarity of either sign, lasting for periods from $5,000$ years to 50 million years. The reversal transitions occur quickly, between $5,000$ years and $20,000$ years. Without regeneration through a dynamo process, the field is expected to dissipate in less than $50,000$ years. Recent numerical simulations of the geodynamo have made remarkable progress in the modeling of three dimensional, time dependent, magnetoconvection in the liquid iron outer core, including viscous and electromagnetic couplings across the inner core boundary and the core mantle boundary. The simulations seem to produce magnetohydrodynamic (MHD) flows whose large–scale features show striking symmetries under parity operations about the centre of the earth; the long–lived, large–scale MHD flows in the earth's core are well approximated by even eigenstates of the parity operator. *S. Sridhar* has formulated even parity dynamics for dissipative, incompressible magnetohydrodynamics (IMHD), including Coriolis and buoyancy forces in the Boussinesq approximation. Even parity IMHD is described by one vector field, $\mathbf{w}$, instead of two; $\mathbf{w}$ is divergence–free, and obeys a non-local Navier–Stokes like equation. No dynamo action is possible for IMHD states with odd parity velocity fields, and magnetic fields of either parity; these are severely constrained, and non-trivial configurations might not even exist. In contrast, even parity velocities can co-exist with magnetic fields of either parity; these states arise naturally whenever the dynamics is dominated by the Coriolis and Lorentz forces. Rotational, and magnetic axes are often misaligned in the earth, planets, and stars; parity symmetry, and its violation, perhaps offers a better approach than equatorial symmetry.

Stellar Physics: Compact Remnants

Neutron stars are one of the most compact objects in the universe. They manifest themselves in the form of pulsars and galactic X-ray sources. Pulsars are believed to be rotating neutron stars having magnetic fields between 10^8 G and 10^{13} G, while most of the galactic (stellar) X-ray sources contain neutron stars accreting from a supergiant, ordinary giant or dwarf star. Observational studies of these objects present us with phenomena that occur either in high magnetic field environments and/or in high gravitational fields where general relativity plays an essential role. Extracting information of the composition of matter in the interior of neutron stars has been the 'holy grail' of neutron star studies. At present, our understanding of neutron star interior (the equation of states) stems from nucleon-nucleon scattering experiments and extrapolation of known nuclear properties (in terrestrial conditions) to ultra-high densities. Astrophysical observations and subsequent theoretical modeling of phenomena related to neutron stars, therefore, provide a means to constrain nuclear properties.

Neutron stars: accretion and rotation

X–ray binaries that contain a compact object accreting from a dwarf star are called low mass X–ray binaries (LMXBs). On the observational front, it has been found by the Rossi X–ray Timing Explorer (RXTE), that the flux from certain LMXBs exhibit very rapid oscillations (frequencies ranging from a few 100 Hz to about a 1000 Hz). These are ascribed to arise due to Keplerian motion of matter in the inner regions of the accretion disk, very close to the central compact star. The hardness-intensity co-variation in LMXBs suggests that these are of two types: the Z sources and the atoll sources. The quantity that plays a key role in deciding the difference in emission from these sources, is believed to be the magnetic field. Since LMXBs have low magnetic fields, it is most likely that the competition between strong gravitational field near the magnetospheric radius controls accretion flows. *A.V. Thampan* and A.R. Prasanna are currently calculating the magnetospheric radius in the curved space–time geometry around non–rotating and rotating neutron stars. Preliminary results prove to be promising. Accreting matter in the inner regions of the accretion disk, deposit considerable amount of angular momentum onto these objects. In consequence, it is believed that they will be spun up to millisecond periods, over dynamical timescales of binaries (10^8 yrs). An interesting question in this regard is, 'how does the structure of the neutron star evolve with accretion?' *Thampan* and D. Bhattacharya have evolved a programme for calculating the structural and angular momentum evolution for accreting neutron stars. The calculations are currently underway.

S. Bhattacharyya, *R. Misra* and *Thampan* have calculated the spectrum of an accretion disk around rapidly rotating neutron stars. This is currently being applied to the source: Cyg X–2 with the aim of deriving constraints on the structure parameters of the central accretor.

Strange stars: accretion and rotation

There have been suggestions since quite sometime now that the absolute ground state of matter might be a homogeneous mixture of u, d and s quarks (termed as strange quark matter) instead of ^{56}Fe. A conglomeration of this matter in the form of a compact object, is called a strange star. Suggestions about the existence of strange stars have recently got a fillip from observations of certain low mass X-ray binaries (X-ray binaries containing a Roche–lobe filling dwarf star as the secondary).

B. Datta, *A.V. Thampan* and Bombaci undertook a study to provide possible signatures for strange stars in stellar X–ray binaries. They found that rotating strange stars can generate Keplerian frequencies about a factor 2 higher than those produced by rotating neutron stars. On the basis of this, they conclude that if frequencies of about (1.9–3.1) kHz if found in LMXBs, then these can be understood in terms of a (nonmagnetized) strange star X-ray binary (SSXB) rather than a neutron star X-ray binary (NSXB).

Further to this, Bombaci and *Thampan* are in the process of calculating equilibrium sequences of rapidly rotating strange stars. Preliminary results for a particular frequency of rotation, show that some of the strange stars and almost all of the neutron stars EOS may be ruled out for the central accretor in the source 4U 1728 -34.

Calculations by *Thampan* and Bombaci are also underway to estimate the energy release from the boundary layers of such rotating and accreting strange stars.

Multi-polar magnetic fields of isolated neutron stars : Effect of equations of state

Multi-polar magnetic fields have long been invoked for the generation of electron positron pairs in the pulsar magnetosphere. Magnetic multipole structure at and near the polar cap is also thought to be responsible for the unique pulse profile of a pulsar. Significant evolution in the structure of the magnetic field during the lifetime of a pulsar may, therefore, leave observable signatures. In an earlier work *S. Konar* and D. Mitra investigated the evolution of multipolar structure of magnetic field of isolated neutron stars assuming the currents to be confined to the crust of the stars. They found that except for very high order multipole ($l \gtrsim 25$), the evolution is similar to that of a dipole. Therefore, no simplification of pulse profiles of isolated radio pulsars with age is expected on this count. More recently, they have investigated the effect of various equations of state on the evolution of the multi-polar structure. Though qualitatively the nature of the evolution is similar, regardless of the equation of state - the change is more pronounced in a star with a stiffer equation of state than with a softer equation of state.

Effect of curvature of spacetime on the magnetic field of neutron star

The literature dealing with the evolution of magnetic field in neutron stars, in general, neglect the effect of the curvature of the spacetime. Recently, it has been reported that such an assumption may not be correct and the field evolution may be seriously affected when the curvature of the spacetime is taken into consideration. *S. Konar* has considered both isolated as well as accreting neutron stars and have solved for the evolution of the magnetic field with full general relativistic equations. These calculations show that the change, compared to the case without taking the relativistic corrections into account, is between 3% and 5%. Hence, the neglect of the curvature of the spacetime while calculating the evolution of the neutron star magnetic field is quite justified.

Coupled spin and magnetic field evolution of neutron stars in X-ray binaries

It is a well established fact that the magnetic field of ordinary (non-*Magnetars*) neutron stars decay is significant only if they are part of a binary system. Even though many population synthesis studies have been done to understand the nature of binary evolution, so far a self-consistent study of coupled spin and field evolution has not been investigated thoroughly. In this study, *S. Konar*, D. Bhattacharya and T. Tauris have incorporated the magnetic field evolution of neutron stars within the scheme of the binary evolution. Their objective is to follow the trajectory of a binary neutron star in the field-period diagram and compare it with the inferred pulsar tracks. This work is in progress.

Evolution of magnetic field in neutron stars accreting at super-Eddinton rates

Recent work shows that the crustal physics of a neutron star accreting at Eddington or super-Eddington rates is likely to be very different from that of a star accreting at much lower rates. The crustal composition changes substantially and with a very large effective impurity content, the crust behaves more like a liquid than a crystal lattice. Also, the heating produced due to stable nuclear reaction in the crust gives rise to a temperature inversion near of beyond the neutron drip point. These effects significantly alter the evolution of a crustal magnetic field. *S. Konar* is investigating the nature of field evolution and compare the results with the case for low rates of accretion.

Absorption of electro-magnetic waves in a magnetised medium

In continuation of an earlier work, in which the structure of the vacuum polarization tensor, in presence of a background electromagnetic field in a medium, was analysed. *S. Konar*, A.K. Ganguly and P.B. Pal calculate the absorptive part of the vacuum polarization tensor. Using the real time formalism of the finite temperature field theory, they arrive at the absorptive part of the 1-loop vacuum polarization tensor and calculate its magnitude in the weak field limit ($eB < m^2$) and estimate the decay probability of the real photons under different physical conditions of the background medium.

High energy emission from neutron stars

F. Sutaria was studying high energy emission from isolated neutron stars, and from neutron stars in X-ray binaries, and the consequences of these observations on the internal structure of the neutron star and its evolution.

The high-energy spectrum (from optical to gamma-ray) of rotation powered pulsars is usually found to be a combination of three components: (1) power-law emission, resulting from non-thermal radiation of particles accelerated in the pulsar magnetosphere, (2) soft blackbody emission from cooling of the neutron star, and (3) a hard component emitted by the heated polar caps. The non-thermal emission serves to probe the properties of the neutron-star magnetosphere, e.g., particle acceleration models and radiation processes of energetic charged particles in magnetosphere. The non-pulsed thermal component gives a direct measure of neutron star surface temperature, and thus provide an insight into crustal properties (e.g., thermal conductivity, dissipative processes leading to magnetic field decay), which controls the cooling rate as well as into possible neutron star reheating mechanisms. Together, the pulsed and the non-pulsed components also serve as an indirect probe of the neutron star equation of state and of the physical conditions within the superfluid interior.

The project, *Sutaria* is involved in, is two pronged – on the observational front, she and her collaborators attempt to carry out multiwavelength observations of pulsars, specifically seeking for either optical or X-ray counterparts of radio pulsars, which have also been detected in any of the high-energy bands. One example is PSR 1821-24, which has been detected in the X-ray band, and for which the optical limit has been set in the present work. Theoretically, old neutron star like this ($\tau >$ few $\times 10^6$) would have been expected to have the surface temperature $T < 10^5$ deg K and would be expected to continue cooling, unless reheating mechanisms like frictional interaction between a rapidly rotating superfluid core and the solid crust causes dissipation of energy.

On the theoretical front, *Sutaria*, A. Ray and B. Taam are looking at the change in the composition and structure of the crust of a neutron star in a compact binary, as it accretes matter from its binary companion. It has been theorised that the source of energy in both type I and Type II X-ray bursts from compact binaries could be due to explosive thermonuclear burning of the accumulated fuel on the surface of the neutron star. Since the composition of the accreted matter would be hydrogen dominated, all the present literature in this field upto now has only taken into account hydrogen and He-burning through a rapid proton capture (rp-) process. This proposal attempts to examine the possibility of a rapid neutron capture (rn-) process taking place close to the neutron star surface on the products of the rp-nucleosynthesis. The neutrons participating in this process would be emitted due to neutron emission, either during rp-process, or due to the neutrons generated by electron captures on the protons. Another goal of this theoretical study is to see how this would influence the evolution of the neutron star's magnetic field, and change the rate of cooling of the neutron star – both phenomenon for which considerable observational input exists in the form of AXPs, magnetars, and millisecond pulsars for the former and multiband observations of pulsars for the latter.

They have also looked at the effects of vacuum oscillations on the neutrinos emitted during the collapse phase of a type II Supernovae.

Instrumentation

Photometer for IUCAA guest observing programme

Under the IUCAA guest observing programme, a SSP-3 photometer and a small portable optical fiber-fed spectrometer were acquired and tested for obtaining bright star spectra with the IUCAA 16" Meade telescope. This will be used for training various university groups who visit IUCAA for learning the usage of telescope.

Automated photoelectric telescope by the universities

The automated photoelectric telescope (APT) under process of installation at Bhavnagar University by IUCAA Associate, S. P. Bhatnagar has undergone some major software modifications in collaboration with *Ranjan Gupta*. This telescope is currently under test observations and the new modifications will be eventually extended to the existing APT under development by Bangalore University at IUCAA visitor laboratory.

CCD cameras

The work on CCD camera controller version 3 is continued. The controller has been completely tested with a Loral 2K x 2K CCD. This system is now ready to be used. The version 3 controller has also been used to test a EEV 2K x 2K CCD on a dummy mount. Additional features to the controller have been added in the form of filter wheel motor controller and driver to handle two stepper motors. *S. N. Tandon, D. V. Gadre, T. Deoskar, P. A. Chordia* and *R. S. Kharoshe* contributed to the development of the controller, while *S. N. Tandon, H. K. Das* and *T. Deoskar* managed the CCD performance evaluation and tests. *V. Mestry* provided support for all mechanical fabrications.

The thermo-electrically cooled CCD camera, which is now a fully working design was duplicated by A. Bhattacharyya of Jadavpur University for use on their telescope as well as for RF plasma diagnostics. A group of engineering students, as part of their final year project, working under *S. N. Tandon* and *D. V. Gadre*, demonstrated the possibility of further compact-ing this CCD camera. Future versions of the thermo-electrically cooled CCD camera will incorporate these changes.

Imager spectrograph for IUCAA telescope (IFOSC)

As reported earlier, a versatile imager spectrograph is being developed for the IUCAA telescope, in collaboration with the CSIO of Chandigarh, and Copenhagen University Observatory of Copenhagen. As the weather has a lot of variability, there is a great advantage in having focal plane instruments which can be switched from one mode to the other, e.g., from photometric imaging (which requires excellent conditions) to spectroscopic observations (which can be done in less than excellent conditions). The instrument would be similar to the well known instrument EFOSC of the European Southern Observatory, and it would have 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. The main optics of the spectrograph is now integrated with the main body, and testing of the full spectrograph is expected to be done in Copenhagen during the month of June 2000, after the prisms have been completed.

Tools for multislit spectroscopy are being developed to allow simultaneous spectroscopy of multiple point objects, e.g. stars in a cluster. The approach is to use the easily available facilities for making electronics PCB, for generating multiple slits on a foil of copper, which can be pasted on a suitable metal holder and mounted on the slit-wheel of the spectrograph.

A calibration unit, consisting of filter wheels and calibration lamps, to be used for observations with this spectrograph and other instruments is under development, fabricated at Copenhagen and the optics being made at Chandigarh. *H. K. Das, A. Kohok,* and *S. N. Tandon* have been working on this; the Council of Scientific and Industrial Research, and the Department of Science and Technology are providing financial support for this instrument.

Observatory control system

The observatory control system design has been completed. A modular client server based design has been adopted to integrate all the devices in the observatory together. To this end, an integrated architecture framework as well as interface structure for individual components were defined. The structure has been implemented with respect to the software layers of CCD camera, data management components, user management components, etc.

A new model for astronomical instrumentation and software layers has been proposed and implemented. A scheduler interface, both stand alone and web based has been designed and integrated into the system. The output of the scheduler may be used to activate the observatory and the executive layer which makes this possible has also been designed. This effort was led by *S. Engineer.*

A fibre fed spectrograph (SILFID)

This project was undertaken with a desire to provide the Vainu Bappu Telescope of the Indian Institute of Astrophysics with a versatile and efficient spectrograph, and is funded by the Indo-French Centre for the Promotion of Advanced Research as a Indo-French collaboration. It involved modifying an existing French spectrograph to match the Vainu Bappu Telescope and to carry out observations with it.

The spectrograph has been modified to match the telescope and is now equipped with its own autoguider, which can guide on stars as faint as magnitude 17. The spectrograph can be used for: wide field imaging, long slit spectroscopy, and for imaging spectroscopy over a circle of diameter 20 arcsec in the visible band.

This spectrograph would be commissioned on the telescope during April 2000. *H. K. Das* and *S. N. Tandon* have been working on this project. The main external collaborators are : Indian - R. Cowsik of the Indian Institute of Astrophysics, French - C. Vanderriest and G. Herpe of Observatoire de Paris, Meudon.

(II) RESEARCH BY ASSOCIATES/SENIOR ASSOCIATES

This account is based on the reports received from associates / senior associates, who were asked to highlight the work done through interaction with IUCAA. While every attempt was made to make it exhaustive, not all associates /senior associates responded in time and so this account is unavoidably incomplete.

Quantum Theory and Gravity

Quantum cosmology

Subenoy Chakraborty

The discovery of new variables by Ashtekar has provided a step forward towards canonical formulation of a quantum theory of gravity. These new variables reduce the constraint equations to simple polynomial form so that quantum formulation is possible. S. Chakraborty and N. Chakraborty have applied these new variables to quantum cosmology to find the wave function of the universe. They have formulated a quantization programme for a particular mode. They have also studied classical solutions using Ashtekar variables for a spherically symmetric spacetime model and known classical solutions have been obtained. S. Chakraborty and L. Biswas have obtained domain wall solutions in a non-static general relativistic spacetime model. Also, motion of test particles in the gravitational field of topological defects have been studied.

Quantum field theory in curved spacetime

S. Biswas

The complex time WKB (CWKB) approximation has been an effective technique to understand particle production in curved as well as in flat spacetime. S. Biswas has generalized the technique of CWKB to the equivalent problems in space dependent gauge. Using CWKB, he has obtained the gauge invariant result for particle production in Minkowski spacetime in strong electric field. He has carried out particle production in de Sitter spacetime in space dependent gauge and obtained the same result that was obtained earlier in time dependent gauge. This ensures the gauge invariant description inherent in CWKB. The results obtained for de Sitter spacetime has an obvious extension to particle production in black hole spacetime. It is found that the origin of Planckian spectrum is due to repeated reflections between the turning points.

The CWKB has an in built feature of rotation of currents, i.e., particle-antiparticle rotation. S. Biswas has demonstrated this generalized result for scalar particle production in curved spacetime. To understand the behaviour of current as it evolves in curved spacetime, he has also studied numerically the evolution of currents in matter dominated, radiation dominated and de Sitter spacetime. The characteristic feature of the current in de Sitter spacetime is that it undergoes rapid oscillations.

Quantum to classical transition of the universe is now being investigated by many workers. The wavefunction of the universe, predicting the quantum state at early times is now under 'debate' w.r.t. ascertaining the boundary conditions at early times. Biswas has considered the Starobinsky model of spontaneous transition due to one loop quantum correction, to calculate the wavefunction of the universe.

Using the wormhole dominance hypothesis proposed by Biswas, it is shown that Starobinsky's description is consistent with Hartle-Hawking's no boundary proposal for the wavefunction of the universe. He has also studied decoherence in the Starobinsky model and finds that the scale factor emerges as a classical variable during quantum to classical transition.

Biswas has investigated the quantum gravity equation in Schrödinger form in minisuperspace description. Biswas, in collaboration with B. Modak and S. Kamilya, has calculated the gravitational coupling function in the vacuum scalar-tensor theory as allowed by the Noether symmetry.

Particle Physics and Field Theory

P.N. Pandita

There is considerable interest in the study of baryon (B) and lepton (L) number violation, especially in the supersymmetric extensions of Standard Model (SM). This interest follows from the fact that in the Minimal Super-symmetric Standard Model (MSSM) and its extensions, there are Yukawa couplings which violate baryon or lepton number. P.N. Pandita along with B. Ananthanarayan and P. Francis Paulraj, has carried out a detailed renormalization group studies of these B and L violating Yukawa couplings involving the highest generation, and the corresponding soft supersymmetry breaking parameters. It has been shown that in the Yukawa sector, there is only one infra-red 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. From the fixed point behaviour, upper and lower bounds on the baryon number violating coupling, as well as on the soft supersymmetry breaking parameters, have been obtained.

P.C. Vinodkumar

P.C. Vinodkumar has been working on the spectroscopy of light-heavy, and heavy flavour hadrons based on qcd motivated models. A unified confinement scheme based on gauge constraints on pure gluon fields has been proposed and successfully employed for the study of these hadrons. He has been able to show the importance of the confined gluon exchange effects in the spectroscopic study of hadrons. Drawing parallels between qed and qcd, he has studied bound quark atoms and qcd-molecules to quantify the residual nonlinear colour contribution in the low energy strong interactions. The dynamical differences between the qed and qcd media at this non-perturbative regime has been extracted through an effective medium coefficient from this effort.

Within the qcd motivated unified confinement scheme, the distinct possibility of a massive neutron under going a phase transition to quark star has been studied by Vinodkumar. A massive neutron star under going a transition from hybrid structure to a pure degenerate quark star has been attempted based on the qcd motivated equation of state studied earlier. Some of the critical parameters of the de-generate quark star have been predicted by him. The consequences of the existence of pure qcd phase in a collapsing star and their right identification based on the colour properties, etc. are some of the problems that he is working on.

Quantum theory

Renuka Datta

The final remark of the EPR paper is that "one would not be able to arrive at the conclusion that quantum mechanical description of physicsl reality given by wave functions is not complete if two or more physical quantities are regarded as simultaneous elements of reality only when they can be simultaneously measured or predicted". On this point of view, because of the collapse of the wave function of the combined system, the EPR entangled relations (or correlations) of momenta and positions belonging to two spatially separated particles considered in the first part of the paper do not hold good simultaneously for two separate measurements. This case does not reconcile with the locality principle and hence, exhibits quantum nonlocality. Moreover, it is quite compatible with uncertainty principle.

Nonlinear dynamics

G. Ambika

G. Ambika with K.I. Thomas, has completed the analysis of the effect of parametric and quasi-periodic modulations in suppressing horseshoe structure in the phase plane of perturbed pendulum systems using Melnikov integrals. Taking the Froude pendulum as an example, four different modulations are studied from the point of view of flexibility and efficiency. The work is now continued to detail the stability regions in the global parameter space of the system by combining the technique of harmonic analysis with modulation and reduction to the Mathieu equation.

Two parameter one dimensional maps are useful in modeling many coupled systems. With her student, Sujatha N.V., Ambika has worked out the basic characteristics that make these maps support phenomena like bistability and bubbling in their bifurcation scenario. This is now being extended to higher dimensional maps and continuous systems.

The nonlinear time series analysis on the light intensities of irregular variable stars, started with A.K. Kembhavi of IUCAA and J.A. Mattei of AAVSO is continued. By isolating the periodic components from the data, the residuals in each case is studied from the point of view of nonlinear dynamics.

M.K. Das

The problem of approach to thermal equilibrium of a system has been investigated by several authors after the unexpected results obtained in the famous FPU problem. Long-time behaviour of one dimensional coupled chain under harmonic and anharmonic forces is known to be nonergodic. The extension of one dimensional case to two dimensional one makes the model much more realistic to investigate the problem of attaining thermal equilibrium as the presence of nonlinear coupling between particles in two dimension may result in ergodicity. L.M. Saha, M.K. Das and Y. Tanaka have studied how random perturbations may affects the approach of a system, in two dimension, towards thermal equilibrium. The model chosen here is that of a two-dimensional lattice of N-identical particles. The control parameters of the system are taken to be anharmonicity and the strength of the external random perturbation. Numerical results on the long term influences of these parameters on the averages of velocilities, energies of different particles for different values of N, etc. were obtained.

V.C. Kuriakose

Fluxon dynamics in long Josephson junctions have been studied for information processing and computing applications. Shaju and V.C. Kuriakose have studied the fluxon dynamics in inductively coupled Josephson junctions and realised using numerical simulations that the system can generate the functions of various logic gates and the calculations are extended to three inductively coupled Josephson junctions. Bindu and Kuriakose studied nonlinear wave propagation through cold collisionless plasma using reductive perturbation method. It is found that different kinds of solitary waves can be generated in the plasma depending upon the orders of perturbation considered. It is found that these waves can interact and can result in novel features which are not possible in soliton-

soliton interactions of the usual type. It is found that waves evolve into a chain of solitons of different amplitudes and speeds. Solitons in optical fibres attract interests from a wide area of science and technology and is being hoped that all future communications will be of soliton type. Nonlinear Schrodinger type equations are used to describe soliton propagation through fibres. There are several factors like inhomogeneity, fibre loss or gain, etc. that can affect the wave propagation and then one has to use inhomogeneous nonlinear Schrodinger equations. Ganapathy, Vinoj and Kuriakose have studied some coupled inhomogeneous NLSEs and obtained the soliton solutions and these equations may find applications in optical switching devices and communications.

Classical Gravity

Exact solutions to Einstein's equations

Zafar Ahsan

It is well known that Petrov type N solutions of Einstein vacuum field equations are amongst the most interesting but rather difficult and little explored of all empty spacetime metrics. From the physical point of view, they represent spacetime filled up entirely with gravitational radiation, while mathematically they form a class of solutions of Einstein equations which should be possible to determine explicitly. Considering the free gravitational field to be the transverse gravitational wave zone which can be identified as Petrov type N gravitational field. Zafar Ahsan has studied on the interaction of Petrov type N gravitational fields and the null electromagnetic fields. These interacting fields are known as the pure radiation fields (PR fields). Using Newman-Penrose formalism, a metric describing the behaviour of PR fields has been obtained. The common propagation vector of these interacting fields is geodetic, shear-free, twist-free and non-expanding and it is seen that along this propagation vector with such pure radiation fields do not admit Ricci collineation and motion, but do admit Maxwell collineation.

A physical field is always produced by a source, which is termed as its charge. Manifestation of fields when charges are at rest is called electric and magnetic when they are in motion. This general feature is exemplified by the Maxwell theory of electromagnetism from which the terms of electric and magnetic are derived. This decomposition can be adopted in general relativity and the Weyl tensor can be decomposed into electric and magnetic parts. Based on this decomposition of the Weyl tensor and by considering purely magnetic spacetimes, Zafar Ahsan has given a classification of the spacetimes.

Zafar Ahsan has obtained the necessary and sufficient conditions for perfect fluid spacetimes to admit space-like Ricci inheritance vector (RIV) in terms of the kinematical quantities of the space-like congruences generated by a unit vector n^a orthogonal to flow velocity vector u^a. Moreover, the stiff equation of state is seen to be related to the vorticity vector. For isotropic and homogeneous universes, dust universes and irrotational dust universes, the existence of RIV is obtained in terms of the expansion and shear of the space-like congruences generated by n^a, and for irrotational dust universe, the integral curves of n^a are found to be the material curves.

Raj Bali

Raj Bali, in collaboration with K. Sharma has considered tilted Bianchi Type I models with heat conduction filled with disordered radiation of perfect fluid in general relativity. To get a determinate solution, they composed a supplementary condition $A = (BC)^n$ between metric potentials. They also discussed the case with $A = (BC)^{1/3}$, for which tilted nature of the model is preserved. The physical and geometrical aspects of the models were considered. One of the models has a point type singularity at $t = 0$.

A. Banerjee

The study of dilaton gravity in compact objects as well as cosmology has been a subject of interest in recent years. Dilaton fields appear to be coupled with the Einstein-Maxwell fields when the low energy limit of the string is considered. A. Banerjee and T. Ghosh have recently studied a few anisotropic Bianchi models in the presence of a dilaton field coupled with a kind of primordial magnetic field. All the models with $k = 0, +1, -1$ are studied and compared with the other anisotropic models. Similar solutions exist for certain Liouville type potentials for the dilaton. The work was extended by Banerjee, Ghosh and S. Chatterjee to cylindrically symmetric spacetime in the presence of both the electric and magnetic fields.

S. Chaudhuri

Exact solutions of Einstein and Einstein - Maxwell field equations with / without external gravitational as well as electromagnetic fields have immense importance in the analysis of the characteristics of astrophysical objects. S. Chaudhuri constructed some exact solutions for stationary axisymmetric spacetimes under the influence of external gravitational fields. The generated solutions generalize Kerr metric and are spatially well behaved. The solutions possess an event horizon. The infinite red shift surface becomes distorted due to the influence of the external superposing field.

In addition to stationary gravitational solutions, Chaudhuri constructed some magnetostatic solutions of Einstein-Maxwell field equations by the technique of Das and Chaudhuri (Pramana-J. Physics, Vol. 40, 277 (1993)). The solutions are asymptotically flat and reduce to the Schwarzschild solution when the magnetic parameter is switched off.

Chaudhuri, in collaboration with M.K. Ray and S. Banerji, has been studying the theoretical model of a void. The core of the void is assumed to be filled up with a conducting fluid of low density (Maity spacetime), surrounded by a spherical shell of radiation (Vaidya space-time). The combination is then embedded in a Robertson-Walker universe with non-flat spatial curvature. If the time coordinate is future directed everywhere, the void appears to contract for a comoving observer as the universe expands. However, in a matter dominated universe (i.e., for zero pressure), the void remains static.

V.O. Thomas

V.O. Thomas is working on exact solutions of Einstein's field equations of spherical distributions of matter on the background of pseudo-spheroidal spacetime in collaboration with R. Tikekar. Senovilla's remarkable discovery of singularity-free solutions with cylindrical symmetry led researchers to search for singularity-free cosmological models with spherical symmetry. N. Dadhich, L.K. Patel and Tikekar have obtained such solutions. In collaboration with Dadhich, V.O. Thomas is also working on singularity-free cosmological models, with spherical symmetry. He has considered singularity-free models with matter distribution in the form of perfect fluid accompanied by radial heat flux.

K.K. Nandi

A very important phenomenon in physics is Sagnac effect. Recently, a similar effect has been proposed in the field of Kerr gravity. K.K. Nandi, in collaboration with James Evans and Paul Alsing, is engaged in finding out the effect of scalar field on this phenomenon, and the prospect of an experimental detection of the scalar field which is supposed to be manifested through that effect.

Higher dimensional theories

A. Banerjee

It is well known that the introduction of extra dimensions to the usual four dimensional spacetime of general relativity often increases the mathematical complications but at the same time may lead to many new results. A. Banerjee and Ajanta Das considered Kaluza Klein type five dimensional cylindrically symmetric spacetime with a source free magnetic field contained by the curvature of spacetime generated by its own strength. The major features are not much different from that due to Melvin's magnetic universe, although there is an interesting feature that near the axis of symmetry, the 5D spacetime exhibits a conical defect, similar to that in the case of a cosmic string.

Alternative theories of gravity

S.S. De

Recently, the original formulation of the modified general relativity (MGR) of Rastall has been found to be equivalent to the gravitational field equations derived by Al-Rawaf and Taha with the use of conventional heuristic methods but not requiring energy-momentum conservation. This MGR theory contains an extra independent constant η, which is peculiar to the non-Newtonian regime, besides the usual gravitational constant. The usual general relativity (GR) appears here as a special case for $\eta = 1$. By employing MGR, S.S. De has dealt with particle creation and the production of specific entropy per baryon in the early universe regarded as a thermodynamically open system in the sense of Prigogine. With a modified thermodynamic energy conservation law, it was possible for him to obtain an equation for the expansion scalar by incorporating the epoch dependence of elementary particle masses. The epoch dependence of particle masses for the Robertson-Walker universe appears as a consequence of his earlier works on hadronic matter extension in an anisotropic Finslerian microscopic spacetime. De obtained a solution that represents a mild inflationary phase in the very early universe. It is also shown that there are no 'turn-on' and 'turn-off' problems for this mild inflation. It can account for particle creation and production of specific entropy per baryon consistent with the observation. De has also considered the production of specific entropy in the MGR framework with the introduction of viscous pressure. It is found that the calculated value is in good agreement with the observation for the GR case, but for MGR case, in order to have its value within observational limits, η should lie in the range $0.75 < \eta < 1$. Interestingly, this formalism does not have horizon and flatness problems.

G.P. Singh

In addition to Einstein's general theory of relativity, many alternative theories have been proposed to explain the cosmological problems of the early universe. Brans-Dicke theory (BDT) has taken considerable attention due to the fact that it solves several cosmological problems, particularly the graceful exit problem in natural way, without recourse to any fine tuning as required in general relativistic models. G. P. Singh, in collaboration with A. Beesham has considered the effect of particle creation and bulk viscosity as separable irreversible processes in the framework of the BDT. In this study, a class of physically plausible models have been taken into consideration. He has also studied the effect of particle production on the evolution of the spatially flat FRW cosmological models during early stages of the universe in reference to higher derivative theory. This investigation shows that during early stages, universe has high energy density, particle number density and temperature in comparison to standard cosmology. At late epochs, both higher derivative theory as well as general relativity give similar results.

S.K. Srivastava

If coupling constants, in the higher-derivative gravitational action, are chosen properly to avoid the ghost problem, the Ricci scalar also behaves like a spinless matter field in addition to its usual nature as a geometrical field. Physical aspect of the Ricci scalar is manifested by scalar fields of unit mass dimension. Particles represented by these fields are called riccions. S.K. Srivastava has found that riccions also behave like instantons and instanton solutions yield primordial inflation in the early universe.

In another work, using dual role of the Ricci scalar, he has obtained cosmological models of the early universe using physical techniques of the phase transition and spontaneous symmetry breaking.

He has also obtained one-loop multiplicatively renormalizable theory for riccions and found that phase transition takes place around 10^{16} GeV indicating decoupling of gravity from other forces. Also, the spacetime above this scale is found to be fractal.

Gravitational wave data analysis

D.C. Srivastava

Pulsars are important sources of gravitational radiation (GR). The signal from pulsar is very weak and is masked by the broadband noise of the detector. In order to achieve appreciable signal to noise ratio, a strategy could be to analyse the data for longer observation time extending over months/year. But the long integration time introduces amplitude as well as the frequency modulation (FM) in the detector output arising respectively due to the quadrupole nature of GR and due to the translatory motion of Earth around the Sun. D.C. Srivastava with his group is engaged in the analysis of the Fourier Transform (FT) of the pulsar signal. They have analysed their earlier results on FT for one day observation time to see the power spectrum with a view to determine how close two points on the sky are to be taken in order to have indistinguishable features. The angular resolutions, thus, determine the size of the patches, i.e., the area of the sky for which similar corrections are required. They have found that the number of patches are approximately 1.5 order smaller than well known estimate of Schutz. They have recently obtained FT for one year observation time. These results are important in the sense that here they have incorporated the amplitude modulation, whereas in the earlier investigations only the FM was considered.

Cosmology and Structure Formation

Moncy John

Recent observation of the magnitudes of high-redshift supernovae by S. Perlmutter, et al., if interpreted in the light of standard cosmology, which contains matter and a very small cosmological constant, indicates the possibility of an accelerated expansion for the universe. Moncy John and K. Babu Joseph have proposed a new cosmological model by generalising an ansatz by W. Chen and Y. Wu, which envisages a time-varying cosmological constant. This new model has a coasting evolution; i.e., the scale factor varies linearly with time. This model has a temperature evolution almost the same as that in the standard model, but has many striking features like the absence of horizon, flatness, monopole, entropy, size, age, cosmological constant and generation of density perturbations at scales much greater than the present Hubble radius in the classical epoch. They also attempt to show that the observational data of Perlmutter, et al., is a more natural consequence of this model.

V.C. Kuriakose

The concept of spontaneous symmetry

breaking plays an important role on the evolution of the early universe and the early cosmology could then be described by a sequence of phase transitions. Quantum fields have a profound role on the dynamical behaviour of the early universe. Quantum field theory in an external gravitational field is usually regarded as a first step towards a more complete theory of quantum gravity. The effect of curvature on model field theories used to describe phase transitions is a topic of current interest. Minu Joy, Ravikumar and V. C. Kuriakose have been studying the effect of curvature on a massive quartic self interacting scalar field nonminimally coupled to gravity in a Bianchi I universe in $(2+1)$ and $(3+1)$ dimensions, using effective loop expansion method. The calculations are extended to include the effect of temperature on symmetry breaking and to understand the nature of phase transitions occurring in these systems.

Quark-gluon plasma and early universe

Deepak Chandra

It is well known that a phase transition from quark-gluon plasma to confined hadronic matter must have occurred at some point in the evolution of the early universe. This leads to an exciting possibility of the formation of quark nuggets through the cosmic separation of phases. Deepak Chandra, along with Ashok Goyal has studied the dynamics of this first order phase transition when the universe was 10-50 microseconds old with quarks and gluons condensing into hadrons. They have looked at the evolution of the universe in small as well as large super cooling scenario, specifically exploring the formation of quark nuggets, their possible survival and identification with the recently observed dark objects in our galactic halo which may account for the dark matter component in the universe.

Quasars

Pushpa Khare

Knowledge of the shape and the intensity of the intergalactic UV background radiation is crucial for the understanding of structure formation and evolution in the early universe. With the aim of determining these, P. Khare has studied the ionization conditions in several high column density, intervening, absorbers, for which an estimate of particle density was available from observations of fine structure excited lines of C II. The background flux was found to be considerably higher than that contributed by the known QSOs. It was also shown that in a few systems, only a part of the required flux can come from galaxies, which indicates the presence of an unseen population of QSOs.

Galactic Dynamics and ISM

Galactic dynamics

D.K. Chakraborty

Projected properties of triaxial mass models are found to exhibit correlations, which can be exploited to set constraints on the intrinsic shapes of the ellipticals. The axis ratio $(\frac{b}{a})$ of the approximate elliptical constant surface density contours, evaluated at very small and large radii, are found to be correlated when a model with given shape parameters is projected in all possible viewing angles. Further, these correlation patterns are distinct occupying non-overlapping region in the parameter space of $(\frac{b}{a})$ at small and large radii. The situation is quite favourable for the intrinsic shape estimation by applying the techniques of Baysian Statistics. D. K. Chakraborty, along with Parijat Thakur has studied the projected properties of triaxial generalisation of modified Hubble model and of Denhan's γ - model.

The radial dependence of the density of these models is different both at small and large radii. However, both show correlation patterns between the above mentioned observed variables. These correlation patterns are qualitatively similar for both the models. The shape determination of test cases when a 'galaxy' from the model itself is chosen, are found to be satisfactory. The likelihood is sufficiently sharply peaked and further most - the probable shape of the 'galaxy' falls within 1σ level of its true shape.

C.J. Jog

C.J. Jog has studied the dynamics of the response of an axisymmetric galactic disk in a spiral galaxy to a lopsided (m=1) perturbation halo potential. The self-gravitational potential corresponding to the non-axisymmetric disk density response is obtained by inversion of Poisson equation for a thin disk using the Hankel transforms of the potential density pairs. The disk response potential is shown to oppose the imposed lopsided potential. The self-consistent calculation shows that the net lopsidedness in the disk is important only in the outer disk and its magnitude increases with radius. This is exactly in agreement with the recent near-IR observations in the literature.

C.J. Jog, in collaboration with M. Das has proposed a physical mechanism to explain the origin of dense molecular gas observed in the centres of galaxies. The galactic gravitational tidal field is shown to be compressive when the central mass distribution has a flat core. This is shown to be applicable in the central regions of ultraluminous and early-type galaxies. The steady-state, virial cloud density is obtained and the resulting high values are shown to naturally explain the observed high gas densities in the nuclei of these galaxies.

Interstellar matter

Suresh Chandra

Under interstellar conditions, the relative occupation of the levels in a given molecule is controlled by the competition between collisional and radiative transitions among the energy levels in the molecule, and in general, it cannot be described by the Boltzmann distribution law. Calculation of collisional rate coefficients for various transitions in interstellar molecules colliding with H_2 molecules in a different task, and the situation becomes even more difficult for the case of an asymmetrical top molecule colliding with H_2 molecules. S. Chandra in collaboration with W. H. Kegal has computed collisional rate coefficients for rotational transitions in C_3H_2 and SiC_2 (both asymmetrical top molecules) due to collisions with H_2 molecules.

Dust in galaxies

S.K. Pandey

With an objective to study properties of dust in early-type galaxies and examine the physical connection among different forms of multi phase ISM in them, S.K. Pandey, M.K. Patil and Mahendra Singh have selected a sample of bright and nearby early-type galaxies with well known dust features. Deep CCD images of a few of them were obtained in broad band BVRI colours using the 1m telescope at U. P. State Observatory during December 1999. The colour index image of NGC 2907 shows very striking dust features. The optical extinction curve for this galaxy is found to run parallel to the galactic extinction curve, as has been the case for most of dusty early-type galaxies studied so far. The value of R_v - the ratio of total to selective extinction for NGC 2907 is found to be 2.27. The smaller value of R_v as compared to the canonical value of 3.1 of this ratio for Milky way suggests that the size of the dust grains responsible for dust extinction in NGC 2907 is smaller than that of our galaxy. Detailed investigation as regards to computation of dust content from optical extinction and from FIR excess is in progress.

P. Vivekananda Rao

Analysis of the light curves of the various type of binaries in several passbands using the modern light curve techniques like Wilson-Devinney method (1971, ApJ, 166, 705) enables one to derive reliable elements which provide valuable information on some general aspects of the evolution and the coherence of the theoretical evolutionary scenario developed. Keeping this in view, a few binaries were observed using the 1.2m telescope of the Japal-Rangapur Observatory by P. Vivekananda Rao. He has analysed the UBV light curves of Abhyankar (1926b, Z. fur Astrophys. 54, 25) using the 1993 version of Wilson-Devinney computer programme, with a view to derive a consistent solution in all the three passbands and to answer the discordant opinions on the general picture of YY Cmi. Initially, a preliminary unspotted solution was obtained and a photometric mass ratio was derived. From the analysis, he has obtained a mass ratio of $q = 0.89$. The light curves were modeled by introducing a spot on the cooler secondary component to represent the observed light curve asymmetries. The primary and secondary components were found to be slightly overluminous and bigger in size when compared to stars of the same mass. In the H-R diagram, both the components are above but near the ZAMS, suggesting that both of them have left the main sequence and have come into contact.

Interstellar clouds

Asoke K Sen

In collaboration with S. N. Tandon and R. Gupta, Asoke K Sen has observed polarimetrically about a dozen of star forming clouds (Bok Globules), from 1.2 m telescope at Mt. Abu using the imaging polarimeter 'IMPOL' at IUCAA. This gave a map of polarization vectors associated with the stars background to the cloud and shining through the periphery of the cloud. As the cloud contains magnetically aligned dichroic grains which scatter the light, it is believed this map can be related to the ambient magnetic field in the cloud. The magnetic field plays a key role in the dynamics of these clouds, which are undergoing gravitational collapse. A detailed analysis of the eight clouds (out of 12 observed) CB3, CB25, CB39, CB52, CB54, CB58, CB62 and CB246 showed that, clouds which were less dynamic (having ^{12}CO line width $\delta V < 2.5 kms^{-1}$), showed better alignment of their polarization vectors (among themselves and also with galactic plane), as compared to the more dynamic ones.

Plasmas and Dusty Plasmas

Manoranjan Khan

Manoranjan Khan has studied the variation of charge on dust grains due to fluctuating plasma currents and dust-dust interactions in collaboration with M.R. Gupta, S. Sarkar and S. Ghosh. It was shown that in one extreme, where dust plasma frequency is small compared to grain charging frequency, the nonlinear characteristics of dust acoustic wave exhibits shock waves. Whereas, in the other extreme where grain charging frequency is small compared to dust plasma frequency, the damped solitary waves are observed.

Stellar Physics

Binary stars

S. K. Pandey

S.K. Pandey, along with Padmakar Parihar and Sudhanshu Barway, has carried out photometric observations of some well known RS CVn binaries and a few suspected ones, using the observing facilities available at Pt. Ravishankar Shukla University, Raipur and IUCAA, Pune. Continuous monitoring of the light curves of these stars is being used later to examine the presence of long-term variation for solar-like activity in these stars. During the forthcoming observing season, it is planned to carry out spectroscopic observations to confirm the presence of chromospheric emission in the suspected RS CVns. Detailed analysis of H-alpha spectroscopy of three serendipitous X-ray sources suspected to be RS CVn type system was carried out using the 1m telescope of VBO, Kavalur, and the optical photometry performed using IUCAA's 16" telescope has provided evidence for one of the stars, HD61396 to be a RS CVn binary. It shows enhanced radio, X-ray and chromospheric emission as well as displays striking photometric variation with a period of about 35 days. This work was a part of collaborative work involving P. Parihar, K. P. Singh, S. A . Drake and S. K. Pandey.

X-ray binaries

K.Y. Singh

Observations of several X-ray binaries with an accreting neutron star or a black hole as the X-ray source, have been made by K.Y. Singh, in collaboration with N. Surchandra Singh and several others with the Indian X-ray Astronomy Experiment (IXAE) on board the Indian satellite IRS-P3. Study of their periodic and aperiodic variability and spectral characteristics provides information about the nature of the sources and physical processes responsible for X-ray emission in them. Among all classes of X-ray sources, most rapid intensity variations are found in accretion powered X-ray binaries. Time scale of variations range from milliseconds as seen from kilohertz-quasi- periodic oscillations (QPOs) in low-mass X-ray binaries (LMXBs) to seconds and minutes as indicated by low frequency QPOs and pulsations in X-ray pulsars. Chaotic variability, flickering and QPOs are common features of most stellar mass blackhole sources and the X-ray variability serves as a powerful tool to probe details of the accretion process very close to the compact objects.

Neutron stars

Somenath Chakrabarty

The theoretical investigation of the effect of ultra-strong magnetic field on stellar matter in nuclear astrophysics has got a new dimension after the discovery of *magnetars*. The observed soft gamma ray repeaters discovered by BATSE and KONUS experiments and X-ray sources observed by ASCA, RXTE and BappoSAX show the presence of strong surface magnetic field up to 10^{15}G. The discovery of these objects pose a great challenge to the existing models of magnetic field evolution, since they require a very rapid field decay in isolated neutron stars. To investigate the global properties of these strange objects, it also requires a detailed investigation of stability of dense stellar matter in presence of ultra-strong magnetic field and know the exact equation of state of such strongly magnetized matter. Influenced by these discoveries, the effect of strong quantizing magnetic field on the nucleation of quark matter droplets and on the chemical evolution of nascent quark phase at the core of a compact neutron star are investigated by Chakrabarty and his Ph.D. student Tanusri Ghosh. The surface energy of quark phase diverges logarithmically. As a consequence, there can not be a first order phase transition to quark matter. However, a metal-insulator type second order transition is possible unless the field strength exceeds 10^{20}G. Since this field strength is too high to achieve at the core of a compact neutron star, one may assume a second order phase transition to quark matter at the core region of a strongly magnetized compact neutron star. The study of chemical evolution of newborn quark phase shows that in β-equilibrium condition the system becomes energetically unstable. It is also shown by Chakrabarty and his Ph.D. student Nandini Nag that pion and kaon condensations are suppressed at the core of a strongly magnetized neutron star. Various possible exotic structures at the neutron star core in presence of strong magnetic field are under investigation by Chakrabarty and Nag.

Also, the effect of strong quantizing magnetic field on low density stellar matter is investigated by Chakrabarty and Nag using Thomas-Fermi-Dirac (TFD) model. The Wigner-Seitz cell structure is assumed for the low density neutron star crustal matter. The significant changes in the properties of such low density matter in presence of strong magnetic fields are discussed in detail in their work. It was shown that the decay time scale for magnetic field decreases by at least two orders of magnitude in such model calculation. The model was applied to the crustal magnetic evolution of magnetar by the authors.

Strange stars

Torun Chandra Phukon

The hypothesis that the true ground state of hadrons may be strange matter (equal numbers of u, d and s quarks) and not 56Fe remains unproved in physics. To date, there is no sound scientific basis on which one can either confirm or reject this hypothesis. If strange matter is stable, it opens up a new family of compact objects like neutron stars and white dwarfs. These new objects are called strange stars.

Previous studies have shown that a non-magnetic strange star may contain a nuclear crust like neutron star. The electrostatic potential of electrons inside and close vicinity of the surface of the quark core is of decisive importance for the existence of nuclear crust. Also, crust mass depends on the quark core of the star. It is not clear that a strange star with a nuclear crust can explain all phenomena associated with pulsar glitching such as healing times and recurrence rates. A strange star with a very thin nuclear crust possibly rules out the existence of strange radio pulsar in nature.

T.C. Phukon has examined the possible existence of nuclear crust for a non-rotating strange star at a finite magnetic field and at zero temperature. His studies were based on a perturbation expansion of pressure, baryon and energy density from zero magnetic field values at zero temperature by a Taylor series.

Results have shown that the interior magnetic field, $H < 10^{18}$ Gauss, does not change the equilibrium gravitational mass and radius of the star appreciably from those values for a non-magnetic strange star. The situation is, however, different for the electrons, since they are bound to the quark core by electromagnetically rather than the strong interactions. Phukon finds that the electrostatic potential, and the amount of nuclear crust decreases with the increase of the magnetic field for a certain range of field values. This range, however, depends on the value of the neutron drip density (NDD). For $\rho_{NDD} \sim 10^{11} gcm^{-3}$, reduces the crust mass considerably and strange star with gravitational mass. $M - 1.4M_{\odot}$ can hold nuclear crust mass $\sim 10^{-5}M_{\odot}$, which is much smaller than the values ($\sim 0.1 - 0.3M_{\odot}$) for a neutron star having same mass. A magnetic field intensity lying outside this range does not have any effect on the crust mass.

Solar and Planetary Physics

Solar interior

Udit Narain

Udit Narain, in collaboration with R.K. Sharma has explored the generation of Alfven waves in the solar convection zone by turbulent motions and estimated Alfven wave fluxes using a modified efficiency factor. As expected, the Alfven wave flux increases appreciably with the turbulent magnetic field. He also investigated the damping length for Alfven waves in linear and nonlinear framework by taking the spreading of the magnetic field into account. The resistive dissipation of Alfven waves is found to be a viable mechanism of coronal heating. R.K. Sharma has submitted a Ph.D. thesis, incorporating this work to C.C.S. University, Meerut.

Udit Narain, in collaboration with P. Agrawal, has studied the generation of magnetoacoustic (fast and slow modes) waves in the solar convection zone and their dissipation in the chromosphere/corona have been investigated. Smaller eddies (turbulent motions) are found to be more effective in producing these waves than the larger ones. He finds that the spreading in magnetic field is quite effective in dissipating these waves in quiet regions and the coronal holes on the Sun. P. Agarwal has submitted a Ph.D thesis on the subject to C.C.S. University, Meerut.

Three-body problem

M.K. Das

L.M. Saha and M.K. Das, in collaboration with Y. Tanaka, have studied the effect of radiation from primaries in the elliptic restricted three body problem. The perturbative expressions for the transition curve has been shown to depend on such radiation and eccentricity of the orbit of the primaries. It was found that the unstable point $\bar{\mu} = 0.0385209$ in the planar circular case shifts to a higher value depending on the values of δ_1 and δ_2 characterising the radiation parameters of the primaries. Further, the radiation from the primaries was found to increase the value of $\mu_b = 0.0285955$ at which one of the periods of motion about L_4 is exactly twice the orbital period of the primaries in planar circular case. The *region of stability* is markedly changed in the $\mu - e$ plane in the presence of radiation from primaries.

P.P. Hallan

P.P. Hallan has examined the existence of all the equilibrium points in the Robe's restricted three body problem in which, one of the primaries is a rigid spherical shell filled with a homogeneous incompressible fluid of density. The second primary is a mass point outside the shell and third body is a small solid sphere of density, inside the shell with the assumption that the mass and radius of the third body are infinitesimal.

B. Ishwar

It has been proved that, when the eccentricity and a quantity K are not simultaneously zero, there are at the most four equilibrium points, all lying in the xz plane, two triangular and one or two lying on x-axis. The coordinates of the triangular points are functions of time, contrary to the classical restricted problem where they are independent of time. When the eccentricity is much smaller than unity, the locus of the triangular points is a parabola. When the eccentricity and K are both zero, there is only one equilibrium point, the centre of the first primary. B. Ishwar and J. Singh have studied the photogravitational generalised restricted three body problem (RTBP) when both primaries are radiating and oblate as well. The second order normalisation of the Hamiltonian of this problem is performed by Birkhoff's normalisation process. It has been shown that third order part of the Hamiltonian vanishes.

Ishwar and S. Sahoo have studied stability of equilibrium points in the generalised photogravitational elliptic restricted three body problem (ERTBP). They supposed that the bigger primary is a source of radiation and smaller primary is an oblate spheroid to study the linear stability of equilibrium points. The stability condition was found to be affected by radiation pressure force and oblateness of respective primaries.

Atomic Physics

L. K. Jha

L. K. Jha (along with B. N. Roy) is carrying out theoretical calculations on ionization cross sections, keeping in view the importance of the results in upper atmosphere physics and astrophysics. As quantal calculations on double ionization cross section for heavy atoms and ions are not tractable, Jha calculatated electron impact double ionization cross sections for copper in the modified binary encounter model, with a view to compare the results with the experimental data obtained by the Belfast group. He used Hartee-Fock velocity distribution while considering the ejection of both electrons for the first time. The dominant Auger emissions at high impact energies were also taken into account. The calculated results have been found to be in satisfactory agreement with the experiment data. In calculations of electron impact single ionization of Copper ($3d^{10}4s$), Jha observed some interesting features. If contributions are taken from 4s and ten $3d$ electrons, the calculated results considerably overestimate the cross sections. It has been concluded that effective ionization of 3d shell of copper does not take place. Apart from these works, calculations on electron impact double ionization cross sections for rare gases, Mg, Ca, N^+, O^+ and Ne^+ are in progress.

R. Ramakrishna Reddy

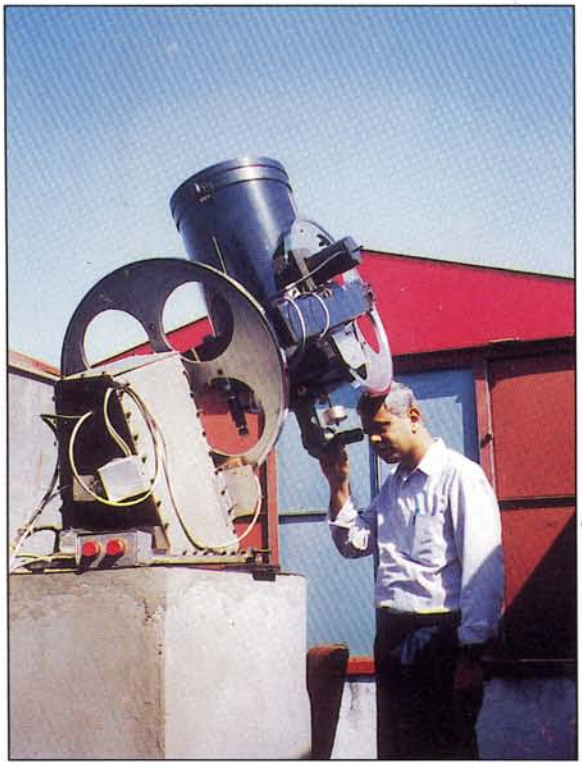
In recent years, the discovery of the presence of various type of molecules, from simple to relatively complex forms, in various astronomical objects has excited many scientists. It was realized that the chemical processes are involved in the constitution of stars and galaxies. Chemical composition studies of processed material, as found in the envelopes of highly evolved stars and in planetary nebulae, provide checks on our concept of stellar evolution and element building. The chemical processes involved in the constitutions of stars and galaxies have also played an important role in the formation of galaxies of the evolution of the universe. It is obvious from the diverse nature of the objects that the similar chemical processes are not responsible for occurrences of molecules in different objects. The underlying physics, however, cannot be different, but differences in physical and dynamical situations in different objects have their effect on the observed molecules. The energetics of the various reactions which create or destroy molecules are determined by dissociation energy and ionization potential of the molecule together with the energy of other reactance such as photons or charge particles. The bond dissociation energies for astrophysically important diatomic molecules have been estimated based on the derived empirical relation. These estimated values are in reasonably good agreement with the available literature values.

Some formulae relating electronegativity differences, ionization potentials and dissociation energies for astrophysically important molecules are proposed. The estimated ionization potentials are in good agreement with the values cited in the literature.

Instrumentation

S.P. Bhatnagar

S.P. Bhatnagar has been working on the construction of an Automated Photoelectric Telescope with Ranjan Gupta and S.N. Tandon. The APT, after dismantling, was transported to Bhavnagar in May 1999. It was found that due to the incompatibility of the old stepper motor controller card with the higher speed computers, it was not useable and thus a commercially available controller card was carefully selected and purchased. The telescope control software was rewritten by S.P. Bhatnagar. Modifications were made to the software by him based on suggestions from B.A. Kagali and M.N. Anandaram of Bangalore University during their visits to Bhavnagar.



S.P.Bhatnagar at the Telescope

Number Theory

Renuka Datta

Renuka Datta, in collaboration with B.K. Datta and V. de Sabbata has given a pedagogic account of the concept of numbers and directed numbers that had been evolving from antiquity to the seventeenth century, when symbolism of algebra had been developed to a degree in commensurate with Greek geometry. The deficiencies in the concept of number in Decartes' time, however, were removed with the advent of calculus that gave a clear idea of the "infinitely small". A transparent idea of "infinity" and of the "continuum of real numbers" was conceived in the later part of the nineteenth century by Weierstrass, Cantor and Dedekind when real numbers were defined in terms of natural numbers and their arithmetic without taking any recourse to geometric intuition of the "linear continuum". But the evolution of the concept of number did not stop here as it would depend more on the geometric notion than on the linear continuum. With a proper symbolic expression for direction and dimension came the broader concept of directed numbers - "multivectors" - with it a powerful mathematical language for physical theories, sine qua non for future direction.

Spectroscopy

Ashok C. Kumbharkhane

He has worked on dielectric relaxation spectroscopy in the frequency range 10 MHz to 10 GHz on series of alcohols, amides, nitriles and aqueous binary mixtures using picosecond time domain reflectometry technique. Theoretical models have been developed to understand the hydrogen bonding of the molecules. Some suggestion have been made in the modification of the theories. The agreement between the experimental results and theoretical calculation is good.

Atmospheric Physics

Shashi K. Pathak

Collision dynamics has long been the subject of extensive investigations in order to understand the role of atmospheric and environmental species. In recent years, considerable attention has been focussed towards the analysis of phase and environment dependent chemical reactivity to probe the stratospheric and tropospheric processes. S.K. Pathak, in collaboration with N.J. Mason, has studied spectroscopy and collision dynamics of ozone and other trace species involving ozone depletion compounds and atmospheric sink compounds. It has been observed that there are intermediate mechanisms and their role still remains unclear in view of their contribution to ozone dissociation dynamics and other related chemical processes. These studies provide a significant account of research findings to understand the general kinetics of ozone depletion mechanisms and those stratospheric processes which are important for atmospheric dynamics and of relevance to the recent environmental change. Major advances have been made to interpret theoretical modeling data and computer simulation studies.

(III) IUCAA-NCRA GRADUATE SCHOOL

The IUCAA graduate school is run jointly with the National Centre for Radio Astrophysics (NCRA, TIFR). Since its inception almost eleven years ago, thirteen IUCAA students have been awarded Ph.D. degrees and another four will be defending their Ph.D's very soon. Presently, the IUCAA graduate school has three students. The quality of doctoral research being done in IUCAA has consistently been of a high standard and has gained recognition both nationally and internationally. Recent Ph.Ds from IUCAA are currently doing their post-doctoral research in premier institutions across the country as well as abroad - in the US, Canada, UK, Israel, etc. Opportunities are available for selected graduate students from universities to participate in the graduate school.

The IUCAA-NCRA graduate school is taught over a single academic year and covers courses ranging from advanced mathematics and physics to specialised topics in astrophysics. The courses include : Quantum and Statistical Mechanics; Electrodynamics and Radiative Processes; Methods of Mathematical Physics; Introduction to Astronomy and Astrophysics; Astronomical Techniques; Galaxies : Structure, Dynamics and Evolution; Extragalactic Astronomy; Interstellar Medium; General Relativity and Cosmology. In addition, elective courses on subjects of topical interest are also taught and students are encouraged to attend seminars and colloquia which are held in IUCAA on a regular basis where distinguished scientists from across the country discuss their work.

Two IUCAA research scholars, K. Srinivasan and A.N. Ramaprakash have defended their Ph.D. theses to the University of Pune during the year of this report. The abstracts of the theses are given below :

Particle Production in Quantum Field Theory

K. Srinivasan

The four fundamental interactions between elementary particles and fields are the electromagnetic, weak, strong and the gravitational interactions. The first three of these interactions have been successfully explained by relativistic quantum field theory up to energy scales of the order of 100 GeV. Quantum electrodynamics, the earliest and most successful of the renormalisable quantum gauge theories, describes the interaction of the electromagnetic field with matter. Several of the predictions of this theory have been experimentally verified to a high degree of accuracy, thereby firmly establishing its validity. The phenomena of weak interactions is described by the theory due to Salam and Weinberg. This theory successfully unifies the electromagnetic and weak interactions into a single renormalisable gauge theory. The W and the Z bosons predicted by the theory have also been observed experimentally, thereby establishing the Salam-Weinberg theory as the correct theory of weak interactions. For the strong interactions, though one is yet to have an adequate theory, a working model in quantum chromodynamics is present. Efforts to describe all these three interactions by a unified gauge theory have also been successful.

All these theories are beset with divergences. Since, only a finite number of divergences arise, these have been sucessfully renormalised with the help of suitable regularisation and renormalisation techniques. However, the odd one out in this unification of forces is the gravitational interaction. All attempts to provide a quantum framework for the gravitational field have so far proved to be unsuccessful. Einstein's theory of gravity, which is well established observationally, is not a renormalisable theory. Perturbative expansions of the gravitational action gives rise to new divergences at all orders that cannot be renormalised in any meaningful manner.

In the early days of quantum theory, before the development of quantum electrodynamics, a picture of a classical electromagnetic field interacting with atomic and molecular systems was used to understand spectroscopic results. Such a semi-classical description yielded results in accordance with the full theory of quantum electrodynamics. One may, therefore, hope that a similar regime exists for gravity, a regime in which the gravitational field can be retained as a classical background, while the matter fields are quantized according to conventional quantum field theory. It can be shown that quantum gravitational effects will be important only at energy scales of the order of the Planck energy $\sim 10^{19}$ GeV (or equivalently length scales of the order of the Planck length $\sim 10^{-33}$ cm). Therefore, there exists a domain of seventeen orders of magnitude between the Planck energy and an energy scale of the order of 100 GeV; a domain in which the gravitational field can be assumed to behave classically and where the matter fields can be assumed to have a quantum nature. Thus, one is led to the subject of quantum field theory in curved spacetimes (henceforth abbreviated as QFT in CST) which has been an area of active research during the past few decades.

Assuming that QFT in CST is valid in some energy regime, non-trivial gravitational effects occur in quantum field modes only when the wavelength λ of the modes is comparable to some characteristic length scale of the background spacetime. For instance, near a black hole of mass M and radius $R = 2M$, only modes whose wavelength $\lambda \gtrsim R$ are expected to be seriously affected. Similarly, if the gravitational field changes significantly on a time-scale T, only those modes with a frequency $\nu \lesssim T^{-1}$ are significantly affected. Thus, if one regards important quantum processes as occuring at length and time scales of the order of 10^{-13}cm (atomic radius) and 10^{-23}s respectively then, it can be shown that only in the vicinity of small black holes or in the earliest epochs of the big bang can important measurable effects be expected. Thus, direct observational evidence seems to be entirely precluded and quantum field theory in curved spacetime must, it seems, rest entirely upon theoretical considerations. This paucity of checks renders all the more significant the results of Hawking in 1975, where he showed that black holes radiate thermally. This result seems to be very fundamental and has been derived in many ways. It also establishes a strong connection between black holes and thermodynamics that was suspected before the application of quantum theory to black holes. It, therefore, appears that the Hawking effect has exposed a small corner of a broad new area of fundamental physics in which gravity, quantum field theory and thermodynamics are closely interwoven. If this is the case, then their synthesis would lead to important new advances in physics, including some with observational consequences. This situation can be compared with the early days of kinetic theory. The atomic hypothesis was not really open to direct experimental verification in the mid-nineteenth century due to the smallness of atomic effects. Neverthless, the full theory was capable of reaching beyond the atomic domain and predicting new phenomena in gas dynamics that could be checked. Similarly, one hopes that a proper understanding of quantum gravity would give rise to observational consequences in other well known and more accessible areas of physics.

Quantum fields in curved spacetime concerns itself primarily with particle production which can arise either due to the presence of the curved background spacetime as in the case of black hole and Robertson-Walker spacetimes or even due to the presence of electromagnetic fields in flat spacetime itself. The Feynman propagator for a quantum field in the given classical background contains all the information about the system. It is this quantity that is usually used to describe particle production in a covariant manner.

It was mentioned in an earlier paragraph that quantum gravitational effects are significant only at scales of the order of the Planck length $L_P = (G\hbar/c^3)^{1/2}$. This length scale is expected to play a vital role in the ultimate theory of quantum gravity. Simple thought experiments indicate that it would not be possible to measure lengths with an accuracy greater than about $\mathcal{O}(L_P)$. This suggests that L_P could be thought of as some kind of "zero-point length" of spacetime. In models of quantum gravity based on Ashtekar variables and string theory, L_P does arise as a mean square fluctuation to spacetime intervals due to quantum fluctuations of the metric. The existence of such a fundamental length scale implies that processes involving energies higher than the Planck energy will be supressed with the consequence that the ultraviolet behaviour of the theory will be improved. One immediate consequence of this will be that the Feynman propagator will be modified accordingly depending on the manner in which the fundamental length scale is inserted into the theory.

This thesis work consists of two distinct parts. The first part studies in detail the effect of introducing a fundamental length scale in spacetime which is done by means of the "path integral duality prescription". The consequences of such a fundamental length scale on standard known quantum phenomena are discussed. The second part is focussed towards improving our understanding of the phenomenon of particle production in black hole spacetimes and in electromagnetic backgrounds in flat spacetime within the framework of QFT in CST.
A chapter wise summary of the thesis is given below.

In chapter (1), the basic terminology and the mathematical framework that is used to study the evolution of quantum fields in gravitational and electromagnetic backgrounds is introduced. Some of the essential results that serve as a background for the chapters to follow are reviewed. The chapter begins by illustrating the coordinate dependent nature of the particle concept with the aid of a simple example in Minkowski spacetime. The example considered is the Minkowski-Rindler system, where it is shown that a scalar field that is initially put in the Minkowski vacuum appears to have particles when observed in the Rindler spacetime. Subsequently, Hawking radiation in a Schwarzchild spacetime is considered. Three different well known methods of obtaining Hawking radiation are described. These different approaches illustrate the semi-classical approach usually taken when dealing with scalar fields in curved spacetime. Next, the (one–loop) effective Lagrangian approach to particle production is described with Schwinger's proper time method being considered in detail. This approach is important because using it, covariant results for gravitational backgrounds and gauge invariant results for electromagnetic backgrounds are obtained. Then, carrying out the canonical quantisation of a complex scalar field in a constant electric field background, it is shown how the tunnelling interpretation is required to obtain the gauge invariant result in the space-dependent gauge. Finally, the path integral approach in a latticised spacetime is studied. It is shown how the Feynman propagator can be constructed in such a spacetime and how the continuum limit is to be taken. Using this formalism, the effect of imposing a fundamental length scale in the spacetime (which is implemented using the "path integral duality prescription") on the Feynman propagator is described.

Chapter (2) is concerned with the applications of the duality prescription. This prescription smoothens out the quantum fluctuations of the metric giving rise to an average large scale spacetime (which can be flat or curved). In the Schwinger's proper time description of the Feynman propagator for a spinless field, the weightage factor for a path with a proper time s is $\exp-(m^2 s)$ where m is the mass of the field. Invoking the path integral duality prescription amounts to modifying the weightage factor from $\exp-(m^2 s)$ to $\exp-[m^2 s+(L_P^2/s)]$. This modified weightage factor is used to evaluate quantum gravitational corrections to some of the standard quantum field theoretic results in flat and curved spacetimes. In flat spacetime, corrections to the following phenomena are evaluated: (1) the Casimir effect, (2) the effective potential for a self-interacting scalar field theory, (3) the effective Lagrangian for a constant electromagnetic background and (4) the thermal effects in the Rindler coordinates. In curved spacetime, the following phenomena are considered: (1) the effective Lagrangian for the gravitational field and (2) the trace anomaly. In all these cases, the Feynman propagator for the system is first written down explicitly in Schwinger's proper time formalism. Then, by applying the duality prescription to the Feynman propagator, the corrections are evaluated. The extra factor $\exp-(L_P^2/s)$ acts as a regulator at the Planck scale, thereby, removing the divergences that otherwise appear in the theory.

The derivation of thermal radiation in a static black hole spacetime by Hawking in 1975 involves the existence of the Kruskal extension. Such an extension of the standard Schwarzchild spacetime gives rise to unphysical regions (one of which contains a white hole and is clearly unphysical). Can Hawking radiation be derived without using the Kruskal extension? Chapter (3) considers the phenomena of particle creation in static black hole spacetimes with a new approach. This approach is different from that used in the standard method in that the Kruskal extension is not used here. The motivation for this new approach is the method of complex paths used routinely in standard non-relativistic semi-classical quantum mechanics to calculate transmission and reflection coefficients. The basic outline of this new method is described as follows. The co-ordinate singularity present at the horizon in the (t,r) co-ordinate system of the standard Schwarzchild metric manifests itself as a singularity in the expression for the semi-classical propagator for a scalar field. A prescription is given, whereby, this singularity is regularised with Hawking's result being recovered in the process. The prescription used is essentially a specific complex contour that is selected by demanding that the semi-classicality condition hold all along the contour. Such a prescription gives the probability of emission, $P_{\rm emission}$, of a particle of energy E from the horizon to the outside and the probability of absorption, $P_{\rm absorption}$, of a particle of energy E into the horizon. It turns out that for a black hole spacetime, the following relation, $P_{\rm emission}=P_{\rm absorption}e^{-\beta E}$ holds, where $\beta=8\pi M$ is the inverse of the temperature of the black hole. It can be shown that a relation such as the above implies the existence of a thermal spectrum. This result, therefore, holds for a time-independent (but unstable) system of a black hole immersed in a bath of thermal radiation at the same temperature as that of the black hole.

In Chapter (4), the content is particle creation in a constant electric field background in Minkowski spacetime which is a well researched subject. The standard result in this field is the one-loop gauge invariant result obtained by Schwinger using the proper time method for a scalar field. Well known flat spacetime quantum field theoretic methods reproduce Schwinger's result only when a purely time-dependent gauge is considered. In such a gauge, a specific boundary condition is first imposed by demanding that the scalar field be in the vacuum state in the far past. As time moves on, particles are produced by vacuum polarisation by the presence of the electric field and the state of the field in the future is not vacuous anymore. This result is quantified by the Bogolubov coefficients, which are related to the probability for the vacuum in the far past to remain so in the far future. However, when a purely space-dependent gauge is considered, the system does not evolve with time in a non-trivial fashion. Therefore, quantum field theoretic principles predict that if the scalar field was in the vacuum in the far past then it remains so for all time implying that no particles are created. This contradiction is resolved by resorting to the "tunnelling interpretation". The system in the space-dependent gauge can be reduced to a one-dimensional effective Schrodinger equation with a potential of $(-x^2)$. The tunnelling interpretation relates the transmission and reflection coefficients in this effective Schrodinger system to the Bogolubov coefficients calculated in the time-dependent gauge and the standard result is recovered. An additional problem in both the time and space dependent gauges is that the mode functions contain parabolic cylinder functions, which are transcendental in nature and difficult to work with. The new and interesting results that are presented in this chapter are a set of non-trivial gauges that give rise to modes that are a combination of *elementary functions*. Further, an uniform tunnelling interpretation is provided that holds for both the time and space dependent gauges. The utility of such a uniform description is that it can be used for all these new gauges in order to obtain the gauge invariant result without much effort. Since the mode functions in these new gauges are elementary, a more accurate picture of particle creation in a constant electric field is attempted by imposing suitable boundary conditions which indicate when the field is switched on and off. This chapter concludes by casting the gauge invariant result discovered by Schwinger in a new light. In classical theory, the action of an uniform electric field on a charge imparts a constant acceleration to it. The spacetime metric in rest frame of the charge is the Rindler frame. It is, therefore, of interest to ask if the electric field particle production is linked in some way to the presence of a Rindler frame since both are, in a sense, natural to this problem. An attempt is made to link particle production by an uniform electric field with processes occuring in the Rindler frame by proposing an interpretation of the standard result in terms of tunnelling between the two disjoint Rindler sectors in imaginary time.

In Chapter (5), classical analogues to the quantum phenomena of black hole radiation are presented. It can be shown that the mechanism of Hawking radiation is mathematically equivalent to the radiation spectrum emitted by the motion of a mirror in $(1+1)$–dimensional Minkowski spacetime along a late time trajectory of the form $x(t) = A - t - Be^{-Dt}$ where A, B and D are arbitrary constants with $D > 0$. This trajectory is usually referred to as a black hole trajectory because the trajectory of the surface of a collapsing star near its event horizon has a similar form. To construct a viable classical model in concrete terms, the following procedure is followed. An observer shines monochromatic light on an object (which can be a mirror in flat spacetime or the silvered surface of a star in Schwarzchild spacetime) which is moving along a specified trajectory in the observer's rest frame. The reflected light is Fourier analysed by the observer and the power spectrum is calculated. The power spectrum is regarded as the classical analogue of the radiation spectrum that arises in quantum field theory in flat and curved spacetime. The crucial difference between the two is that the radiation spectrum is a function of the photon energy (expressed as $\hbar\Omega$ with Ω being the mean photon frequency) which explicitly contains $\hbar$, while the power spectrum is a function of the Fourier transform frequency Ω alone and does not contain $\hbar$. As it stands, the power spectrum too is a well defined and measurable quantity although in the limit of low frequencies (like radio frequencies) or a large number of photons where the classical limit is applicable. In order to state that a particular classical power spectrum is the analogue of the corresponding quantum radiation spectrum, similarities in the *form* of the two spectra are considered. The specific terms of the power spectrum are then suitably interpreted based on the properties of its quantum analogue. The focus, in this chapter, will be on the thermal radiation spectrum obtained in the study of collapsing stars and moving mirrors in quantum field theory. Classical scenarios are now constructed where the resulting power spectrum is "thermal" in form. Two mirror-observer configurations in Minkowski spacetime that are considered are: (i) an inertial mirror viewed in an accelerated observer's frame and (ii) an uniformly accelerated mirror viewed in an uniformly accelerated observer's frame of reference. Then the classical analogues and implications of these mirror configurations in the Schwarzchild spacetime, where star-observer configurations are studied, are considered. This chapter concludes with a discussion on the radiation field of a charged particle moving along a black hole trajectory.

In chapter (6), conclusions and future outlook are presented. This thesis is mainly based on the following publications.

- **K. Srinivasan**, L. Sriramkumar and T. Padmanabhan, *Possible quantum interpretation of certain power spectra in classical field theory*, IJMP-D **6, 607 (1997).**
- **K. Srinivasan**, L. Sriramkumar and T. Padmanabhan, *Plane waves viewed from an accelerated frame: quantum physics in classical setting*, Phys. Rev. D **56**, 6692 (1997).
- **K. Srinivasan**, L. Sriramkumar and T. Padmanabhan, *The hypothesis of path integral duality II: corrections to quantum field theoretic results*, Phys. Rev. D **58**, 044009 (1998).
- **K. Srinivasan** and T. Padmanabhan, *Particle production and complex path analysis*, Phys. Rev. D **60**, 24007 (1999).
- **K. Srinivasan** and T. Padmanabhan, *Doing it with Mirrors: Classical analogues for black hole radiation*, submitted to IJMP D.
- **K. Srinivasan** and T. Padmanabhan, *Planckian power spectrum from a charged particle trajectory*, under preparation.

Development of and Observations with an Astronomical Imaging Polarimeter

A.N. Ramaprakash

The primary interest in this work is to study, employing polarimetric techniques, the role of magnetic fields in the dynamics and evolution of molecular clouds in the interstellar medium of our Galaxy and star-formation occurring in them. In spite of the classical nature of the problem, it has been least addressed with, mainly because of the difficulty of doing polarimetry with conventional aperture photometric techniques. The situation has completely changed with the advent of accurate array detectors and the instrument described in this thesis, makes good use of these developments.

Bok globules, as a class of objects, are ideally suited for studying the formation and evolution of a simple, self-gravitating system, not contaminated by environmental effects. It is now confirmed that a majority of Bok globules are in the process of forming stars. There are also evidences which show that there is an evolutionary connection between the elephant trunk globules, cometary globules and Bok globules. Magnetic fields are known to be of considerable importance in all of these phenomena. Another interesting class of objects in the galaxy are the elongated clouds, which might be truly filamentary in nature or are sheets seen edge-on. Magnetic fields influence the formation of these clouds and the field patterns are associated with their structure. Magnetic fields also produce alignment in the aspherical, dichroic, dust grains in the molecular clouds. When unpolarized starlight scatters through these dust grains, it becomes partially polarized and the polarization vector traces the magnetic field. Thus, imaging polarimetry of stars background to these clouds offer a powerful technique of determining the magentic field patterns as projected in the plane of the sky. Quantitative studies of the magnetic field patterns, have become now feasible because of the high angular resolution and high accuracy with which polarimetry can be carried out with the imaging instrument.

In order to carry out such observations, it was conceived to design, develop and commission a CCD Imaging Polarimeter (IMPOL) suitable for observations at some of the telescope facilities in India. Though the design uses standard optical and electronic components, by paying careful attention to the various sources of errors like atmospheric scintillation, moving optical components, reflection from surfaces, tracking, etc., an instrument could be constructed which gives photon-noise limited performance for linear polarization measurement accuracies better than 0.05% in the optical wavelength bands.

A Wollaston prism is used as the analyzer in the instrument and the two orthogonal components of polarization are recorded simultaneously on a cooled CCD detector. In order to determine the three parameters, namely, the total intensity, the fraction of light in linear polarized condition and the position angle of polarization, at least one more independent measurement is required. This is accomplished by rotating the plane of polarization of the incoming beam through a known angle using a half-wave plate kept in front of the Wollaston prism and then making another measurement. The Wollaston prism and the half-wave plate are placed in the path of a reimaging system, in which a field lens reimages the primary mirror on to the half-wave plate and a camera lens reimages the telescope focal plane on to the CCD. Because of the Wollaston prism, two images (ordinary and extraordinary) are produced on the CCD plane per source point and in order to avoid the overlap of the images of adjacent points, a grid of parallel obscuring strips is placed at the telescope focal plane.

A block schematic representation of IMPOL is shown in page 84.. The polarimetry optics and CCD are mounted at the Cassegrain port of the telescope, so is the acquisition and guidance system. Most of the electronic subassemblies associated with instrument control and image acquisition are also mounted on the telescope. The two computers in the telescope control room allow the observer to carry out instrument control and image acquisition operations.

The instrument development took two years, from February 1994 to February 1996, during which time, the mechanical fabrication and assembling of the instrument as well as the development of the electronics back-bone and the software tools for user-interface, instrument control and image acquisition were carried out. This phase ended with the laboratory commissioning of IMPOL, which involved operating, testing and optimizing the instrument in the laboratory when various sources of error were investigated in detail and some improvements made. In the second phase, the instrument was taken to the 1.2 m telescope (GIRT) facility at Gurusikhar, Mt. Abu in March 1996 and during the three day observation run, it was interfaced to the telescope and several polarized and unpolarized standard stars were observed in various filters for instrument calibration. Observations required for implementing the off-axis acquisition and guidance (A&G) unit of the instrument also were made at this time. The A&G unit was successfully incorporated during a second observation run in May 1996. During this second observation, optical polarimetry of the stars behind the periphery of some dark molecular clouds were made. The results of these observations are summarized in the two figures on page 85.

The figure on the left, shows the normalized Stoke's parameters q against u, plotted for all the unpolarized star measurements made. The extremely low correlation coefficient (0.06) of the points indicates the absence of systematic effects in the measurement of polarization, which if present, should make these points tend to cluster. The mean values $\bar{q}$ and $\bar{u}$ are equal to 0.022 and -0.022 respectively, which gives an instrumental polarization floor of about 0.03%. The points in the righthand side figure are the 1σ errors, for about an hour of observation time, in the measurement of polarization of stars behind B133 as a function of their visual magnitudes. The solid curve in that figure is the theoretical estimate of the errors based on photon statistics alone, which is the dominant noise source. This curve rises fast around 15^{th} mag. because of the high sky brightness during the observations due to the presence of the moon.

The data analysis is carried out from within the IRAF environment using a polarimetry package that has been developed for the purpose. The data is in the form of a set of image frames for each filter, with about 12-20 frames per set, the exact number depending on the nature of the source and the accuracy of measurement demanded vis-à-vis the photon noise. Aperture photometric techniques are used to determine the intensities. Provision has been made to slightly dither the telescope pointing while tracking so that optimum sampling of about 3 pixels is obtained in stellar images. The polarization information is extracted in terms of the ratios of the intensities in the ordinary and extraordinary images in these frames and hence, is devoid of the effects of atmospheric scintillation, variation in effective exposure times, etc. These ratios correspond to the normalized Stoke's parameters q and u and a non-linear chi-square fitting technique is used to estimate the polarization parameters and the errors. Since the polarization values follow the Ricean distribution, they are corrected for bias using the maximum likelihood estimate method.

Several observations of galactic molecular clouds have been made with the instrument so far. We find very interesting features in the magnetic field patterns which are closely associated with the dynamical conditions of the clouds. In two Bok globules, CB 16 and CB 17, which are known not to show any signs of star-formation, the magnetic fields are quite uniform and are aligned closely with the ambient galactic magnetic field. However, another Bok globule, CB 60, which harbours an young stellar object, displays a very disturbed magnetic field pattern (see figure on page 86). We have also observed two cometary globules, which show that the magnetic fields tend to align along their bright rims. This probably indicates that the fields are anchored to the ionized rims of these globules and are being stretched by the movement of the material along their tails. Our observations of an elongated molecular cloud near the open cluster IC 5146, are consistent with the hypothesis that the cloud is supported against gravitational collapse along its long axis, by the magnetic field.

A brief outline of the presentation

Considerable effort has been made to make the thesis concise – repetitions have been avoided wherever possible. Instead, the appropriate sections have been referred to, whenever a relevant discussion has been made in a different context. Once in a while, this has led to the inconvenience of having to refer forward, but the material has been arranged so as to minimize such instances.

All topics which are not directly part of the basic theme of the thesis – the development of the instrument, using it for observations and analyzing the results – but are complementary, have been collected together in five appendices. Appendix 1 discusses briefly the Stokes vector formalism of representing light, which has been employed extensively in the description of the instrument's working; appendix 2 presents how polarized light results from some of the physical phenomena of relevance in astronomy; appendix 3 contains brief descriptions of two polarization sensitive optical elements that have been employed in the instrument. The last two appendices are intended to serve as a user's guide while making observations with the instrument.

Chapter 1, begins by briefly tracing the history of understanding of the phenomenon of polarization, but soon focuses onto astronomical polarimetry and the merits and demerits of the different techniques practised. Based on this understanding, in chapter 2, first, a set of guidelines for the construction of an imaging polarimeter with a view of achieving specific scientific goals are arrived at. This is followed by descriptions of the various phases in the development of the instrument, beginning from the optical principle and components, their testing, mechanical structure, assembling, electronics and software for instrument control and image acquisition. In chapter 3, the various sources of uncertainties involved in the measurement of polarization with such an instrument and make theoretical estimates of the performance limits which it can reach when used for realistic observations are considered. This chapter is concluded by discussing a few issues of relevance during the extraction of polarimetric information from raw observational data. The need for an accurate acquisition and guidance system for the instrument, was realized at the very beginning of the project. Chapter 4 discusses the design and construction of such a system and how it has been integrated as part of the main instrument. Estimates are also made to verify that this system is sufficient to serve the requirements of polarimetry. The commissioning of the instrument, in two stages – first in the laboratory and then on the telescope – is the subject of chapter 5 and with this we come to the end of part I. Part II is concerned with using the instrument for real observations, which is the ultimate test of performance an instrument. Chapter 6 and 7 presents the results of the observations of magnetic field patterns in some classes of molecular clouds in the galaxy, employing polarimetry of field stars behind the clouds as tracers of the field pattern.

The following articles have been published based on this work :

- **A. N. Ramaprakash** , R. Gupta, A. K. Sen and S. N. Tandon, *Imaging Polarimeter(IMPOL)*, 1995, in: *Ground-based Astronomy in Asia*, Proceedings of the Third East-Asian Meeting on Astronomy, ed. Kaifu N., National Astronomy Observatory, Japan

- **A. N. Ramaprakash** , Gupta R., Sen A. K., Tandon S. N., *An Imaging Polarimeter (IMPOL) for multi-wavelength observations*, Astronomy and Astrophysics Supplement, 1998, **128**, pp.369-375

- **A. N. Ramaprakash** , Gupta R., Tandon S. N., *Flexible off-axis acquisition and guidance system*, To appear in *Telescope Control Systems III*, SPIE proceedings, **3351**, 1998

- **A.N. Ramaprakash** , R. Gupta and S. N. Tandon, *Magnetic Fields in Molecular Clouds*, To appear in Proceedings of the 104-cm Sampurnanand Telescope Silver Jubilee Workshop, 1997

- **A. N. Ramaprakash**, R. Gupta and S. N. Tandon, 1997, *Imaging Polarimetry of nearby molecular clouds*, To appear in *The Local Bubble and Beyond*, Proceedings of the IAU Colloquim No. 166

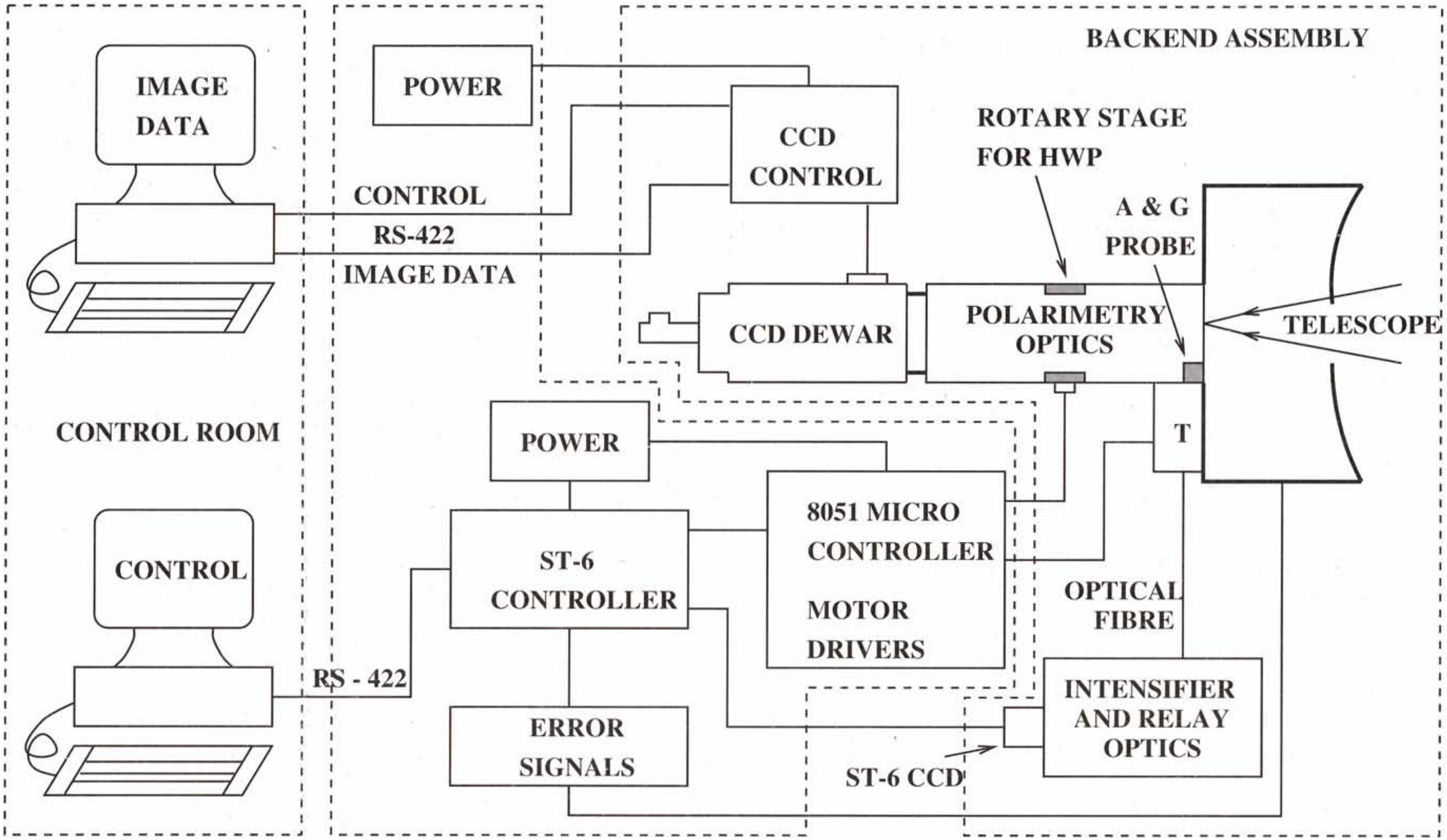


Figure 7: BLOCK SCHEMATIC OF THE IMPOL SYSTEM

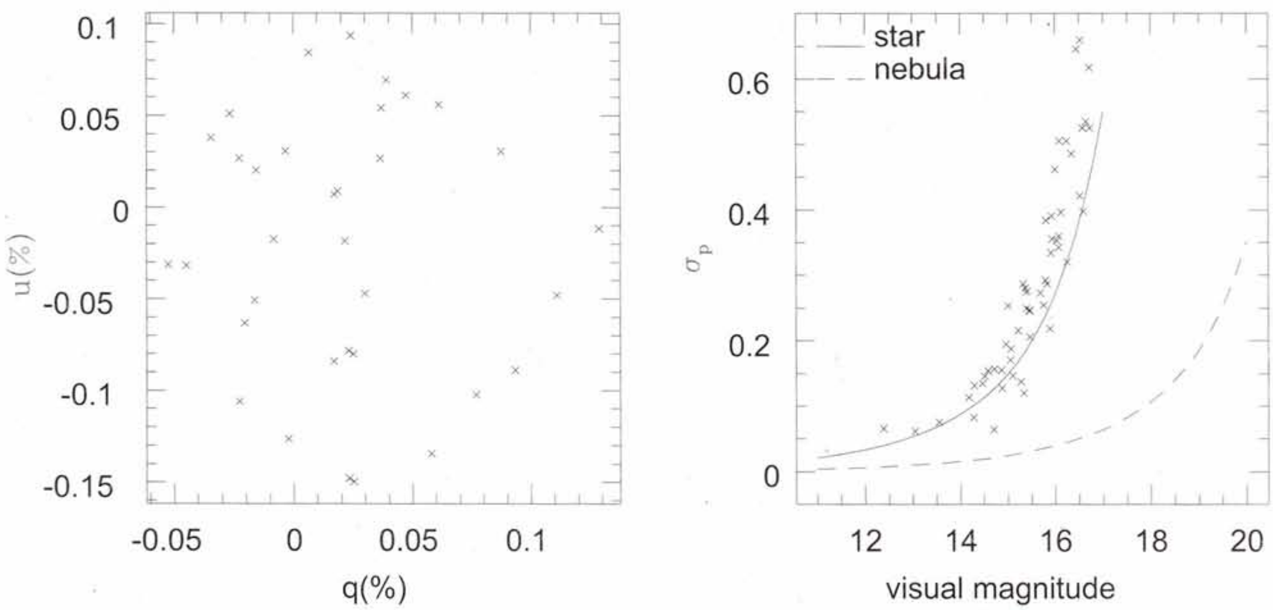


Figure 2: Results of the commissioning tests of IMPOL

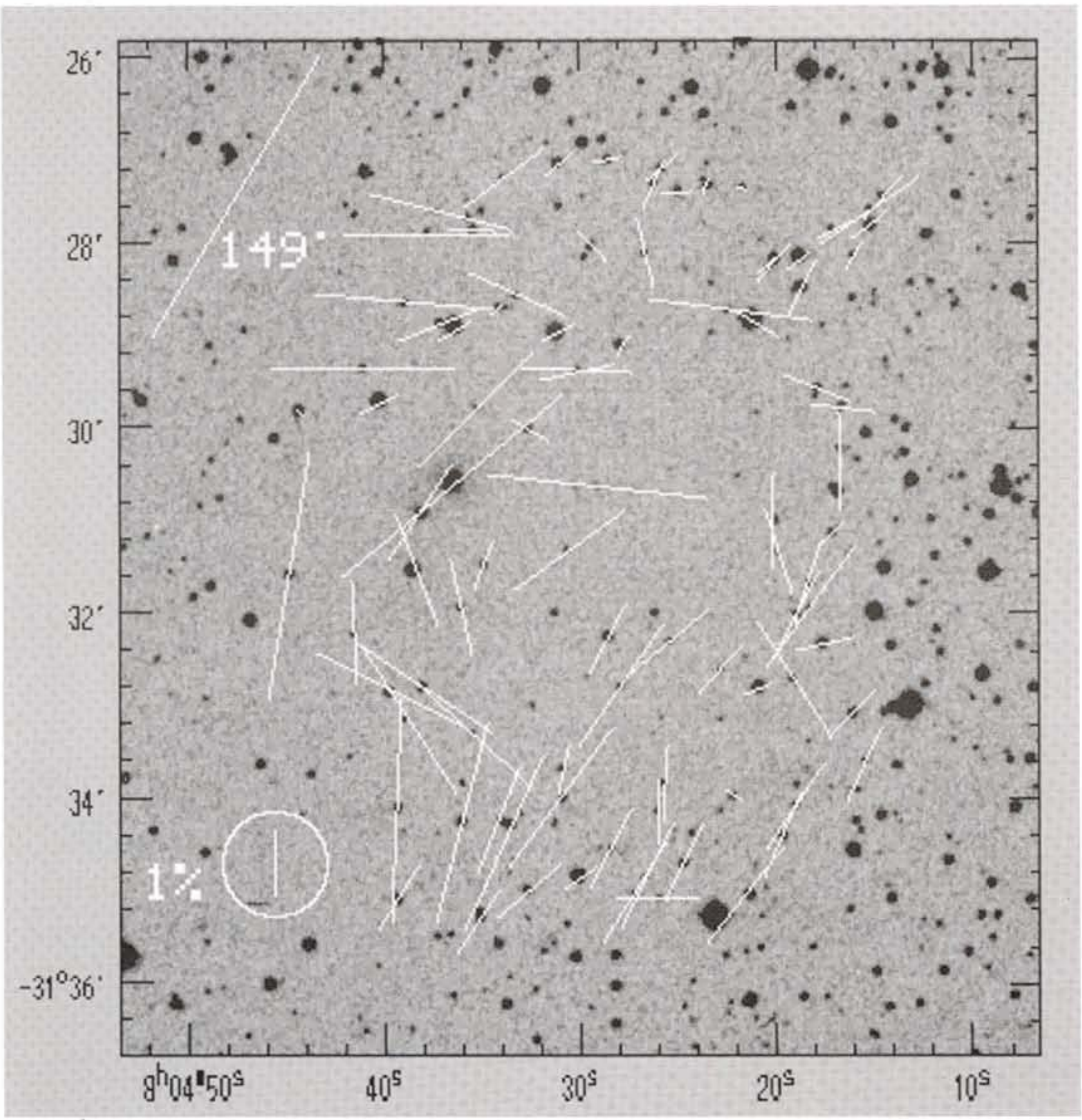


Figure 9: Polarization pattern of stars detected near the Bok globule CB60

(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 an Associate / Senior Associate of IUCAA, the name of the latter is displayed in italics.

a) Journals

Richard A. White, Mark Blinton, **Bhavsar, S.**, Patricia Bornman, Jack O. Burns, Michael J. Leadlow and Christen Loken (1999) A catalogue of nearby poor clusters of galaxies Astron. J. **118**, 2014-2037

Bose, S. and **N. Dadhich** (1999) Brown-York quasilocal energy, gravitational charge and black hole horizons, Phys. Rev. **D60**, 064010(7).

Bose, S., **N. Dadhich** and S. Kar (2000) New classes of black holes in 2+1gravity, Phys. Lett. **B477**, 451.

S. Bose, **S. V. Dhurandhar** and **A. Pai** (1999) Detection of gravitational waves using a network of detectors, Pramana, **53**, 1125.

Dadhich, N. (1999) On gravito-electromagnetic duality in general relativity, Mod. Phys. Lett., **A14**, 759.

Dadhich, N. and *L. K. Patel* (1999) On spacetime dual to spherically symmetric solutions, Pramana, **52**, 359.

Dadhich, N. and A. K. Raychaudhuri (1999) Oscillating non-singular relativistic spherical model, Mod. Phys. Lett., **A14**, 2135.

Dadhich, N., *L. K. Patel* and *R. Tikekar* (1999) Global monopole as a dual-vacuum solution in Kaluza-Klein spacetime, Mod. Phys. Lett., **A14**, 2721.

Dadhich, N. and *L. K. Patel* (2000) Gravoelectric dual of the Kerr solution, J. Math. Phys. **41**, 882.

D.B. Vaidya and **Ranjan Gupta** (1999) Interstellar extinction by porous grains, A & A, **348**, 594-599.

Sen, A.K., **Ranjan Gupta**, A.N. Ramaprakash and **S.N. Tandon** (2000) Imaging polarimetry of some selected dark clouds, A & A Supp. Ser., **141**, 175-183.

Mahabal, A., **A. K. Kembhavi** and P. McCarthy (1999) Effective radii and colour gradients in radio galaxies, Astrophysical Journal Letts., **516**, 61.

Sahu D. K., *S. K. Pandey* and **A. K. Kembhavi,** (1999) Properties of dust extinction in NGC2076, BASI, **27**, 271.

Konar, Sushan and Dipankar Bhattacharya (1999) Magnetic field evolution of accreting neutron stars - III, MNRAS, **308**, 795.

Dipanjan Mitra, **Sushan Konar** and Dipankar Bhattacharya (1999) Evolution of multipolar magnetic fields in isolated neutron stars MNRAS, **307**, 459.

Avijit K. Ganguly, **Sushan Konar** and Palash B. Pal (1999) Field theoretic formulation of Faraday effect, Phys. Rev. D., **60,** 105014.

Narlikar, J.V. and **S.K. Banerjee** (1999) The quasi-steady state cosmology, MNRAS, **307**, 73.

Narlikar, J.V., **Ali Nayeri**, **Sunu Engineer** and Fred Hoyle (1999) Structure formation in the quasi-steady state cosmology, The Astrophysical Journal, **525**, 10.

Narlikar, J.V. (1999) The case against the big bang, Comptes Rendus, **327**, Series II b, 481.

Narlikar, J.V. (1999) Reply to Professor Silk, Comptes Rendus, **327**, Series II b, 859.

Srinivasan, K. and **T. Padmanabhan** (1999) Particle production and complex path analysis, Phys. Rev. D, **60**, 24007

Padmanabhan, T. (1999) Event horizon: Magnifying glass for Planck length physics, Phys. Rev. D., **59**, 124012.

Padmanabhan,T. (1999) Probing the quantum microstructure of spacetime Mod. Phys. Lett. A., **14** , 24, 1667-1672.

Padmanabhan, T. and Nissim Kanekar (2000) Gravitational clustering in a D-dimensional universe, Phys. Rev. D., **61**, 023515.

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

Müller, K. R., G. Wegne, **Somak Raychaudhury** and W. Freudling (1999) Fundamental plane distances to early-type field galaxies in the south equatorial Strip. I. The spectroscopic data, Astron. Astrophys. Supp. Ser., **140**, 327 - 344.

Roukema, B.F., D. Valls-Gabaud, B. Mobasher and S. Bajtlik (1999) Galaxy clustering at z ~ 2 and halo radii, MNRAS, **305**, 151.

Roukema, B.F. and S. Bajtlik (1999) Transverse galaxy velocities from multiple topological images, MNRAS, **308**, 309.

Roukema, B.F. and J.P. Luminet (1999) Constraining cosmological metric parameters via global topology, Astronomy and Astrophysics, **348**, 8.

Roukema, B.F. (2000) COBE and global topology: An Example of the application of the circles principle, MNRAS, **312**, 712.

Schmalzing, J., T. Buchert, A. L. Melott, **V. Sahni**, B. S. Sathyaprakash and S.F. Shandarin (1999) Disentangling the Cosmic Web I: Morphology of isodensity contours Ap. J. **526** , 568-578.

Sahni, V. (1999) Generating lambda from the vacuum, Mod. Phys. Lett. A **14**, 2269-2275.

Bharadwaj, S., **V. Sahni**, B.S. Sathyaprakash, S.F. Shandarin and C. Yess (2000) Evidence for filamentarity in the Las Campanas redshift survey, Ap.J. **528**, 21.

Srianand, R. (2000) High-resolution study of associated C IV absorption systems in NGC 5548, Ap. J., **528**, 617.

Srianand, R. and **Shankaranarayanan, S.** (1999) Probing the broad-line regions in active galactic nuclei using time variability of associated absorption lines, Ap.J., **518**, 672.

Petitjean, P and **Srianand, R.** (1999) The $z_{abs} \sim z_{em}$ absorption line systems toward QSO J2233-606 in the Hubble Deep Field - South: Ne VIII absorption and partial coverage, A&A, **345**, 73.

Mangalam, A., Nityananda, R. and **Sridhar, S.** (1999), Constrained violent relaxation to a spherical halo, Ap.J., **524**, 623.

Das, H.K., S. M. Menon, **A. Paranjpye**, and **S. N. Tandon** (1999) Site Characterisation for the IUCAA Telescope Bull. Astr. Soc. India, **27**, 609.

Mookerjea, B., S. K. Ghosh, A. D. Karnik, T. N. Rengarajan, **S. N. Tandon**, and R. P. Verma, (1999) Far-infrared observations of the galactic star-forming regions associated with IRAS 00338+6312 and RAFGL 5111 Ap. J., **522**, p. 285.

Sutaria, F.K., A. Ray, J. A. Sheikh and P. Ring (1999) Nuclear properties in early stages of stellar collapse - Relativistic Mean Field calculations, Astron. and Astrophys. **349**, 135.

Datta, B., **A. V. Thampan** and I. Bombaci

(2000) Possible signatures of strange stars in stellar X-ray binaries, A&A, **355**, L19.

Wadadekar, Y. and **A.K. Kembhavi** (1999) A study of quasar radio emission from the VLA FIRST Survey, Astron. J., **118**, 1435.

Khoshroshahi, H.G., **Y. Wadadekar**, **A. K. Kembhavi** and B. Mobasher (2000) A near infrared plane for elliptical galaxies and bulges of spiral galaxies, Ap.J. L. **531**, 103.

b) Proceedings

Bose, Sukanta, **S.V. Dhurandhar**, and **Archana Pai** (1999) Detection of gravitational waves using a network of detectors, in Proceedings of workshop on Cosmology: Obervations Confront Theories, held at Indian Institute of Technology, Kharagpur Pramana, **53**, 6, 1125-1136.

Dhurandhar, S. V. (1997) Hierarchical search strategy for inspiralling compact binaries, p. 97, proceedings of the Second Workshop on gravitational wave data analysis, Orsay, France, Ed. M. Davier and P. Hello.

Dhurandhar, S.V. (1998) On the Detection of gravitational waves from inspiraling compact coalescing binaries, blackholes, gravitational radiation and the universe: Essays in honour of C. V. Vishveshwara, ed. B. R. Iyer and B. Bhawal, (Kluwer Publishers).

Narlikar, J.V. (1999) Quantum mechanics via path amplitudes, Physics Education, 16, 1, 31.

Narlikar, J.V. (1999) An alternative cosmology: the QSSC, Proceedings of the IAU Symposium 183 on Cosmological parameters and the evolution of the universe, Ed. K. Sato (Kluwer, Dordrecht), p.277.

Narlikar, J.V. (1999) Cosmology, Transactions of the International Astronomical Union, Ed. J. Andersen, XXIIIB, p.173.

Narlikar, J.V. (1999) The quasi-steady state cosmology, Pramana, 53, 6, 1093.

Narlikar, J.V. (2000) The lighter side of gravity - How Swami Gurutwananda received enlightenment, Current Science, 78, 4, 510.

Sahni, Varun (1999) The Cosmological Constant revisited in Proceedings of the Workshop on cosmology: Observations Confront Theories, Pramana, 53, p. 937.

Sahni, Varun (1999) Pancakes and filaments in cosmological gravitational clustering in Proceedings of the Workshop on Cosmology: Observations Confront Theories, Pramana 53, p. 995.

Sridhar, S., Syer, D. and Touma, J. (1999) Self-gravitating eccentric discs around black holes, in Astrophysical Discs: An EC Summer School,160, ASP conference series, 307 - 314, (Ed. J. A. Sellwood and Jeremy Goodman)

c) Books Authored

Kembhavi, A. K. and **J.V. Narlikar** (1999) Quasars and Active Galactic Nuclei: An Introduction, Cambridge University Press, Cambridge.

Narlikar, J.V. (1999) Motion and Gravity, Book in the Exploratory Series, Shekhar Phatak & Associates, Pune.

Narlikar, J.V. (1999) Seven Wonders of the Cosmos, Cambridge University Press, Cambridge.

Narlikar, J.V., Fred Hoyle and Geoffrey Burbidge (2000) A Different Approach to Cosmology, Cambridge University Press, Cambridge.

d) Book Reviews

Dadhich, N. (2000) The expanding worlds of general relativity, eds. H. Goenner, et al

(Birkhauser, Berlin) *Reviewed in* Current Science, 78, 627.

Narlikar, J.V. (1999) Observational cosmology with the new radio surveys, Eds. M.N. Bremer, N. Jackson and I. Perez-Fournon, *Reviewed in* Astrophysics and Space Science Library, Vol. 226, Kluwer Academic Publishers, Dordrecht [Space Science Reviews, 87, 540].

Narlikar, J.V. (1999) The Cosmic Microwave Backgrond, Eds. C.H. Lineweaver, J.C.T. Bartlett, A. Blanchard, M. Signore and J. Silk, *Reviewed in* NATO ASI Series C, Vol. 502, Kluwer Academic Publishers, Dordrecht; [Space Science Reviews, 87, 541] .

Narlikar, J.V. (1999) The American Astronomical Society's First Century, Ed. David H. DeVorkin, *Reviewed in* Nature, **409**, 213.

Narlikar, J.V. (1999) Mr. Tompkins makes a comeback, Ed Peter Rodgers, *Reviewed in* Physics World, IOP Publishing, **12**, 11.

e) Popular Articles

Dadhich, N. (2000) Of blind faith and science, Vritta Vidya, Science Congress issue, January 3, .

Kulkarni, V. (2000) Vigyan Diwas - vigyanpreminsathi parvani (in Marathi), February 21.

Narlikar, J.V.
(in English)

- (1999) Eyes Wide Shut: Big Bang Theorists Out of Orbit, (Times of India, April 10).

- (1999) No Fizz and Spark : Decline of Science Education, (Times of India, May 6).

- (1999) Higher Education in the Twenty First Century (Higher Education : Challenges and Visions, University of Pune), Ed. Prashant K. Sinha, p.33.

-(1999) A different approach to Cosmology, (Co-authors: Geoffrey Burbidge and Fred Hoyle), Physics Today, 52, 38.

- (1999) India in the Twenty First Century (New India Digest), 71, p.10.

- (1999) The interaction between nuclear science and astronomy (Universe & Beyond), 3, p.6.

- (1999) A Modern Mindset : Combining Tradition and Technology, (Times of India, October 23).

- (1999) The Numbers Game : Overcoming the Millennium Mania, (Times of India, November 11).

- (1999) Science and Technology (Celebrate India 2000 : Endings and beginnings, Tulika).

- (1999) Fred Hoyle : A Profile (Petals, a publication of the South Indian Cultural Association Senior Secondary School, Indore), Commemorative Vol.XIII, p.26.

-(1999) The concept of God (Gentleman, December Issue).

- (1999) The Selection Effect : The Inaccuracy of Millennium Rankings, (Times of India, December 28).

- (2000) Science Journalism in India and Abroad, (Vritta Vidya, January 3 and January 7).

- (2000) Reaching out to the sky, (Innovative India), Eds. L.K. Sharma and Sima Sharma, Mediland Ltd., U.K., p.188.

-(2000) Astronomy in the millennium (Prabuddha Bharata), 105, p.22

- (2000) Science of the Times : From Abstract Concepts to Daily Life, (Times of India, March 1).

Narlikar, J.V.
(in Marathi)

- (1999) Urja Aani Paruavaran (in Marathi), [Energy and Environment], (Shikshan Sankraman, April, p.16).

- (1999) Maze `Sushlok' Aajoba (in Marathi) [My `Sushlok' Grandfather], (Maharashtra Times, May 9).

-(1999) Ekvishave shatak : Swapne aani avhane (in Marathi), [Twenty-first century : Dreams and challenges], (Raviwar Sakal, July 11).

- (1999) Apangatvala na-jumannara shastradnya - Stephen Hawking (in Marathi), [Stephen Hawking - a scientist who surmounted disabilities], (Apangasmurti, August 15).

- (1999) Khare kiva Khote (in Marathi), [True or False], (Shikshan Sankraman, October, p.18).

- (1999) Bahurangi pratibhecha vaidnyanik (in Marathi) [A scientist of multifaceted talents], (Vishranti, Diwali Issue).

- (1999) Pradushan Aani Khagol Nirikshan (in Marathi) [Pollution in Observational Astronomy], (Vidnyan Vedh, a publication by Marathi Vidnyan Parishad, Barshi).

- (1999) Ekvisavya Shatkat (in Marathi)[In the Twentyfirst Century], (Patrika, a publication of Marathi Vidnyan Parishad, December Issue, p.3).

- (1999) Bharatatil prachin udaharane (in Marathi)[Examples from Ancient India], (Shikshan Sankraman, December, p.5).

- (2000) Pannas varshanantar (in Marathi) [After 50 years], (Parivartan: Sankalpana, Vedh Ani Vastav, Commemoration Volume in honour of Professor J.M. Waghmare, p.64).

Paranjpye, Arvind
(in Marathi)

(1999) Sawrgache Dwar "Disha", Saturday supplement of Sakal Newspaper, May 22.

- (1999) Mazhi Vedhshala - Parjanya Mapak Yantra Chatra Prabodhan, June.

- (1999) Mazhi Vedhshala - Adrata Mapak Yantra Chatra Prabodhan, July.

- (1999) Mazhi Vedhshala - Vayu gatimapan Chatra Prabodhan, August.

- (1999) Mazhi Vedhshala - Dhag Chatra Prabodhan, September.

Raychaudhury, Somak (1999) From Chandrasekhar to Chandra, The Hindustan Times, Delhi, August.

- (1999-2000) Alpha Omega, a weekly column in Pune Mid-day, every Monday August 26 till present, on scientific and technological issues.

- (1999) Will it (the Leonid meteor shower) be a storm or a drizzle? The Telegraph, Calcutta, November 8.

- (1999) X-kirananchya chashmyatun Viswadarshan (in Marathi, tr. Vinaya Kulkarni), Sahitya Sadhana (Diwali Issue), Nagpur, October.

- (2000) Something out of nothing knowhow (Millennium issue on the Universe), The Telegraph, Calcutta, March 27.

Roukema, B.F., (1999) L'Univers est-il fini ?, l'Astronomie, 113, 162.

Roukema, B.F., (1999) La Cosmologie globale empirique existe-t-elle ?, Journal des Astronomes Franccais, 59, 12.

f) Resource Summaries in the IUCAA quarterly Bulletin "Khagol".

Ranjan Gupta (1999) Artificial Neural Networks - An Application to Stellar Spectroscopy (Issue No. 39, July 1999).

Ajit Kembhavi & Yogesh Wadadekar (1999) Surface Photometry of Galaxies (Issue No. 38, April 1999).

Sushan Konar (2000) Magnetic Fields of Neutron Stars (Issue No. 41, January 2000).

Somak Raychaudhury (1999) Clusters and Superclusters of Galaxies (Issue No. 40, October 1999).

by Associates / Senior Associates

[*Publications co-authored by Associates / Senior Associates and a member of IUCAA staff appear in the previous section and are not repeated here.*]

a) Journals :

Ahsan, Zafar (1999) Electric and magnetic Weyl tensors, Indian J. Pure Appl. Maths. **30 (9)**, 863-869.

Ahsan, Zafar (2000) Interacting radiation fields, Indian J. Pure Appl. Maths. **31 (2)**, 1-11.

Thomas, K.I. and **G. Ambika** (1999) Suppression of Smale horseshoe structure via secondary perturbations in pendulum systems, Pramana, **52**, 375.

Bali, Raj and Sharma, Keshav (1999) Tilted Bianchi Type I models with heat conduction filled with disordered radiation of perfect fuid in general relativity, Astrophys. and Space Science, **12**, 1.

Banerjee, A. and Ghosh, T. (1999) Dilaton electromagnetic field in Bianchi models, Class. Q. Grav., **16**, 3981.

Banerjee, A. and Ghosh, T. (2000) Motion of particles around a monopole, Int. J. Mod. Phys., **A15**, 869.

Das, Ajanta and **A. Banerjee** (1999), Five dimensional magnetic universe, Astrophys. and Space Science, **268**, 425.

Banerjee, A., Chatterjee, S. and Ghosh, T. (2000) Coupled dilaton and electromagnetic fields in cylindrically symmetric spacetime, Pramana, **54**, 1-9.

Biswas, S., Shaw, A. and Modak, B. (1999) Decoherence in the Starobinsky Model, General Relativity and Gravitation **31,** 1015.

Sarkar, N.G., **S.Biswas** and Shaw, A. (1999) Dirac current in expanding spacetime, Pramana, **53,** 685.

Biswas, S., Shaw, A. and Biswas, D. (1999) Starobinsky model in Schrodinger description, Pramana, **53,** 815.

Biswas, S., Shaw, A. and Modak, B. (2000) The complex time WKB approximation and particle production, General Relativity and Gravitation, **32,** 53.

Chakraborty, S. and Rahaman, F. (1999) Motion of test particle in global monopole with Brans-Dicke theory, Pramana, **51**, 689.

Chakraborty, S. and Chakravarty, N. (1999) Quantization of Kantowski Sachs model and the wave function, General Relativity and Gravitation, **31**, 999.

Chakraborty, S. and Biswas, L. (1999) Non-static general relativistic domain walls, Physica Scripta, **60**, 199.

Chakraborty, S. and Rahaman, F. (1999) Gravitational field of a global monopole in Brans-Dicke theory field of gravity, IL Nuova Cimento Delle Societa Italiana di Fisic, **114**, 9, 1017

Chakraborty, S. and Roy, A. (1999) String-dust in higher dimensional cylindrically symmetric cosmological model, Int. J. Mod. Phys., D., **8(5)**, 645-650.

Chandra, Suresh and Kegel, W.H. (2000) Collisional rates for asymmetrical top molecules, Astron. Astrophy. Suppl., **142**, 113.

Datta, B.K., V. de Sabbata and **Renuka Datta** (1999) From Greek concept of geometric magnitude to numbers and directed numbers - A Pedagogic Discussion, Science and Culture, Calcutta, **65**, 64-67.

De, S.S. (1999) Mild inflation and modified general relativity in the early universe, Int. J. Theor. Phys. **38**, 2419.

Ishwar, B. and Singh, Jagdish (1999) Stability of triangular points in the generalised photogravitational restricted three body problem, Bulletin of Astronomical Society of India, **27**, 3, 415-424.

Ishwar, B. (2000) First order normalisation in the generalised restricted three body problem, Bulletin, Cal. Math. Soc., **6**, (2), 73-80.

Ishwar, B. (2000) Unsolved restricted three body problem, News Bulletin, Cal. Math. Soc., **23**, 3, 2000.

Jog, C.J. (1999) Dynamics in a lopsided spiral galaxy: negative disk response to perturbation halo potential, Astrophys. J., **522**, 661-668.

Das, M. and **C.J. Jog** (1999) Tidally compressed gas in centres of early-type and ultraluminous galaxies, Astrophys. J., **527**, 600.

John, Moncy V. and Joseph, K. Babu (2000) Generalised Chen-Wu type cosmological model, Phys. Rev. **D61**, 087304.

Susmita Sarkar, Ghosh, S. and **Manoranjan Khan** (1999) Low frequency wave propagation in cold magnetized dusty plasma, Planetary and Space Science, **47**, 273.

Samantray, Archana and **Pushpa Khare** (2000) Nature of the background ultraviolet radiation field at high redshifts, Journal of Astronomy and Astrophysics, **21** 19-27.

Shaju, P.D. and **V.C. Kuriakose** (1999) Logic gates using stacked Josephson junctions, Physica C, **322**, 163.

John, Raju K. and **V.C. Kuriakose** (1999) Temperature dependence of the upper critical field H_{c2} of superconductors with inequivalent conducting layers, Ind. J. Phys. **73A**, 727.

Bindu, S.G. and **V. C. Kuriakose** (2000) Non-linear wave propagation through a ferromagnet with damping in (2+1) dimensions, Pramana, **54**, 275.

Santhosh Kumar, G. and **V.C. Kuriakose** (2000) Squeezed coherent state representation of scalar field and particle productions in the early universe, Int. J. Theo. Phys. **39**, 351.

Nandi, K.K. and Alam, S.M.K. (1999) Stringy wormholes, General Relativity and Gravitation, .**31**, .9, 1263.

Nandi, K.K. (1999) Reply to comments on the Brans-Dicke wormholes in the Jordan and Einstein frames, Phys.Rev.D, **59**, 7, 088502.

Padmakar and **Pandey S. K.** , (1999) New BVR photometry of six prominent RS CVn binary stars, A&A, **138**, 203.

Pandita, P.N. and Paulraj, P. Francis (1999) Infra-red stable fixed points of Yukawa couplings in non-minimal supersymmetric standard model with R-parity violation, Phys. Lett. **B462**, 294.

Ananthanarayan, B. and **P.N. Pandita** (1999) Infra-red stable fixed points of Yukawa couplings in supersymmetric models with R-parity violation, Phys. Lett. **B454**, 84.

Phukon, T.C. (2000) How large can the crust of a strange star be?, Astron. Astrophys. **355**, 1009.

Vivekananda Rao, P., Sarma, M.B.K. and Abhyankar, K.D. (1999) A rediscussion on the eclipsing binary YY Canis Minoris, A&AS, **139**, 57.

Ramakrishna Reddy, R. (1999) RKRV potential energy curves, dissociation energies, r-Centriods and Franck-Condon factors of YO, CrO, BN, ScO, SiO and AIO molecules, Astrophysics and Space Science, **262**, 223.

Ramakrishna Reddy, R. (1999) Optical and magnetic susceptibilities for semiconductors and alkali halides, Journal of Magnetism and Magnetic Materials, **192**, 516.

Ramakrishna Reddy, R. (1999) Bulk modulus and Debye temperature of ternary Chalcopyrite semiconductors, Ind. J. Pure and Appl. Physics, **37**, 25.

Ramakrishna Reddy, R. (1999) Correlation between optical basicity, electronegativity and electronic polarizability for some oxides and oxysalts, Optical Materials, **12**, 425.

Ramakrishna Reddy, R. Y. Nazeer Ahmmed, K. Rama Gopal and S. Anjaneyulu (1999) Bond dissociation energy of astrophysical important molecules, Journal of Quantitative Spectroscopy and Radiative Transfer **61**, 711.

Ramakrishna Reddy, R., Y. Nazeer Ahmmed, K. Rama Gopal, P. Abdul Azeem and T.V.R. Rao, Dissociation energies of astrophysically important MgO, SO, SiN and TiO from spectroscopic data, Journal of Quantitative Spectroscopy and Radiative Transfer, **66**, 501.

Ramakrishna Reddy, R. (2000) Ionization potential of Astrophysically important molecules, J. Quant. Spectro Radio. Trans (USA), **67**, 85-90.

Singh, G.P. and T. Singh, (1999) String cosmological models with magnetic field, Gen. Rel. Grav., **31**, 371-378.

Singh, G.P. and Beesham, A. (1999) Bulk viscosity and particle creation in Brans-Dicke Theory, Aust. J. Phys. **52**, 1039-49.

Agrawal, P.C., Mukherjee, K., Naik, S., Paul, B., Rao, A.R., Jadav, J.S. Kasturirangan, K., Seetha, S. and **K.Y. Singh** (2000) Studies of binary sources with the Indian X-ray Astronomy Experiment, Adv. Space Res., **25**, 357.

Srivastava, S.K. (1999) The Riccion, the

instanton and primordial inflation, Int. J. Mod. Phys. A **14**, 875.

Srivastava, S.K. (1999) Dual nature of Ricci scalar and models of the early universe, Mod. Phys. Lett. A, **14**, 1021.

Vinodkumar, P.C., Pandya, J.N., Bannur, V.M. and Khadkikar, S.B. (1999) A unified scheme for flavoured mesons and baryons, Eur. Phys. Jnl. **A 4**, 83.

Pandya, J.N. and **P.C. Vinodkumar** (1999) Dielectric properties of QCD medium from mesons, Ind. Jnl. Phys. **73B**, 272.

b) Proceedings

Datta, B.K., V. de Sabbata and **Renuka Datta** (2000) The EPR argument and quantum nonlocality, Classical & Quantum Nonlocality, Eds. P.G. Bergmann, V. de Sabbata & J.N. Goldberg (World Scientifc, Singapore), 1-6.

Bindu, S.G. and **V.C. Kuriakose** (2000) The stability analysis of modified Kadomstev-Petviashvili equation, in Nonlinear Dynamcis: Integrability and Chaos, Eds. M. Daniel, K.M. Tamizhmani and R. Sahadevan (Narosa, Chennai), 143-146.

Vinodkumar, P.C., Upadhyaya, Tushar and Tiwari, Anita (1999) Glue-balls, hybrids and di-mesons, DAE Nucl. Phys. Symp, 42B, 266.

Patel, Divyesh, J., **P.C. Vinodkumar** and Ray, Asim K. (1999) Critical parameters for degenerate quark stars, DAE Nucl. Phys. Symp. 42B, 340.

c) Books (Authored)

Ahsan, Zafar (1999) Differential equations and their applications, Prentice-Hall of India Pvt. Ltd., New Delhi.

d) Books (Reviewed)

Jog, C.J. (1999) Review of a book titled 'Watching the Universe' by John Gribbin, Resonance, 4, No. 7, 90-91.

e) Popular articles

Pathak, S.K. (1999) Hole in the sky, The Times of India, June 16.

f) Pedagogical Activities by Associates

Supervision of Thesis

S. K. Pandey

D. K. Sahu,
Photometric studies of some early-type galaxies, August 1999, Pt. Ravishankar Shukla University, Raipur. Ph.D.Thesis

(V) PEDAGOGICAL ACTIVITIES

a) IUCAA-NCRA Graduate School

S.V. Dhurandhar: Methods of Mathematical Physics - I

N.K. Dadhich: Methods of Mathematical Physics -II

Ajit Kembhavi: Introductory Astronomy II

S. Konar: Quantum Mechanics - I

T. Padmanabhan: Structure Formation in the Universe (Topical course)

T. Padmanabhan: Cosmology

Somak Raychaudhury: Astrophysical Techniques- I

R. Srianand: Electrodynamics and Radiative Processes

b) Other Graduate Schools

T. Padmanabhan: Advanced Cosmology AY212 (15 lectures), California Institute of Technology (April-May, 1999).

T. Padmanabhan: High Energy Astrophysics AY125 (5 lectures), California Institute of Technology (May, 1999).

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

Ranjan Gupta: Astronomy and Astrophysics-I

Ranjan Gupta: Laboratory course (Semesters III and IV)

J.V. Narlikar: Electrodynamics - I, Core Course, (Semester II)

Varun Sahni: Astronomy and Astrophysics - II (General Relativity and Cosmology)

d) Supervision of Projects

Suketu Bhavsar
Srabani Dutta (M.Sc.)
Fractal nature of molecular clouds

Naresh Dadhich

Raja Paul (VPUS, JNU)
K.G. Arun (VSP, CUSAT)
Motion in the Schwarzschild like field

Ranjan Gupta

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

Sushan Konar

Ashwini Rajaram and Abhijit Phanse (M.Sc.)
Faraday Rotation : Relativistic Corrections

J. V. Narlikar

Sachin Nanavati (M.Sc.)
Synchrotron Radiation from Radio Sources.
Shripad Kulkarni (M.Sc.)
Radiation Processes.

J.V. Narlikar

Shweta Havele
Smita Kamthe
Pallavi Zagade
Gita Lakkhan
Ambika Rai
Rupali Chindhe
Pradnya Jogalekar
Smita Todkar
Chaitanya Ambi
Chetan Chaudhari
Mangesh Bhosale
Yogesh Salvi
Nikhil Mahadar
Kaushik Bodas
Foucault Pendulum and the Spin of the Earth
(School Students' Summer Programme Project)

Project sponsored by other agencies:

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

Arvind Paranjpye

Madhura Gokhale and Jyoti Kokil (B. Sc.)
Estimating distances in sstronomy

Somak Raychaudhury

Lovleen Kaur Banga, (VSP, Delhi University)
Supernovae in gravitationally lensed arcs

S. Sanjuktha, (VSP, Pune University)
The age of the Universe (supervised jointly with Varun Sahni)

L. Resmi, (Cochin University of Science and Technology, JNCASR visiting M.Sc. student)
A mass model of the milky way from distant satellites

Varun Sahni

Debasish Das (VSP)
Cosmology in the presence of a cosmological constant

F. K. Sutaria

R. Raina (M.Sc. 2nd year, Pune University).
Study of equations for stellar evolution.

S. N. Tandon

Pankaj Bhagavat and Sudarshan Vasudevan, (Regional Enineering College, Tiruchirapalli)
Estimation of cloud cover in CCD pictures

V. A. Sarurkar, (University of Pune)
Grating spectrometer

Arun Thampan

Arijit Sarmah (B.Sc.)
White dwarf stars

Supervision of dissertation / Thesis

T. Padmanabhan

K. Srinivasan
Particle Production in Field Theory
Ph.D. Thesis

S.N. Tandon

A. N. Ramprakash
Development of and Observations with an Astronomical Imaging Polarimeter
Ph.D. Thesis

Somak Raychaudhury

S. Sanjuktha (Pune University)
M.Sc. Dissertation (1999-00)
Multivariate analysis of galaxy cluster parameters

(VI) IUCAA COLLOQUIA, SEMINARS, ETC.

a) Colloquia

Yashodhan Hatwalne: *Abrikosov phases of soft matter*, September 21.

Naresh Dadhich: *Empty space and its dual in general relativity*; October 11.

Kailash C.Sahu: *Gravitational microlensing, dark matter, and extra-solar planets*, December 23.

S. R. Sarma: *Astronomical instruments in medieval India*, December 27.

Jiri Bicak: *Relativistic Disks: Exact models*, January 24.

b) Seminars

George Efstathiou: *The heating of IGM and Ly α Forest,* May 5.

George Efstathiou: *Formation of disk galaxies*, May 6.

Mahendra K. Verma: *Energy spectra and cascades in MHD turbulence*, May 14.

Sujan K. Sengupta: *General relativisitc effects on the magnetic field and thermal evolution of neutron stars*, May 27.

A. Gopakumar: *Constructing search templates for LIGO/VIRGO gravitational wave detectors*, June 11.

Sushan Konar: *Highlights of NATO/ASI meeting on neutron star - black hole connection*, July 26.

Tirthankar R. Choudhury : *Quantum cosmology of Bianchi type I models*, August 4.

Jatush V. Sheth: *Particle production in the inflationary universe*, August 4.

Arun Mangalam: *Violent relaxation to a spherical halo*, August 9.

Boud Roukema: *High z clustering conference*, Marseille, September 10.

Andrzej Zdziarski: *Spectral states of black hole binaries*, September 27.

Daksh Lohiya: *Going beyond standard big bang cosmology*, October 28.

H.S. Hans: *My nuclear physics experiments in four decades*, November 15.

Jiri Bicak: *Radiative spacetimes*, January 25.

Tarun Deep Saini: *A new method of mass reconstruction from shear*, February 17.

Yogesh Wadadekar: *Optical studies of VLA FIRST survey sources*, February 17.

Shibu K. Mathew: *Solar magnetic field measurements using voltage tunable FP etalon*, February 21.

Tadashi Mukai: *Observation of interplanetary dust bands by CCD camera*, March 21.

Akihide Kamei: *Laboratory measurements of laser light scattering by rough surface*, March 22.

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

D.B. Vaidya	)
Boud Roukema	) **April 21.**
Ali Nayeri	)
Chanda Jog	)
Kanti Jotania	)
Habib Khosroshahi	) **May 12.**

A. Beesham	)	
A. Abraham	)	**November 17**
Kamal Kanti Nandi	)	
Archana Pai	)	
Arun Thampan	)	**December 15**
Suketu Bhavsar	)	
Alain Omont	)	
P.P. Hallan	)	
P.S. Goraya	)	**January 19**
Tarun Deep Saini	)	
Sunil Maharaj	)	
Ch.V. Sastry	)	**February 16**
Soumya Chakravarti	)	
T.C. Phukon	)	
Diego Malquori	)	**March 15**
Yogesh Wadadekar	)	

(VII) TALKS AT WORKSHOPS OR AT OTHER INSTITUTIONS

a) Seminars, Colloquia and Lectures

S. Bhavsar

Dark matter and large scale structure in the universe, Benaras Hindu University, Varanasi, October, 1999.

Is the standard big bang model still viable? Jawaharlal Nehru University, New Delhi, October, 1999.

S. V. Dhurandhar

Adaptive filtering for removing noisy transients from interferometric data, AEI, Max Planck, Potsdam, Germany, May 6.

Detecting coalescing binary signals with a network of laser interferometric detectors, AEI, Max Planck, Potsdam, Germany, June 15.

The search for gravitational waves, Research scholars symposium, Physics Department, Pune University, December 10.

Searching for gravitational waves from rotating neutron stars, Plenary talk at ICGC-2000, IIT Kharagpur, January 4.

N. Dadhich

Electromagnetics of gravity, Invited talk in the Symposium on Relativity, Astrophysics and Cosmology, Quid - e- Azam University, Islamabad, Nov. 18-22

Non-singular cosmological models, Invited talks in the Symposium on Relativity, Astrophysics and Cosmology, Quid - e- Azam University, Islamabad, Nov. 18-22

Light bends the universe, Kalyani University, March 24.

Light bends the universe, North Bengal University, March 27.

Light bends the universe, IUC-DEF, Calcutta Centre, March 29.

Electrodynamics from Newton's law of motion, Jadavpur, University, March 28.

Electrodynamics from Newton's law of motion, IIT, Kharagpur, March 31

Ranjan Gupta

Artificial neural networks: An application to stellar spectroscopy, StSci, Baltimore, USA, June 14.

Spectral classification by automated artificial neural networks, University of Hamburg, Hamburg, Germany, July 8.

IR astronomy plans at IUCAA, Current trends in infrared astronomy, August 17-19, PRL, Ahmedabad.

Observational astronomy: Facilities in India, Assam University, Silchar, Sept. 20.

Spectroscopic observations with small telescopes, UPSO-IUCAA workshop on observations with 2-metre size telescopes, UPSO, Nainital, October 26-29.

Astronomical observations I and II, IIIrd, Level 1 workshop on Astronomical Photometry, IUCAA, January 17-21.

Stellar spectroscopy and instrumentation & data analysis for stellar spectroscopy, Department of Astronomy, Osmania University, Hyderabad, February 28-29.

Interstellar dust and its modeling, Graduate School of Science and Technology & Department of Earth and Planetary Sci., Faculty of Science, Kobe University, Japan, March 13.

Sushan Konar

Magnetic field of neutron stars, NATO-ASI on Neutron Star - Blackhole Connection, Crete, June 11.

Accretion and magnetic field of neutron stars, Department of Physics, University of Milano, Italy, June 24.

Neutron Sstar - black hole connection - IUCAA, Pune, August.

Field theoretic formulation of Faraday rotation, Raman Research Institute, Bangalore, November 20.

Curvature of spacetime and magnetic fields of neutron stars at ICGC 2000, IIT Kharagpur, January 6.

Magnetospheric accretion on neutron stars, Indian Academy of Sciences meeting on 'High EnergyAstrophysics' held in Coorg, February 3.

Neutron stars - the dream laboratory of condensed matter physicists, Department of Physics, Indian Institute of Science, Bangalore, February 11.

Ajit Kembhavi

Galaxy morphology and correlations, Workshop on New Trends in Near Infrared Astronomy, PRL, Ahmedabad, August 17-19.

Image processing (2), Mini-school on Computer Astronomy, St. Thomas College, Charal Mount, Kerala, August.

How black are black holes?, S.B. College, Changanacherry, Kerala, August.

Quasars, Cochin University of Science and Technology, Cochin, Kerala, September.

Gamma-ray Bursts (2), Workshop on Observational Programmes with 2m Class Telescopes, UPSO, Nainital, October.

Stars- structure and evolution (2), Workshop on Interstellar Molecules, Sri Krishnadevaraya University, Anantapur, October.

B-K Colours of QSOs, Mini-workshop on Quasar Spectroscopy, IUCAA, Pune, January 21.

Supermassive black holes, Mini-workshop on Quasar Spectroscopy, IUCAA, Pune, January 22.

Birth and Death of Stars, Workshop on Astronomy, Smt. Chowgule College, Margao, Goa, February 3.

Black Holes in Action, Workshop on Astronomy, Smt. Chowgule College, Margao, Goa, February 4.

Quasars and black holes, Association of Friends of Astronomy & Public Astronomical Observatory, Panjim, Goa, February 5.

Photometric plane of galaxies, NCRA, Pune, February.

Black Holes, National Science Day, IUCAA, Pune, February 28.

Active galaxies, quasars and monsters, Amateur Astronomers Society, Durban, March 15.

Relativity in cosmic gamma-ray bursts, University of Zululand, March 17.

Quasars, Astronomical Society, University of Durban, March 20.

Fundamental planes and galaxy formation, University of Natal, Durban, March 24.

General relativity through x-ray astronomy: The iron line, University of Durban, March 27.

J. V. Narlikar

The redshift-magnitude in the quasi-steady state cosmology, Institute of Astronomy, Cambridge, June 11.

The redshift-magnitude relation in the quasi-steady state cosmology, Harvard-Smithsonian Centre for Astrophysics, USA, June 22.

Challenging problems in astrophysics, Physics Department, Aligarh Muslim University, Aligarh, August 9.

Formation of large scale structure in the quasi-steady state cosmology, Instituto Astronomico e Geofisico of the University of Sao Paulo, Brazil, September 15.

The quasi-steady state cosmology, CBPF, Rio de Janeiro, Brazil, September 17.

Some present ideas in cosmology, INPE, Brazil, September 24.

Speculations about dark matter, INPE, Brazil, September 24.

The quasi-steady state cosmology, IFS, Sau Paulo, Brazil, September 29.

Some current speculations on dark matter, Indian Institute of Geomagnetism, Mumbai, October 15.

Cosmology : past, present and future, Indian Physics Assocation's seminar on Physics in 20th Century and Emerging Trends for the New Millennium, Tata Institute of Fundamental Research, Mumbai, November 10.

The mysterious force of gravity (a thematic workshop for school children on "Mysteries and Challenges in Physics"), Nuclear Science Centre, New Delhi, December 19.

The lighter side of gravity (How Swami Gurutwananda received englightenment)(the After-Dinner Talk at the International Conference on Gravitation and Cosmology (ICGC-2000)), Indian Institute of Technology, Kharagpur, January 6.

T. Padmanabhan

Facets of gravitational clustering, Astronomy Colloquium, Caltech, May 19.

Aspects of gravitational clustering, TIFR, (Mumbai) Colloquium, November 3.

Understanding our universe, Indian Science Congress, Pune, Millennium Medal Lecture, January 6.

Modeling of intergalactic medium, Mini-workshop on Quasar Spectroscopy, IUCAA, Pune, January 21 - 23.

Archana Pai

Detection of graviational waves using a network of detectors, Department of Physics and Astronomy, Cardiff University, July 9.

Detection of graviational wave signals from inspiralling compact coalescing binaries with a network of laser interferometric broadband detectors, ICGC-2000, IIT-Kharagpur, India, January 7.

Arvind Paranjpye

Solar eclipse photography, Total solar eclipse 1999 Master Resource Persons Training Programme, July 4.

Introduction to astronomy, Shaheed Razai University, Tehran, Iran , August 1 to August 6.

Somak Raychaudhury

Cosmological parameters from luminosity distances and angular sizes, Seminar at Department of Astrophysics, Liverpool John Moores University, Liverpool, UK, October.

The cosmic equation of state from supernova distances, Seminar at the Institute of Astronomy, University of Cambridge, Cambridge, UK, December.

Boud Roukema

ArFus - un logiciel convivial pour modeliser laformation de galaxies selon son propre gout,"Institut d'Astrophysique de Paris, May 6.

ArFus a tool for modeling galaxy formation, NCRA, Pune, July.

Comment mesurer Ω_0
al pr`es, Institut d'Astrophysique de Paris, October.

Cosmic topology: Recent and future observational test, Review talk at ICGC 2000, IIT, Kharagpur, January 7.

Tangential large scale structure as a cosmological standard ruler, ICGC-2000, IIT, Kharagpur, January 7.

Cosmic topology: Recent and future observational tests, TIFR, Mumbai, January 25.

La topologie cosmique : risultats ricents, LAOG, Observatoire de Grenoble, February 10.

Resultats observationnels recents en topologie cosmique DARC, Observatoire de Meudon, February 11.

Large scale structure as a Standard Ruler for constraining the curvature parameters, MRI, Allahabad, March 27.

Risultats observationnels ricents en topologie cosmique, Observatoire de Bordeaux, April 19.

Resultats observationnels recents en topologie cosmique, Institut d'Astrophysique Spatiale, Orsay, April 20.

Varun Sahni

The case for the cosmological constant, Plenary talk at Workshop on High Energy Particle Physics (WHEPP-6) Matscience, Chennai, January.

Living with Lambda, Plenary talk at International Conference on Gravitation and Cosmology, IIT Kharagpur, January.

The morphology of large scale structure, International Conference on Gravitation and Cosmology, IIT Kharagpur, January.

The cosmological constant Λ reexamined, Plenary talk at Structure Formation and Dark Matter, Santa Fe, USA, June 28 - July 16 1999.

The case for a cosmological constant, Indian Institute for Science, Bangalore, April.

The morphology of the supercluster-void network, Raman Research Institute, Bangalore, April.

The cosmological constant revisited, Institute of Mathematical Sciences, Chennai, April.

The large scale structure of the universe, Institute of Mathematical Sciences, Chennai, April.

Geometrical methods of analysis of large scale structure in the universe, Institut d'Astrophysique de Paris, France, October.

The mystery of Λ, Observatoire de Paris-Meudon, France, October.

The vacuum energy reexamined, The University of Cardiff, UK, November.

The cosmological constant: Theory and Observations, The University of Newcastle upon Tyne, UK, November.

Measuring the supercluster-void morphology, The University of Durham, UK, November.

The cosmological constant revisited, Isaac Newton Institute for Mathematical Sciences, Cambridge, UK, November.

S. Shankaranarayanan

Particle production and unstable vacuum, Raman Memorial Conference, University of Pune, December 11, 1999.

R. Srianand

Associated absorption systems in QSOs, Mini-workshop on Quasar Spectroscopy, IUCAA, January 22.

Molecules in high-z damped systems, IUCAA, January 22.

X-ray from AGNs, Discussion meeting on High Energy Astrophysics, Coorg, February 2-3 (2 talks)

Optical spectroscopy, IUCAA, February 10-11 (2 talks)

Probing the nuclear regions of AGN with associated absorbers, IAP, Paris, March 25.

Associated absorption system in QSOs, Paris Observatory, Meudon, March 25.

S. Sridhar

Dynamics of galaxies, Colloquium at the Centre for Advanced Mathematical Sciences, American University of Beirut, November 3.

F.K. Sutaria

Neutrino emission from early stages of stellar collapse, Montana State University, July.

Fe-line broadening in MCG 6-15-30, Aspen Center for Physics, August.

Nuclear astrophysics of neutron stars, TU-Muenchen, Garching, September.

Equations of state for collapsing stellar cores , Institute of Astronomy, Cambridge University, October.

S.N. Tandon

Observing polarisation with IUCAA's Polarimeter, Mini Workshop on Gamma Ray Bursts, IUCAA, August 26-28.

Arun Thampan

Luminosities of Disk - accreting Non - magnetic neutron stars, ICGC- 2000, IIT, Kharagpur, January 1.

Constraining equations of state of compact stars, Discussion Meeting on High Energy Astrophysics, Coorg, February, 2.

The standard model of accretion disks, Discussion Meeting on High Energy Astrophysics, Coorg, February, 3.

Yogesh Wadadekar

Refresher Course in A & A for College / University Teachers, IUCAA, June (11 -16).

(i) Demo on astronomical data on the Internet, June 12.

(ii) The solar system, June 14;

(iii) The Hubble Space Telescope, June 16.

Morphological image processing at Mini School on Computer Astronomy, Kozhencherry, Kerala, September 1.

Modeling galaxy light profiles, Mini-School on Computer Astronomy, at St. Thomas College, Kozhencherry, Kerala, September 2.

Demos on Linux, Iraf, Filters using IRAF, GIMP, and Astronomical data on the Internet, Mini-School on Computer Astronomy at St. Thomas College, Kozhencherry, Kerala, August 30 - September 3.

Radio emission from quasars in the VLA FIRST Survey, Raman Memorial Conference, Pune, December 11.

Radio emission from optically selected quasars, Mini-Workshop on Quasar Spectroscopy, IUCAA, January 21.

Space missions to explore the solar system, Introductory Workshop on Astronomy, Parvatibai Chowgule College, Margaon, Goa, February 4.

The universe through the eyes of the Hubble Space Telescope, Introductory Workshop on Astronomy, Parvatibai ChowguleCollege, Margaon, Goa, February 4.

b) Lecture Courses

N.K. Dadhich:

Basic general relativity, IIT, Kharagpur, March 29 - April 4, 6 lectures.

S.V. Dhurandhar

Introduction to relativity, Refresher course, Physics Department, University of Pune, January 17, 18, 19 and 20, (6 lectures).

Ajit Kembhavi

Stellar structure and evolution, University of Mumbai, September-October, (10 lectures).

J.V. Narlikar

Introductory cosmology, IUCAA, Pune in the VSP - VSRP, May 24, 25, 26, (3 lectures).

Theories and observations in cosmology

Instituto de Fisica, Sao Paulo, Brazil, September 9, 14, 16, 21, 23, 28 (6 lectures).

Cosmology, Mumbai University, October 12-22, (15 lectures).

Somak Raychaudhury

Stellar and galactic dynamics, Workshop on Astrophysics for Physicists, at Santiniketan, West Bengal, March 1999, (4 lectures).

Observational tests to determine cosmological parameters (IUCAA), Pune, VSP, May 27-31, (3 lectures).

T. Padmanabhan

Order of magnitude astronomy, VSP - VSRP, June 8-11, (4 lectures).

R. Srianand

Observational cosmology, Refresher Course in A & A for College/University teachers, IUCAA, May-June, 1999, (4 lectures).

Intergalactic medium, IUCAA, October, (10 lectures).

S. Sridhar

Fundamentals of fluid dynamics, American University of Beirut, October, 4 lectures.

c) Popular Lectures

Naresh Dadhich

Light bends the universe, National Science Day, IUCAA, February 27.

Living by science, National Science Day, IUCAA, February, 27.

Ranjan Gupta

A journey through the universe, M.P. Birla Planetarium, Evening Course Alumni Association, Calcutta, September 22.

Sushan Konar

Compact objects in the sky, National Science Day, IUCAA, February 27.

Ajit Kembhavi

Introduction to astronomy, Chinmaya Mission, Hubli, April.

Black holes (English & Marathi), Exploratory, Pune, May.

T. Padmanabhan

The story of stars (School Students' Lecture Demonstration Programme), IUCAA, August 21.

Nobel prize in physics 1999, National Science Day, IUCAA, February 27.

J.V. Narlikar

Space, time and gravitation, Summer Workshop conducted by Exploratory, IUCAA, April 17.

Kal, avakash ani gurutvakarshan (Time, space and gravitation) (in Marathi), Summer Workshop conducted by Exploratory, IUCAA, April 28.

Vidnyan ani adhyatma (Science and Religion) (in Marathi), Jyesth Nagarik Sansad, Ahmednagar, May 2.

Structure formation in the quasi-steady state cosmology, Max-Planck Institut for Astrophysics, Germany, June 8.

Ekvishave shatak : Swapne ani avhane (Twenty-first century : Dreams and challenges) (in Marathi), BMM Convention, California, June 3.

Vishwachi rachana (Structure of the universe) (in Marathi), Lecture demonstration programme for school students, IUCAA, July 10.

Structure of the universe (in English), Lecture demonstration programme for school students, IUCAA, July 10.

The frontier between physics and astronomy (Lecture for the junior college students), IUCAA, July 24.

Higher education : Opportunities and challenges, frustrations and rewards, Third Rais Ahmed Memorial Lecture at the Aligarh Muslim University, Aligarh, August 9.

The challenges and rewards of creating and managing a scientific institution, Seventh Naval Tata Memorial Lecture at the National Institute of Personnel Management, Mumbai, August 30.

Interaction between laboratory physics and astrophysics, Popular lecture at the Mumbai University, Mumbai, October 16.

Challenges and benefits of studying astronomy, D.N. Wadia Memorial Lecture at the Wadia Institute of Himalayan Geology, Dehradun, October 23.

Pruthvipalikadil jeevashristhicha shodh, (Search for extraterrestrial intelligence) (in Marathi) (Margaon, Goa,) October 30.

Sanshodhanachya vata, (Pathways to research) (in Marathi), Chowghule Mahavidyalaya Sabhagriha, Goa, October 31.

Are we alone in the universe, Assocation of Friends of Astronomy, Kala Academy Hall, Panjim, Goa, November 2.

From scientific literacy to scientific research: The Indian experience, India Habitat Centre, New Delhi, December 12.

The frontier between astronomy and nuclear science, Tenth Foundation Day Lecture of the Nuclear Science Centre, New Delhi, December 19.

Some outstanding problems on the frontier of physics and astronomy, Sir K.S. Krishnan Memorial Lecture at the National Physical Laboratory, New Delhi, December 20.

Puzzles and challenges in astronomy Garware College, Pune, December 22.

Prithvipalikadil jeevshrishticha shodh (The search for extraterrestrial intelligence)(in Marathi), The Padmashree Bhausaheb Vartak Sanskritik Bhavan, Virar (W), February 6 .

The challenges and rewards of creating and managing a scientific institution, Dr Yelavarthy Nayudamma Memorial Lecture at the Administrative Staff College, Hyderabad, February 11.

Nature of the universe: Facts and speculations, A popular talk to the Osmania University teachers and students in Mekaster auditorium at IETE in the university, Hyderabad, February 12.

Excitement of doing science, Lecture to school and college students in Bharatiya Vidya Bhavan auditorium arranged by Exploratory, Pune, February 16.

Kya suraj kabhi urga dena band karega? (Whether the Sun will stop giving energy?) (in Hindi), Central Water and Power Research Station, Pune, February 18.

Manav ani gurutavakarshan (Man and gravitation)(in Marathi), Mumbai Marathi Granthasangrahalay, Dadar (E), Mumbai, organized by Khagol Mandal, Mumbai, February 20.

Media and scientific literacy, Symbiosis College of Mass Communication, Pune, IUCAA, February 24.

Networking in science: The astronomy experience, Lecture delivered at the Indian Institute of Technology, Powai, organized by the Tata Infotech Limited, Mumbai, March 3.

Instrumentation in observational astronomy, Lecture delivered at the Cummins College of Engineering for Women, Pune, March 5.

The benefits of astronomy and astrophysics to science and society, Lecture delivered at the Naval College of Engineering, Lonavla March 11.

Illusions in space, Lecture delivered at the NCL auditorium organized by the Indian Meteorological Society, Pune Chapter, Pune, March 21.

Arvind Paranjpye

Minor bodies in the solar system, Lecture series on the Solar System, Jyotirvidya Parisanstha, Pune, April 12.

Threat from above, Lecture series on the Solar System, Jyotirvidya Parisanstha, Pune, April 12.

Vedh Sadhane (in Marathi) Astronomy Course for the School Students, Vidyanan Bharati, Pune, April 21.

Surya Maletun Ek Pravas: Introduction to Science, A camp for secondary school students, Pune, April 28.

In search of ETI, Summer Course on "Scientific Thinking and Research Aptitude" Abasaheb Garware College, Pune, June 4.

Khagras Grahan on 11 August 1999 at Kolhapur (2 talks); Chandgadh (1 talk); Ajra (2 talks); Gadhhinglaj (2 talks).
[These talks were part of total solar eclipse - awareness programme organized by Marathi Vidyan Parishad, Mumbai with the help of National Council of Science and Technology Communications and Maharashtra Council of Science andTechnology.]

Asteroids and comets, Introductory Astronomy Course, Madgaon, Goa, February 2.

Meteor Showers, Introductory Astronomy Course, Margaon, Goa, February 2.

Kahi Shodh Khagol Shatratale (in Marathi) Bal Vidyan Samelan, Dhamod, February 5.

Observations in astronomy, Cadets Astronomy Club, I. N. S. Shivaji, Lonavla, February 10.

Somak Raychaudhury

From Chandrasekhar to Chandra, Lecture Demonstration programme for Junior College students at IUCAA, September 1999

First results from the Chandra observatory, lecture given to the Jyotirvidya Parisanstha, Pune, March, 2000

Boud Roukema

How can one measure the curvature of the universe?, IUCAA, February 27.

S.N. Tandon

Meteors (in Hindi) National Science Day, IUCAA, February 27.

Yogesh Wadadekar

Suryamalechi Safar, Jyotirvidya Parisanstha, Pune, May 16.

Total solar eclipse on August 11, 1999, at Jyotirvidya Parisanstha, Pune, August 1.

Total solar eclipse on August 11, 1999, Rotary Club of Pune, Hotel Blue Diamond, Pune, August 3.

Black holes, Modern College, Pune, September 17.

d) Radio / TV Programmes

Vinaya Kulkarni

Asteroids, meteors and meteor showers, AIR, Pune, November 13.

J.V. Narlikar

Gyan Vigyan, Amul Surabhi, DD-I, April 4

Gyan Vigyan, Amul Surabhi, DD-I, June 13.

Gyan Vigyan, Amul Surabhi, DD-I, September 9.

Gyan Vigyan, Amul Surabhi, DD-I, October 31.

Gyan Vigyan, Amul Surabhi, DD-I, December 12.

Interview on BBC, London, December 29.

Participation in a curtain raiser discussion on International Conference for Science Communicators, Akashvani, Pune, January 27.

Gyan Vigyan, Amul Surabhi, DD-I, January 30.

Arvind Paranjpye

Surya Grahan 1999, All India Radio, Pune, August 8

Running Commentary on Leonid Meteor Shower, Pune, November 18.

Live Akashdarshan, All India Radio, Pune, December 16.

Live Akashdarshan, All India Radio, Pune, January 11.

Nate Nisargache : Tarayanchi Prakharta, Pune, January 11.

Live Akashdarshan, All India Radio, Pune, February 10.

Nate Nisargache: Avkashatil Antare, All India Radio, Pune, February 10.

Live Akashdarshan, All India Radio, Pune March 10.

Nate Nisargache, All India Radio, Pune, March 10.

[Live Akashdarshan was a live broadcast from IUCAA terrace from 9:30 p.m. to10:00 p.m. on identifying the star and constellations. Yogesh Wadadekar participated in AIR Radio programme on Leonid meteor showers, November 18.]

Somak Raychaudhury

Interviewed by BBC World Service radio on the occasion of the launch of the Chandra Observatory, July 20.

Interviewed by BBC World Service television on the early performance of the Chandra Observatory, July 27.

Scientific Advisor (along with Professor J. V. Narlikar) for a series of TV programmes on Introductory Astronomy for high school students to be shown on E-TV (Produced by CIET/ NCERT).

(VIII) SCIENTIFIC MEETINGS

Refresher Course in Astronomy and Astrophysics for College/University Teachers

The Refresher Course in Astronomy and Astrophysics for College/University Teachers was held during May 17 - June 18, 1999. Fourtee college and university teachers from different parts of the country paricipated in the course.

The course consisted of two series of lectures on basic Astronomy and Astrophysics, Observational Techniques and on various topics of Galactic and Extragalactic astronomy. An important feature of the course was that assignments and problem solving sessions made up a substantial part of the course. A brief introduction to accessing data on the Internet was provided.

Lectures were given by the faculty members of IUCAA as well as NCRA. S. Sridhar was the faculty coordinator.

Mini-workshop on Gamma Ray Bursts : Status and Future

This mini-workshop was organised by T. Padmanabhan and S. N. Tandon at IUCAA during August 26-28, 1999. Out of about thirty participants, six were from outside India, and five of the participants were from Indian universities.

The value of coordinated observations in different wave-bands and from many observatories (for a good temporal coverage) was specially emphasized during the talks and discussions. Shri Kulkarni (Caltech, USA) reviewed the history of gamma ray bursts observations, and discussed results obtained with optical observations on properties of the afterglows and host galaxies; Dipankar Bhattacharya (RRI, Bangalore) discussed the fireball physics, and spectral and temporal properties of the afterglow; Fiona Harrison (Caltech, USA) discussed high energy properties of the bursts, and talked about future space missions on gamma ray bursts; Dale Frail (NRAO, USA) discussed radio

Participants of the Refresher Course in Astronomy and Astrophysics

Participants of the Workshop on "Gamma Ray Bursts: Status and Future"

observations of the afterglows; Ram Sagar (UPSO, Nainital) presented results showing the usefulness of small (1-2 metre) telescopes in observations of afterglows and S. N. Tandon (IUCAA) discussed the possibility of using imaging polarimeter on small telescopes to study the polarisation of afterglows in optical band. During last session of the workshop, importance of REACT Network was discussed; REACT Network is a proposal from the Caltech group in which several observatories would participate to get well-calibrated temporal coverage of the light curves, with similar multiband optical cameras.

Workshop on New Trends in Near Infrared Astronomy

Physical Research Laboratory (PRL), Ahmedabad and IUCAA, Pune, jointly organized the workshop on New Trends in Near Infrared Astronomy, during August 17-20, 1999 at PRL. The workshop was inaugurated by G.S. Agarwal, Director, PRL. There were thirty outstation participants representing different institutes IIA (5), IUCAA (2), UPSO (3), NCRA (1), TIFR (3), SAC (3) and universities (12), apart from a similar number from PRL.

The workshop covered a wide range of topics in IR astronomy, both from instrumentation and theory/observation viewpoints. Ian S. Glass (South African Astronomical Observatory) was the main resource person and gave a series of talks covering basics of near IR photometry, study of the Milky Way through the imaging of the inner bulge and variability of AGNs in near IR. He cautioned on the use of IR standards and underlined the need to prepare a set of standard stars for the observatories. There were also talks by experts from various institutes within the country on various topics - ISOGAL, DENIS and 2MASS surveys, IR detectors, their characterization, imaging

Fabry-Perot Spectrometer in near IR, lunar occultation approach in near IR to measure angular sizes of late type stars, inner Milky Way and the extinction map in the central region of the galaxy, morphology of star burst galaxies in near IR, elliptical galaxies and fundamental plane, young galactic star clusters, Mira variables, novae, Be Stars, etc. The main speakers were I. Glass, A. Kembhavi, Ram Sagar, T.N. Rengarajan, U.C. Joshi, D. Ojha, R. Bisht, G.C. Kilambi, K.S. Baliyan, B.G. Anandrao, T. Chandrasekhar, N.M. Ashok, S. Rao, A.K. Sen, Shashikiran, U.S. Kamath, A. Chitre, M.S. Nandakumar, P.V. Watson and A. Tej.

In addition to these talks, there were presentations on future plans and new facilities coming up in IR astronomy by various institutes, such as IIA (T.P. Prabhu, G.C. Anupama), IUCAA (R. Gupta) and UPSO (Ram Sagar). One of the main attractions of the workshop was presentation of the new results obtained using NICMOS-3 and other IR instruments relating to galactic and extra-galactic studies.

A panel discussion was organised as a part of the workshop on the future direction of IR astronomy and issues related to astronomy at large. The discussion, which was very lively and stimulating, also took into consideration the remarks made by the PRL Director in his inaugural speech on the lack of interest in astronomy among the young students. Ian S. Glass chaired the panel discussion. One common opinion was that the IR community in the country is small and there is a need to have more interaction and collaboration among the astronomers and also to exchange expertise in IR technique. It was also felt that such workshops should be organised every year, reviewing the progress made and the direction to be taken in future.

Mini-school on Computer Astronomy

A mini-school on Computer Astronomy was jointly organized by IUCAA and St. Thomas College from August 30 to September 3, 1999 at Charal Mount, which is a retreat on a hill top, a short distance away from Kozhencherry.

The workshop dealt with image processing, with particular emphasis on applications to astronomy. Photometry of stars and galaxies was discussed, following lectures on image processing techniques. The lecturers included Yogesh Wadadekar and A. Kembhavi from IUCAA, S. K. Pandey from Pt. Ravishankar Shukla University, Raipur and G.C. Anupama and Annapurni Subramanian from the Indian Institute of Astrophysics, Bangalore. Sarah Ponarathnam of IUCAA provided able and much needed support with the hardware and software. Lectures were also given by local resource persons.

The participants included lecturers, post graduate students and a sprinkling of undergraduates from various places in Kerala.

An outstanding feature of the mini-school was the set of demonstrations of computer techniques, and most importantly, practical training in the installation and use of *Linux* and image processing software, particularly *IRAF*. Some participants brought their own computers to the event, and with the help of local and visiting experts, loaded them with useful softwares. The Principal of St. Thomas College, P.J. Philip, and the Head of the Physics Department, Abraham Kuruvilla Kunnilethu provided much active support. The Manager of the college, the Rt. Rev. Euakim Mar Kurilos Episcopa provided the infrastructure and encouragement. But the person who has been most important in initiating and sustaining the activity has been the Most Rev. Philipose Mar Chrysostam, who will be the next Metropolitan of the Marthoma Church.

Participants of the Mini-school on Computer Astronomy

He understood how information technology could be harnessed even in a remote place, and arranged for an ERNET node of sorts at St. Thomas College, much before many of the larger institutions in the region began to appreciate the importance of having access to e-mail and related facilities. The workshop coordinator was A. Kembhavi.

Seminar on 1500 Years of the Aryabhatiya

Eighteen scholars from all over India participated in the workshop organized at IUCAA to commemorate the 1500th year of the composition of the influential astro-mathematical text, ARYABHATIYA. This seminar was held at IUCAA during October 7-8, 1999.

Rajesh Kochhar, P. V. B. Subrahmanyam, S. Balachandra Rao, Vinod Mishra and S. L. Singh gave lectures at the seminar.

Jayant Narlikar welcomed the participants and Rajesh Kochhar gave the concluding remarks. The workshop was coordinated by Arvind Paranjpye.

Workshop on Observational Programmes with 2-m Class Telescopes

The workshop was organised jointly by Uttar Pradesh State Observatory (UPSO), Nainital and IUCAA, Pune during October 25 - 29, 1999 at UPSO. There were thirty outstation participants representing different institutes, university and colleges and about 20 participants from UPSO.

In the near future, 2 to 3 metre sized telescopes will be installed in the country. This workshop was organised to identify observational programmes to be taken up on such telescopes. The topics covered included gamma-ray bursts, open clusters, close binary systems, galaxies, AGNs, rapidly oscillating stars, microlensing, stellar spectroscopy and polarimetry. The speakers were Ram Sagar, S.N. Tandon, A.K. Kembhavi, S.K. Pandey, N.M. Ashok, Ranjan Gupta, U.S. Chaubey, B.B. Sanwal, Vijay Mohan and M.K. Das. Ph.D. students from UPSO also presented their research work in the workshop.

A visit to Devasthal, proposed site for setting up the 3-metre telescope of UPSO and TIFR was organised on October 28.

Workshop on Interstellar Molecules

A workshop on Interstellar Molecules was held in Sri Krishnadevaraya University, Anantapur, during October 29 - 31, 1999. The workshop was organized by R. Ramakrishna Reddy and T.V. Ramakrishna Rao of the Sri Krishnadevaraya University (SKU), Anantapur, on their campus. During the workshop, there were lectures on interstellar matter, molecular hydrogen emission lines, shock waves, dust in molecular clouds, spectroscopy of stars, stellar structure and evolution and atomic and molecular spectroscopy. The topics were covered in an introductory level to benefit the students and teachers participating in the workshop. The lectures were delivered by J.N. Desai and B.G. Anandarao (PRL, Ahmedabad), H.C. Bhatt, Sunetra Giridhar and C. Sivaram (IIA, Bangalore), Ajit Kembhavi (IUCAA, Pune) and R. Ramakrishna Reddy (SKU, Anantapur). In addition to the lectures, activities like video screening of astronomical films and exhibition of books were organized.

Participants of the Workshop on Interstellar Molecules

Participants of the Mini-workshop on Quasar Spectroscopy

Mini-workshop on Quasar Spectroscopy

A mini-workshop on Quasar Spectroscopy was held at IUCAA during January 21 - 23, 2000. Topics covered in this workshop include, multiwavelength study of quasars and AGN, models of continuum emission, chemical enrichment, quasar formation and the intergalactic medium. Talks were given by M. Burbidge (University of California, San Diego), Suzy Collin (Meudon Observatory), Jayaram Chengalur (NCRA), U. C. Joshi (PRL), Ajit Kembhavi (IUCAA), Pushpa Khare (Utkal Univ.), Gopal Krishna (NCRA), T. Padmanabhan (IUCAA), P. Shastri (IIA), R. Srianand (IUCAA) and Yogesh Wadadekar (IUCAA).

International Conference for Science Communicators (ICSC 2000)

A meeting for science communicators was organized at IUCAA by the National Centre for Science Communicators during January 28-30, 2000, at which 200 science writers, journalists and popularizers participated from India and abroad. The main discussion sessions were on the social implications of science and technology, resources for science communicators, the financial viability of science publication in the popular media, and the networking of communicators at the national and international levels. The invited speakers were E. Candotti (Brazil, Kalinga awardee 1998), M. E. Addy (Ghana, Kalinga awardee 1999), N. K. Sehgal and J. V. Narlikar (earlier Kalinga awardees), J.C.

Pecker (France), M. Burbidge (USA), Zaffarullah Choudhary (Bangladesh), V. G. Bhide, Saroj Ghose, Bal Phondke and Sam Pitroda.

Vacation Students' Programme (VSP) 1999

During the period May 24 - July 9, 1999, IUCAA conducted the Vacation Students' Programme for young students from universities and engineering colleges. Twelve students, hailing from all parts of India, participated in this year's VSP. They participated in a fairly comprehensive lecture programme of about 20 days' duration, in which faculty members from IUCAA and NCRA, gave a series of lectures that covered various aspects of observational and theoretical astrophysics. Under the VSP programme, these students, depending upon their aptitude and interest, also took up their own research projects, which they conducted with great deal of enthusiasm and interest. During this period, they freely interacted and discussed their ideas with faculty members, post-doctoral fellows and research scholars. They also made excellent use of IUCAA resources, such as the computer centre, the library and audio-visual aids. During the final phase of VSP, the students presented their project results and took a written test. Based on the performance two meritorious candidates were preselected to join IUCAA as regular research scholars in August 2000.

Participants of the Vacation Students' Programme 1999

Facilities

(I) Computer Centre

The IUCAA Computer Centre continues to provide state-of-the-art computing facilities to the users from IUCAA as well as visitors from the universities and institutions in the country and abroad.

Previously, the IUCAA local area network (LAN) was based on 10 BASE 2 technology, where the users shared the 10 mbps bandwidth. During 1999-2000, it has been upgraded to 100 BASE T switched network. The new LAN offers a dedicated 100 mbps speed for an individual user. Because of the star topology adopted, each machine is now independently connected to a switch. As a result, problems with one machine do not affect the performance of the entire network.

Recently, a mirror site of VizieR has been set up at IUCAA in collaboration with CDS, Strasbourg, France. IUCAA is one of the three such mirrors worldwide of the original site of VizieR at CDS - Strasbourg, France. VizieR provides access to the most complete library of published astronomical catalogues and data tables available on line, organized in a self-documented database. Query tools allow the user to select relevant data tables and to extract and format records matching given criteria. Specific care has been taken for optimizing access to some very large catalogues such as Guide Star Catalog or USNO-A2.

The IUCAA Computer Centre continues to extend support to university departments and colleges for configuring networks, obtaining hardware and software, setting up applications and training personnel.

(II) Library and Publications

The total library collection in the fully automated IUCAA library amounts to about 16,400, which includes 330 books and 580 bound volumes which were added during the period under review. In addition to strengthening the resources at IUCAA, Pune, the library has acquired books for the IUCAA Reference Centres at: (1) School of Studies in Physics, Pt. Ravishankar Shukla University, Raipur; (2) Department of Physics, Cochin University of Science and Technology, Kochi; (3) Department of Physics, North Bengal University, Siliguri and (4) Department of Physics and Astrophysics, University of Delhi.

During the current year, the library initiated article alert services to the university based visitors participating in various scientific activities organised by IUCAA. The library caters to the needs of the academic community inhouse as well as to visitors coming to IUCAA, providing traditional and IT based services. The online databases, publishers and booksellers websites, preprint servers and online journals were extensively made use of to provide service to its variety of users in a more efficient manner.

IUCAA has a 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. The facilities are also used by visitors from the universities and colleges for developing and testing their instruments.

A 3rd, Level 1 workshop on Astronomical Photometry was organised by A. Paranjpye to introduce the teachers from universities and colleges to the basics of stellar photometry. In order to get introduced to the elements of observational techniques, each of the participants made a small photo-diode based photometer for their laboratory. In addition to Paranjpye, P. Chordia, R. Gupta, and V. Mestry conducted the activities of the workshop.

The thermo-electrically cooled CCD camera was succesfully duplicated by A. Bhattacharyya of Jadavpur University for use on their telescope as well as for RF plasma diagnostics.

Observation with the IUCAA 16" Telescope

A computer controlled 16" Meade telescope has been installed at IUCAA for use by undergraduate and graduate students from university departments and colleges as well as serious amateur astronomers with some observing experience. The telescope is equipped with SLR camera, a ST-7 CCD camera, a SSP-3 photometer and a simple spectrograph. A variety of research and training projects have been undertaken using this telescope.

During the last one year, the telescope has been extensively used by research students from Pt. Ravishankar Shukla University, Raipur. Padmakar Parihar of this university has used the telescope to photometrically observe nearly 10 RS CVn variable stars. This work will form an important part of his Ph.D. thesis. Parihar also handled a survey project to discover new RS CVn binary stars in collaboration with K.P. Singh and Steve Drake, and an important result from this project has been the discovery of a new highly active RS CVn stars HD61396. Sudhanshu Barway of the same University monitored some suspected variable stars for two months and has discovered three relatively long period (> 50 days) chromospheric active variables.

About 20 college teachers, graduate and undergraduate students and amateur astronomers were introduced to observational techniques with this 16" telescope. They also reduced and analyzed data taken with various instruments available at the telescope. An experienced amateur astronomer, Parag Mahajani, has regularly observed Delta Scuti and eclipsing binaries and has accumulated and reduced high quality multi-band photometric data on the W-Uma type eclipsing binary "I Boo".

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, and is expected to arrive in the beginning of the year 2001. The site is at a distance of about 80 km from IUCAA, and within the constraint of easy logistics for efficient operations of the observatory, it provides good observing conditions.

The telescope has an alt. - azimuth mount, and would only have a f/10 Cassegrain focus. A corrector would provide a large field of 40 arcmin. diameter with sub arcsecond images in the optical band, whereas the uncorrected field would give sub arcsec. images upto a radius of 10 arcmin. Many of the major subassemblies of the telescope, e.g., the mirrors, the acquisition and guiding unit, the primary mirror cell, etc., are ready and the assembly has started.

The enclosure for the telescope has been designed for simplicity of construction and to minimise the thermal perturbations. A contract for construction of the dome would be given in April 2000.

A design for dome position encoder has been finalized. Absolute shaft encoders to be used in this system have been acquired and preliminary tests have ben performed by D. V. Gadre and R. S. Kharoshe.

To allow multiple instruments (using RS-232 serial link) on the telescope, focal plane to communicate with the controlling PCs in the control room using a common fibre link, a switch has been designed by D. V. Gadre. Upto eight instruments will be able to share a single high speed fibre link.

The approach road to the site of the observatory is expected to be ready by April 2000 and the work on the buildings would start immediately after. It is expected that the buildings would be ready to receive the telescope by beginning of the year 2001.

There has been some delays in aquiring the land for the site, but it is hoped that the construction would start soon, so that the buildings could be ready before the arrival of the telescope.

Picture of the campus model at Giravali, the IUCAA Telescope Site.

(IV) IUCAA Reference Centres (IRC)

Four IUCAA Reference Centres (IRCs) have been set up by IUCAA in 1999 at:

1. Department of Physics, University of North Bengal (NBU), Siliguri.

2. School of Studies in Physics, Pt. Ravishankar Shukla University (RSU), Raipur.

3. Department of Physics, Cochin University of Science & Technology (CUSAT), Kochi.

4. Department of Physics & Astrophysics, University of Delhi (DU).

The space and other infrastructure for each IRC is provided by the host department and IUCAA Associate or Senior Associate from the department acts as the coordinator. IUCAA has provided funds to each IRC for setting up an internet connection and IUCAA library has loaned a small set of books. Researchers from universities and colleges situated around each IRC, visit it for short durations for library work, use of the internet and discussions with members of the host departments and other visitors to the IRC. Funds for these visits are provided by IUCAA. Each IRC is expected to conduct regular seminars and short meetings to bring together people interested in astronomy, astrophysics and related areas. Brief reports from the IRCs are given below :

1. NBU (Coordinator : S. Mukherjee)

The facilities at IRC have helped in nucleating a number of research collaborations. In quantum cosmology, B. C. Paul, S. Mukherjee and R. Tavakol studied the problem of nucleation of an open universe as described by a singular instanton in R^2 and R^3 theories. The possibility of building a traversable wormhole with a global monopole was considered by N. Dadhich, S. Mukherjee and S. Kar. In relativistic astrophysics, extensive studies have been made on cold compact relativistic stars, in particular, Hercules X-1, by R. Sharma, S. Mukherjee and S. D. Maharaj. S. Chakraborty (Visva Bharati) and S. Mukherjee are studying the relativistic fine-hyperfine interactions in heavy quarkonia. Various aspects of relativistic Sagnac effect have been studied by S. K. Ghosal. B. Roychaudhuri, A. Chaudhuri and M. Sarkar. Some experimental work is also in progress. The muon anomaly in ultra-high gamma-ray astronomy has been studied by A. Bhadra. Also, Delbruck scattering at 1.115 MeV is being studied with a Pure Ge detector by S. K. Sengupta, A. Bhadra, B. Kunwar and R. H. Pratt (Univ. of Pittsburg). This project is sponsored by NSF, USA.

Seminars were given by B. Bhawal (Caltech), D. P. Datta (NERIST), D. Krige and S. D. Maharaj (Univ. of Natal), S. Chakraborty (Visva Bharati), N. K. Dadhich (IUCAA). In addition, there were several informal group discussions.

2. RSU (Coordinator : S.K. Pandey)

Activities of the IRC have gradually gained momentum with installation of internet facility and a small library for the users of the IRC. Being the first year of the IRC, visitors from outside Raipur were limited, and facilities were used by staff members and students of the department. The installation of internet has indeed been extremely useful to all the users not only in communicating with the external world but also in sending articles by e-mail, accessing unpublished as well as published articles in various journals It is hoped that in future, as the activities of IRC will gain momentum, the number of visitors from outside Raipur will increase.

Some of the important activities of the IRC, Raipur during 1999-2000 include (1) Lecture by T.P. Prabhu on July 30, 1999 on Indian Astronomical Observatory Hanle in the Physics Department of the University, (2) Lecture by S.K. Pandey (Coordinator, IRC) in some of the schools and teacher's training school/college in the town on the solar eclipse and some selected topics in A&A, (3) Public show of solar eclipse using 6" telescope fitted with the solar filter. (Huge crowd had gathered in the terrace of the Physics Department building of the University to watch the solar eclipse on August 11, 1999, even though Raipur was not on the path of total eclipse.) and (4) Visit by S.K. Pandey to Durg/Bhilai for giving popular lectures in A&A and inviting teachers and students to make use of the IRC facilities for initiating and strengthening teaching and research activities in A&A.

3. CUSAT (Coordinator: V.C. Kuriakose)

The IRC has regular monthly seminars titled as "IRC EVENING LECTURES". Teachers and students gave seminars as detailed below. V.C. Kuriakose: *Gauge theory*; Nov. 18, 1999. Minu Joy : *Phase transitions in early universe*; Dec. 8, 1999. Ramesh Babu T : *An introduction to spontaneous symmetry breaking;* Jan. 28, 2000. Viji Varghese : *Gauge invariance in optics*; Feb. 23, 2000. S. Jayalekshmi : *Super conducting spinel oxides;* March 29, 2000.

Ninan Sajith Philip and Moncy V. John of St. Thomas College, Kozhencherry visited this centre for one week for reference and computational works required for their research studies. A few teachers and students of local colleges also visited the centre for reference and internet use. Research students, PG students and teachers of the department made use of the library facility at the centre. It is hoped that there will be more users of the facilities of the centre in future.

4. DU (Coordinator: V. B. Bhatia)

An IRC has also been set up in the Physics Department of Delhi University. It is expected that activities will soon commence here.

Science Popularization Programmes

One of the major goals of IUCAA's science popularization programmes is to help to bring current scientific research into the public domain in the country. These events mostly involve high school students, since it is felt that the exposure to scientific thought might inspire the future citizens from being overwhelmed by the widespread superstitions and misconceptions about the physical world around us. It is also hoped that one could inspire young people to consider research as a viable option in their choice of careers. IUCAA is also committed to support and assist in the growth of the amateur astronomy community in India.

Current programmes involving high school students are restricted to the Greater Pune area. In the summer programme, about two hundred high school students spent a week at IUCAA each during their vacation, supervised by an IUCAA member. There were also lecture demonstrations for high school students. In addition, in the annual Science Festival, a number of interschool competitions were held to bring together a large number of students and science teachers.

The annual Open House for the general public presented the research areas pursued at IUCAA, including demonstrations of our facilities. Once a month, visitors would view the sky using telescopes assisted by IUCAA members. There were also a host of activities for amateur astronomers in Pune and all over India. Amateur astronomers from anywhere in India could visit IUCAA for a couple of weeks any time during the year to make a six-inch reflector telescope for their club or institution, guided by members of our laboratory. Several relevant pages on the world-wide web were maintained by IUCAA and popular lectures in schools, colleges or club were organized by IUCAA. .

(I) National Science Day

The National Science Day was celebrated at IUCAA on February 28, 2000. On this day, the Science Festival comprised of various competitions for high school students was organised. In the evening, a series of telescopes were set up for night-sky viewing for members of the public till midnight.

(a) The Open House for the public

About five thousand visitors attended IUCAA's Open House, meant for members of the general public on Sunday, February 27, 2000 from 11 a.m. to 5 p.m.

Over five thousand visitors attended the Open Day Exhibition. Showing examples of research carried out at IUCAA

Most of the IUCAA faculty gave public lectures for visitors on National Science Day

The Auditorium was full for the lecture demonstration by members of the Homi Bhabha Centre on National Science Day

Simple experiments demonstrating basic physical principles for the public

Many of the academic members (including students and visitors) of IUCAA were present during the day to discuss their research with the visitors with the help of posters and displays. In the Instrumentation Laboratory, one could witness various optics demonstrations, as well as a model of the IUCAA telescope. The staff of the Computer Centre and a few students provided demonstrations of the working of the Internet, and examples from the Astronomical Data Centre at IUCAA and the image processing research that is carried out at IUCAA.

Almost all visitors spent a considerable time with the interactive outdoor exhibits in the IUCAA Science Park, where a row of additional exhibits were set up by the Homi Bhabha Centre (Mumbai), illustrating basic physical principles for the younger visitors.

Two parallel series of half-hour lectures (in English, Hindi and Marathi) were given by IUCAA scientists to capacity audiences, all through the day, at two different locations. The lecturers found themselves surrounded by members of the audience with questions for long times outside the lecture halls. The event concluded with J. V. Narlikar's one-hour session of answering questions about the universe from the general public, which proved to be very popular.

The Library's display included an account of C. V. Raman's work, which is commemorated by the National Science Day each year. Video films on astronomy and space programmes were also shown at yet another location.

From 7 in the evening till midnight, hundreds of visitors viewed Saturn and Jupiter, and other objects of astronomical interest, like the Orion nebula, through a row of six and eight-inch telescopes, set up by IUCAA members, with the help of members of the Jyotirvidya Parisanstha, Pune. Almost all the telescopes used had been made by various amateur astronomers at IUCAA as part of our year-long mirror-grinding and telescope making workshop.

(b) The Inter-School Science Festival

The Science Festival on Monday, February 28th consisted of several inter-school science competitions for students up to Class X. About 450 students from 76 schools in the Greater Pune area (English, Marathi and Hindi mediums) participated in a Science Quiz contest, two Essay (English and Marathi) competitions and a Drawing competition on scientific themes. In addition, there was a science crossword contest for the teachers who had accompanied the students.

One student from each school took part in the Drawing competition, The first and second prizes were awarded to Vrishali Talwalkar (N. M. V. Girls' High School) and Manas Marathe (Vidya Bhavan) for their portrayal of the working of mathematics in nature.

Girija Ranade (Abhinava Vidyalaya) won the 1st prize in the English essay competition for her account of living in a world with two stars, while Noopur Singhal (Rewachand Bhojwani Academy) and Aditya V. Bidikar (Kalmadi Shamrao High School) shared the second prize for their imaginative account of what would have happened if mankind had evolved as aquatic beings. Ashwin Pundalik (MES Boys' High School) and Sudheer S. Khandelwal (Vimlabai Garware Prashala) shared the second prize for the Marathi essay competition. No first prize was awarded for Marathi essay competition.

In the qualifying round of the Science Quiz, each of the 75 teams had to answer 25 short questions in physics, astronomy, mathematics, chemistry and biology. In this event, each school was represented by a team of three students. Five teams were chosen to compete in the final round of the Science Quiz, which took place in the afternoon of the same day, in the Chandrasekhar Auditorium, in the presence of a capacity crowd. The team from Vikhe Patil Memorial School was the clear winners of the Quiz trophy and St. Ursula's and St. Vincent's winning the second and third places respectively.

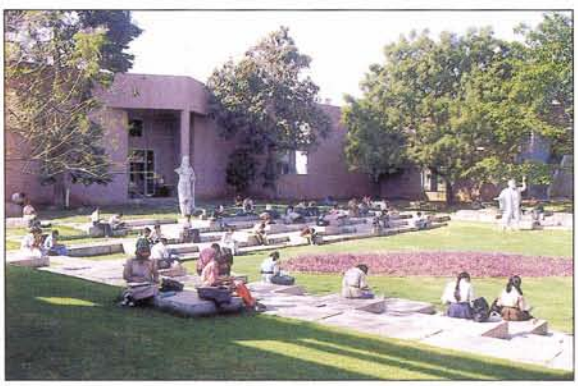
The trophy for the best overall performance (the N.C. Rana Memorial Trophy) was won by Vikhe Patil Memorial School. While the winning schools get to keep the trophies for the year, the individual winners were awarded prizes (book tokens) as well. J. V. Narlikar gave away the prizes.

(II) Other Programmes for School Students

(a) Summer Programme

The School Students' Summer Programme was held between April 12, 1999 and May 21, 1999. About 160 students from 75 schools in the Greater Pune area participated in this programme. Each group of 4-6 students worked under the guidance of a member of the academic or scientific staff of IUCAA for a week.

No set syllabus or course guidelines were made for this programme. The supervisors were asked to involve the students in scientific activities, which were not ordinarily undertaken in schools. During the week, there were some common activities for the students, in the form of scientific films, lectures or visits to the Science Park. The students had a free access to the IUCAA library. Question and answer sessions with the academic staff, including the Director, were also conducted for the students.



Aryabhatta and Galileo are silent witnesses to the Inter-School Science Drawing Competition

Vikhe Patil Memorial School won the N.C. Rana Memorial Trophy for the best all-round performance

One of the batches of the School Students' Summer Programme

This year another dimension was added to this six-year old programme. On Fridays, the students were asked to give an oral presentation of their work to the other students and their supervisors.

Some of the projects undertaken by the students involved the Foucault's pendulum, measuring time with the Samrat Yantra, studying symmetries in nature, studies of the solar system, Kepler's laws, Hubble's law, understanding Olbers' paradox, non - Euclidean geometry, and optical studies involving lenses, reflecting surfaces, prisms, telescopes and microscopes.

Students with their Supervisor

On the last day of the programme, the station director of All India Radio, Pune personally visited with her crew and covered the final proceedings of the event and interviewed some of the participants of the programme.

(b) The outdoor Science Park at IUCAA

In 1998, a public interaction facility in the form of a Science Park was opened at IUCAA. Though its development is not complete yet, about 100 people visit the Park every fortnight, along with the school students who come for the various programmes at IUCAA.

The Park occupies a plot of 5000 sq. m. surrounding the Chandrasekhar Auditorium in the Aditi complex of IUCAA. Only the first stage of the Park, consisting of 12 exhibits, is in place at the moment. The Park will have about 30 exhibits in all, to be added in the course of the next two years.

This outdoor ensemble of exhibits illustrate basic principles of astronomy, physics and mathematics that are of interest to lay person. Most of these exhibits require the interactive involvement of the visitor in their operation. All the exhibits in the Park have been fabricated and installed by the National Council of Science Museums (NCSM), Calcutta, who are involved in the planning and fabrication of the future exhibits as well.

(c) Lecture Demonstrations

For High School Students (Classes VIII-X)

J. V. Narlikar (IUCAA)
The Structure of the Universe (in English and Marathi), July 10.

T. Padmanabhan (IUCAA)
The Story of Stars (in English) August 21

Naresh Dadhich (IUCAA)
Why is the Universe Curved? (in English and Hindi), September 11.

Suketu Bhavsar (IUCAA/University of Kentucky, USA)
Einstein's Universe, Escher's Art (in English) October 9.

Pradeep Gothoskar (National Centre for Radio Astrophysics, Pune),
Life and Death of Stars (in English and Marathi), February 12.

For Sudents of Jr. College (Classes XI-XII)

J. V. Narlikar (IUCAA)
The Frontier Between Physics and Astronomy (in English), July 24.

Somak Raychaudhury (IUCAA)
From Chandrasekhar to Chandra - In search of the most massive objects in the Universe (in English), September 4.

Arvind Paranjpye (IUCAA)
The Colours Above (in English), October 23.

Suketu Bhavsar (IUCAA/University of Kentucky, USA)
Einstein's Universe, Escher's Art (in English), February 26.

(d) The Children's Science Congress

This year, the 87th Session of the Indian Science Congress, was held at the Pune University Campus during January 2 - 6, 2000. IUCAA took part in the activities by organzing, among other things, a workshop on **"Science for Children"** as a part of the Congress.

Get-together on the occasion of the making of the 100th Telescope

"Akashdarshan" programme in progress. It is dark outside. The photograph looks bright only because of the photographer's flash.

From left, Sujata Paranjpe (AIR, Pune) monitors the time, Ushaprabha Page (Station Director, AIR, Pune) is asking a question to Arvind Paranjpye while Mangala Narlikar concentrates on the progress of the commentary.

(III) Programmes for Amateur Astronomers

(a) Making small telescopes for schools and amateur organizations

The workshop for assisting amateur astronomers in the grinding and polishing of their own 6-8 inch mirrors and building telescopes for the use of their respective institutions is now a year-round activity. The response among enthusiastic users of this programme has been overwhelming.

Vinaya Kulkarni and Arvind Paranjpye have been assisting visiting amateurs in making such telescopes at an average rate of five per month. It takes approximately sixty hours to make a 6-inch mirror for a Newtonian reflector. Groups from Ludhiana (Punjab), Indore (Madhya Pradesh), Kurnool (Andhra Pradesh), Goa, Kerala, Dehra Dun (Uttar Pradesh), many parts of Maharashtra (Daund, Junnar, Ahmednagar, Aurangabad, Solapur, Mumbai, Nashik, Satara, etc.), as well as many groups from Pune have made telescopes in this workshop. *This year IUCAA celebrated the completion of its 100th telescope.*

(b) Observing meteor showers

The activities of the IUCAA meteor observers' group with amateur astronomers in Pune area continues to grow. They have been organizing trips to some darker suburbs of Pune to observe meteor showers. The Association of Indian Meteor Observers (AIMO), affiliated to the IMO, has been formed, with its coordinator being Arvind Paranjpye of IUCAA.

In November 1999, the group took more than 50 hours of Leonid observations, most of which were accepted and used by the International Meteor Organization as part of their global observing report. They have also observed all the major showers, notably the Geminids and Quadrantides.

Arvind Paranjpye also coordinates the observations of occultations by Indian amateurs for the International Occultation Timing Association.

(IV) Live Introduction to the Night Sky

All India Radio (AIR), Pune and IUCAA have jointly launched a monthly live programme ***"Akashdarshan — An Introduction to the Starry Heavens".*** These programmes, in Marathi, were in the form of a live commentary anchored by Arvind Paranjpye. Listeners were invited to take their portable radio/transistor set to an open place and follow the instructions to learn about the starry skies live.

The first programme was aired on December 16, 1999 at 9:30 p.m. Ushaprabha Page, the Station Director of AIR, Pune, opened the programme and Jayant Narlikar gave the over view and also answered a few questions put to him by two collegian amateur astronomers, Amruta Modani and Yashodhan Gokhale. Nileema Thatte (who is a paediatrician by profession and an avid amateur astronomer) participated in showing the sky. Sky maps were also being made available at IUCAA. The programme was well received in and around Pune.

Subsequently, one programme was broadcast every month till May 2000. Mangala Narlikar co-anchored these programmes with Arvind Paranjpye.

(V) Programmes for the General Public

Apart from the Open House activities around the National Science Day which is open to all, there were several other programmes for the general public.

Some lectures were organized for the general public, which were widely advertised through the public media.

J. C. Bhattacharyya, (Professor Emeritus Indian Institute of Astrophysics, Bangalore) *Solar Eclipses*, July 3.

S. R. Kulkarni, (California Institute of Technology) *Search for extra-solar planets*, August 27.

(VI) The Indian Astronomy Olympiad 1999

Somak Raychaudhury, on behalf of IUCAA and the Astronomical Society of India, organized the first Indian Olympiad Camp (jointly with M. N. Vahia of TIFR, Mumbai) for the selection and training of the Indian Olympiad team at the Nehru Science Centre (two weeks in June 1999). From this Camp, the Indian team was selected for the International Astronomy Olympiad held at the Crimean Astrophysical Observatory, Ukraine, during September 23-30, 1999. The Indian team emerged the overall champions, winning two gold, two silver and one bronze medals.

The Eleventh IUCAA Foundation Day Lecture

Chalk and Duster

(Musings of a Mathematics Teacher)

by

P.C. Vaidya

1. Class-room moulds a teacher

I started my teaching career as a college teacher in 1940. So for almost 60 years now, I have been in constant touch with a chalk and duster. All along, I have been writing so much interesting matter with the chalk and all that has been cleaned by the duster. Still, certain uncleaned portion is retained in my memory. I propose to reproduce from memory my experiences as a maths teacher.

In June 1940, immediately after passing my M.Sc., I joined Dharmendrasinhji College, Rajkot, as a lecturer in mathematics. This was an intermediate college since 1938. In 1940 it started degree classes. So new teachers were recruited and I was selected in the maths department in the scale 80-5-100-10-140. The department consisted of only two teachers and both of us were lecturers. So I got a chance of starting my teaching career with a clean slate. This had a distinct effect in moulding me as a teacher. As a matter of fact, I had to use the trial and error method to learn some tricks of the trade. I am going to describe here one such trial and error sequence.

In the first year class, I was teaching trigonometry. In mathematics, there are several occasions when we have to add fractions and in such cases, we begin by taking the L.C.M. of the denominators. I must have worked out some such example in my lecture one day, and the next day a student met me in connection with that example. I do not remember that example now; so to explain the point involved, I am taking a simple illustration. The student had written in his class-notes, 1/2 + 1/3 = 6/(3+2) and he, of course, could not follow this step. He had come to me with this difficulty. I told him that he had written the right hand side in the wrong way, (upside down, so to say). It should be (3+2)/6. But he insisted, "Sir, you wrote on the black-board, 6/(3+2)". Somehow I could satisfy the student regarding the correct step and sent him home, perhaps only half-satisfied. But I was myself a bit disturbed. So I looked into the notes of several students and found that some had written the right hand side with 6 in the numerator and 3+2 in the denominator while some others had 3+2 in the numerator and 6 in the denominator!

And, the root of this peculiar type of misunderstanding dawned on me. When we simplify 1/2 + 1/3, we draw a line following the "equal to" sign (1/2 + 2/3 = -----). Since the L.C.M. of 2 and 3 is 6, we write 6 below the line. Now when you talk in this way to a class of 150 students and first write the L.C.M. (of course, below the line) and then write 3+2 above the line, these students have to keep pace with the teacher's speed of black-board work and some of them may not find time to look at the black-board to read your (3+2)/6; they only hear your 6 first and then your 3+2 and so write in their notes 6/(3+2)!

I realized that my way of working at examples in a notebook cannot be used in a class-room. In the class-room, after I give a step, I must wait till my sentence reaches the last student and I should not take the second step till students have taken down the first step in their note-book. But in a class-room situation it may not be possible for the teacher to remain quiet for a few seconds after every step. So a teacher must form a habit to slowly express the procedure in words. Thus, after this experience, I reoriented my teaching in the following way. "We have to simplify 1/2 + 1/3. First we shall find the L.C.M. of 2 and 3; it is 6. Now in such examples we have learnt a method of working. As per that method we write the L.C.M. in the denominator." After talking in this manner I shall write on the board 1/2 + 1/3 = .../6 and so on.

In modern terminology, I can say that the feedback I got from my students helped me to organise my blackboard work properly.

II

I joined M.T.B. College, Surat, as a lecturer in mathematics in 1943 and worked there for four years. In the beginning, my salary was Rs. 100/- p.m. Later, we got dearness allowance of Rs. 8/- p.m. In the second year of my service, I was promoted as a Professor of Mathematics with a monthly salary of Rs. 150/-. In the third year, my salary was raised to Rs. 250/- p.m. And in the fourth year, I left the college with good wishes from all to join Tata Institute of Fundamental Research to do research under Dr. H.J. Bhabha. Thus, during the 4 years at Surat, I experienced continuous progress. But as far as my teaching career is concerned, the most important aspect of these 4 years is that I got an opportunity to work with the mathematician-Principal N.M. Shah -- and learnt from him lessons in organised maths-teaching and class-room discipline.

I had to engage large classes of about 150 students four days a week. In the first term, I found it difficult to exercise classroom-control. The classes were rowdy and all sorts of shouts and noises were a continuing phenomena. However much I tried, I could not control the class. The students would not pay attention and I would not be able to teach effectively, let alone enjoy teaching. One day, I got tired of this rowdism. I gave a lecture on discipline in harsh tones and announced that the whole class is fined-each student is fined Rs.1/-. This had an immediate effect and the class remained peaceful for that period.

Next day, I met Principal Shah and told him that I had imposed a fine on the whole class. Principal told me in a very quiet tone, "It is only the Principal who could impose any punishment. The teacher should just report to the Principal about any indiscipline in his class. There are about 40 teachers in the college, if these teachers decide on their own to impose fines, indiscipline will increase rather than decrease.!" He also gave me a piece of advice. In a large class, the teacher must have patience and under no circumstance must he lose his self-control.

Next day when I went to that class, I announced that some students had approached me and expressed regrets for the indiscipline in the class so I am withdrawing the fine imposed the day before. But as a teacher, I learnt a very important lesson -under no circumstance, must we lose our self-control.

And now, I describe an incident which shows how this lesson which I learnt in 1943 came to my help in 1959. In 1959, I was working as Professor of Mathematics and Principal of M.N. College, Visnagar. In those days, all students who got admitted to the first year class were to be medically examined by a panel of doctors appointed by the university. There was a Government Hospital neat Visnagar college so it was decided that the medical check-up would be conducted at the hospital. Hence a time-table was drawn up according to which a definite number of students went to the hospital for medical check-up. One day, the Superintendent of the hospital came to see me with a complaint. On a particular day, the students for medical examination had entered a class-room used for nurses' training programme. There were no nurses in the class, but students wrote some unprintable sentences on the black-board. In the afternoon when nurses went to the class, they saw those sentences and felt very much aggrieved and insulted. I was indeed very sad to hear this complaint and pacified the agitated Superintendent saying that I would look into the matter and take necessary steps to see that such events do not recur.

I first found out the names of seven students who were scheduled to go to the hospital for medical check up at the time of the incident. I met each one of them individually and also all of them together. But they all said that they know nothing about the incident. Then I changed my method and talked to them somewhat on the following lines. "You are young and at such a stage in your life you may be tempted to write such things on the board. On the walls of houses in our streets we read such writings and that may also lead us to this writing on the black board. I am pained to realize that someone of you has written these remarks. But I am more pained to see that the writer does not realize that he has taken a wrong step in the path of building his own character. I would wish that the one amongst you who has done this writing on the board comes forward and frankly tells me so; if not now, he may come to me later. If a student makes a mistake my duty is not to punish him but to persuade him not to commit such error again. So rest assured, I am not going to punish anyone. I have decided that I shall not take any food and be on fast till the student who has done this writing comes forward and tells the truth". With these words, I asked the students to go to their class.

Circumstantial evidence had convinced me that the writer was one of these seven students. My experience of working with the younger generation led me not to make public this decision of mine. But in the evening, I came to know that my peon Nanji had come to know about the fast. Spending his own money be bought some bananas from the market in the hope that on fasting days one can eat banana! I was very much impressed by his feelings towards me, but I told him that in such fasts, the only thing one can take was water.

Next day, one of those seven students came to my office; his eyes were filled with tears. I called him to my side, patted him and tried to pacify him. I told him, "You need not say anything now but make sure that you are not tempted to such an act in future". I offered him a glass of water and then he left the room. I, on my part, ate one of the bananas brought by Nanji, wrote a letter to the Superintendent expressing the apologies of the college staff and students and thus closed the chapter.

III

I shall end this discussion on the role of students in moulding a teacher by citing some personal experiences which show that the main asset of a teacher is his students. This is all the more relevant in my case because for almost seventeen years I was a college teacher. And in those days (1940 - 1960) admission to professional courses like engineering or medicine was after spending the first two years in a science college, i.e., after passing the inter-science examination. Again, in those days I had written a mathematical text on elementary mechanics which was well received by students. Partly due to my method of teaching and partly due to the receptive nature of young students in the 18-20 age-group, I have received very warm feedback from my past students to this day.

At a bank or a post-office or a railway station or at the airport, wherever I go in Gujarat, I generally meet a past student who would say, with some sense of pride, "Sir, do you recognise me? I was a student of I.Sc. in such and such year, or I was a member of the kho-kho team". Such happy encounters with past students gives me a sense of self-satisfaction. I had such happy experiences during travel to foreign countries also. I shall recount one or two such experiences.

In 1964-65, I went to U.S.A. as a visiting professor of mathematics for a year at Washington State University, Pullman. Washington State is in the North-East corner of United States and Pullman is a small university town like our Vallabh Vidyanagar. I was scheduled to go there in September; but in the May issue of the university news bulletin there was a news item regarding my visit to the university for a year. An Indian research scholar doing post-doctoral research in chemistry in that university read this news item. He happened to be my student. He had studied maths in my class during his college days in Gujarat. He immediately wrote me a letter. The net result was that when we (my wife and a young daughter were with me) reached Pullman in September, a rented residential flat fully equipped with kitchen facilities was kept ready to receive us!

That year in December, I attended an International Conference on Quasars, Pulsars and Black-Holes in Texas state. At that time, my nephew, Arun M. Vaidya, happened to be a

Professor of Mathematics at one of the universities in Texas. After the conference was over, Arunbhai and I with our family went by car on our long sight- seeing visit to the Grand Canyon, Las Vegas and California. After 5 days' journey, we reached Los Angeles in California. We were all vegetarians. Purees and Parathas which we had brought with us were all used up in 3 days and we were on bread, butter and toast for the last two days. We all pined for a usual Gujarati meal. But we did not know any Gujarati family in Los Angeles. We stayed there in a motel. There, we picked up the telephone directory and opened up a page on Patels. As in Gujarat, there were several pages of Patels in the telephone directory in some cities of USA. I chose arbitrarily one J.G. Patel's telephone number and dialled that number. I started talking in Gujarati. "Can I speak to Jayantibhai?" The reply was: "I am not Jayantibhai, but Jerambhai. May I know who is at the other end?" I gave my name. Immediately I got reply from the other end. "Hello Vaidya Saheb, how do you happen to be here? I was your student at Vidyanagar...." Well, the net result was that Jerambhai took us all to his house and helped us in sight-seeing. For two days, we had hearty Gujarati meals and when we proceeded further on our tour Jerambhai gave us Purees and Parathas that would last for two days!

Two of my daughters have studied in USA and one of them has settled there working as a Professor of Biophysics. Wherever they went among Gujaratis they so often heard, "So you are Vaidya Saheb's daughters"! The daughter who is a professor married one Indian young man there. We could not attend that marriage, because on the same day, the marriage of our other daughter was celebrated here at Ahmedabad. But one of my students saw to it that the daughter in America does not feel our absence. He was my student in Vallabh Vidyanagar in 1948, and was, at that time a Professor at a University there. He drove 500 miles to attend the marriage and he and his wife deputised for bride's parents at the Kanyadan ceremony!!

IV

I shall end this discussion of teaching experiences of a teacher, with some experiences in teaching I had as a student. As a college teacher I had not taken any private coaching. But during college-days as a student from 1934 to 1940, family finances were such that I had to undertake a tuition or two. Here are some interesting experiences of teaching that I had in my pre-teacher days.

While studying for my M.Sc. in Bombay, I used to teach mathematics to a first year college student for one hour everyday. Within a couple of days, I started wondering how this student could pass his school leaving examination. He did not have any interest in mathematics. While I was working with him an example in Trigonometry, I stopped half-way to see if he was following. At that time he said, "Sir, is the example over?" I realized that my working examples before him was like "reading Bhagavat Gita before a buffalo." So I replied, "Yes, the example is over." Thus, throughout the year, our relationship could be described by the dialogue, "Sir, is the example over?" "Yes, it is over."! And still my prestige as a tutor remained unhampered because the day on which his annual examination was to commence was also the day of his own wedding. And, of course, it was decided that he would forego his examination and opt for his own wedding!

At about the same time, I also had a happy experience. A medical doctor couple approached me to coach their son for the college examination due a couple of weeks later. The boy was very intelligent. But as the examination approached he started getting diffident in mathematics. I spent an hour with him everyday. I had not much to do. The student would do his work and put before me any difficulties he encountered in Maths. He was well prepared in the subject and only needed someone to tell him that he was on the right lines. I also talked to him about the use of mathematics in our social development as also about mathematics as our cultural heritage. As a result, the student got self-confidence and cheerfully appeared for his examination. And for this work of two weeks the doctor couple paid me Rs.75/- (Medical doctor's fees for a psychic patient!). Note that when I joined later as a lecturer, the monthly salary was only Rs.80/-!

In June 1943, I joined M.T.B. College, Surat as a lecturer and in that year I had a strange experience. In those days the First Year examination was conducted by the college and I had set the question paper in trigonometry, which appeared rather difficult to students. After the examination was over, I received a note from an ICS officer of the Excise department requesting me to see him at his home address. When I went to see him, he informed that his son had appeared for the First Year exam of the college and had found the trigonometry paper rather difficult. He made an offer, "Please give tuition to my son in mathematics for a month". The offer of a tuition after the examination is over! The meaning was clear. I, of course, informed him that I did not practice private tuitions and left his house.

But these are all old stories about tuition. After 1955, times have changed and there has been an upward trend of tuition mongering among college teachers of mathematics. So let me describe an incident of these new times. I joined Gujarat College, Ahmedabad as Professor of Mathematics in November 1955. By that time, I had already acquired a standing in Gujarat as a non-tuition-mongering teacher with some reputation for good maths-teaching. So no one would forward me any offer of private coaching. But needy students of M.Sc. class would request me to arrange, if possible, some tuition-work for them to supplement their income. By October, some students of the Inter Science class would approach me for help in coaching and I would suggest the names of needy M.Sc. students.

In this way, I had arranged for a needy M.Sc. student to give tuition to an I.Sc. student. Two months later he came to see me and told me that he had lost that tuition-assignment. The other day, as usual, he went to coach the student. But the student handed him the monthly payment and asked him not to go for tuition from then on. And what was the reason for this sudden decision? Well, in the words of that student, "From tomorrow Professor E is to give me coaching. And you know, Professor E is an examiner at the university examination."

So I got the first information that honesty in teaching profession has started waning!!

2. Bose's Laws for a Mathematics Teacher

I

In 1952, I had the good fortune to attend a lecture on Mathematical Education by the well-known Indian Scientist, Professor S.N. Bose. In modern physics, S.N. Bose's name is connected with the name of Albert Einstein. Einstein first developed the quantum theory of propagation of light, describing this propagation as a flow of particles of light called photons. But then a problem arose. In a ray of light, a large number of photons are moving. How are these photons arranged statistically? The statistics which these moving photons satisfy was discussed by Bose and is known as Einstein-Bose statistics. In addition to photons, several other quantum particles are found to follow these Einstein-Bose statistics and all such particles are known by the general name Bosons.

In that lecture, Professor Bose had formulated two laws to characterise a good mathematics teacher. His first law was:

"Take away his note-books. Take away his text books. Does he still remain a teacher? If yes, then he is a teacher."

This statement of Bose points to the academic equipment of a teacher. This is a very important aspect to be looked into in order to become a successful teacher. You must have wide as well as deep knowledge of the subject you are to teach.

Bose's second law is:

``What does a teacher do? He presents himself as a model for his students to imitate.''

What a fine way of describing the role of a teacher in the process of character-building of his students! I shall now describe how these laws have moulded me as a teacher.

II

Immediately after my M.Sc., when I started my teaching career at Rajkot College, I did not know anything about research in Mathematics. In those days, being a professor in a college was the highest attainment for a mathematics student. It was, therefore, natural that no one would leave this smooth path of teaching in a college and go on the unknown rough track of mathematical research. But in the years 1940-41-42 certain situations developed in my life, which landed me on the path of mathematical research. Let me now describe these ups and downs of my life during 1940-42.

As it happened, the Gandhian atmosphere in which I passed my student days would not make me comfortable in a job under a small native state in pre-independence India. Those were the days of individual satyagraha. The Secretary of State for India in the British Government had declared that India had joined World War II as an ally of Britain without even casually consulting any representative of India. As a protest against this, national leaders led by Vinoba Bhave were offering individual satyagraha by making anti-war public speeches and were being arrested and jailed. At such a time, the college (managed by Rajkot State) started deducting 10% of our salary as our contribution to War-Fund. Every day, the national leaders were courting arrest to protest against a war thrust on India by its foreign rulers and we teachers serving in state Government College were shamefully (or shamelessly) paying to the war fund every month. I was very much troubled by this situation. and was in a fix. Then an incident occurred on the day of Holi festival. On that day, Thakore Saheb of Rajkot invited all college-teachers to Darbar Garh and there, Thakore's hirelings subjected us professors to oil-painted colour bath and in the same blue, black and red coloured wet clothes we returned home. It was then that I decided that it was not possible for me to continue in such a "dignified" post of college professor.

In April 1941, I resigned from my lecturership at Rajkot College and joined Ahimsak Vyayam Sangh founded by one-time revolutionary, Sardar Prithvi Singh with blessings from Gandhiji. However, as it happens in politics, Sardar Prithvi Singh had some differences with Gandhiji regarding India's stand on World War II and so the Ahimsak Vyayam Sangh was wound up in May 1942. And I was in a fix, what should I do, where to get a job?

As a college student, I had attended lectures on Theory of Relativity by Professor V.V. Narlikar of Benares Hindu University and I had studied that subject at M.Sc. level. So I decided to write to Professor V.V. Narlikar for advice. I wrote to him in May 1942 and after some correspondence it was decided that I should take training in mathematical research under his guidance. Thus, on 26th June 1942, I left for Benares with my wife and a 6-month old baby with all my savings amounting to Rs. 600/-!

In short, I left the quiet waters of lecturership in a college and plunged into the stormy waters of the national independence struggle; but as circumstances unfolded, I was thrown on to the banks of Mathematical Research!!

III

I learnt the ABC of mathematical research under Professor V.V. Narlikar at Benares for a year and then joined the M.T.B. College, Surat, as a lecturer in Mathematics from June 1943. During 1940-41, I taught maths at Rajkot College and again after experiencing the joy of mathematical research for a year at Benares, I started teaching at Surat. But there was a marked difference in my teaching at Surat from that at Rajkot. Normally, when we have to teach a particular mathematical proposition, we would first try to acquire a thorough understanding of the problem from text books and then while teaching we try to pass on that understanding to the students. And this was what I did at Rajkot. But after one year's research experience, I found that there was a fundamental improvement in my class-room teaching. Now, while teaching a mathematical proposition, several new ideas came to my mind: What is the history of the proposition? Who discovered this proposition for the first time? What thoughts must have passed in his mind when he first discovered the proof of the proposition? And I made it a point to mention all these thoughts in the class. In short, earlier I was imitating the author of the text-book in the class, but later I made efforts to imitate the original discoverer of the proposition under consideration. The net result was that I developed more and more interest in maths-teaching and my students also appeared to enjoy the mathematics that they learnt. Thus one thing became clear to me. If a teacher has tested the joy of mathematical research, his class room teaching follows a very healthy trend and he is sure to pass the criteria of Bose's laws of mathematical education.

3. Teacher as a Youth Leader

A college or a university teacher has to work with students in the age-group 18 to 24, i..e.. he has to deal with the youth. So, in addition to adequate knowledge of the subject, he has to teach, he must have certain basic qualifications of a youth leader.

During 1940-41, I taught at Rajkot College and from June 1943, I started teaching at Surat College. But my teaching at Surat had considerably improved from that at Rajkot mainly due to two reasons. One source of improvement was my research training which I discussed earlier. The other source was my activity at the Ahimsak Vyayam Sangh during 1941-42. I spent that year in learning and teaching physical exercises, sports, maintaining group-discipline, etc. And thus I got the necessary training of youth-leadership. As it happened, I developed some characteristics of a youth leader such as (i) face the youth with a smiling face; (ii) have a sympathetic attitude towards activities in which the young generally interested and have direct interest in such activity; (iii) have definite and logically consistant thinking on prevailing political, social or economic situation, but without any preconceived leaning towards party politics. And this had a distinct effect on my class-room teaching.

In 1944, I conducted a 7-week shibir (camp) of young student workers as a part of training for the independence struggle. Also during 1950-55, I organised several shram shibirs (Labour camps) under NSS scheme for college students. Thus, class-room teaching and other youth-activities went on side-by-side throughout my career.

Let me end these musings with some interesting non-teaching class-room experiences.

I joined as a Professor of Mathematics at the prestigious Gujarat College, Ahmedabad in 1955. It was a government college and it had maintained certain British traditions in dress (coat-pant-tie), even in 1955. But as a Professor, I put on the native dress of pyjama and kurta. This exceptional dress of mine immediately drew the attention of students. One day when I went to the class, I found the following writing on the board: "Sir is putting on a pyjama". I read aloud what was written on the board and then added, "If you so desire, from tomorrow I shall come without putting on pyjama". And the whole class roared with laughter! These and several such incidents made that pyjama-kurta-clad teacher quite popular among students.

Now, I describe a different type of class-room incident in an American University I worked as a visiting Professor of Mathematics at Washington State University, Pullman (Washington). There, I had to teach calculus to a class of about 20 advanced level freshmen for three days a week. In a small class, it is possible to get familiar with the students within a few weeks. One week, I found that a particular student was absent in all the three periods. So I casually enquired as to why he was continuously absent. The whole class was quiet and there was no response to my query. So I repeated my query. Then one student got up and said, "Sir, why do you worry about that boy? If you don't see him in the class, mark him absent." Then I said, "No more calculus today. Let me tell you, how I was led to make that query''. I then described to them the traditional Guru-Shishya Parampara; how Guru and Guru-patni looked after the well-being of the students. I added that, "Nowadays, we too have schools, colleges and universities on the same lines as you have. But that cultural tradition which we have inherited leads us to enquire if all is well with a student who is continuously absent." With these remarks, the class ended.

At my next lecture, one of the students got up and reported that the particular absent student was ill and in hospital. He added, "He is better now and expected to join class next week".

ACRONYMS

AAVSO	:	American Association of Variable Star Observatory
AGB	:	Asymptotic Giant Branch
AGN	:	Active Galactic Nuclei
ASCA	:	Advanced Satellite for Cosmology and Astronomy
ASI	:	Astronomical Society of India
AU	:	Astronomical Unit
BARC	:	Bhabha Atomic Research Centre
BH	:	Black Hole
BLR	:	Broad Line Region
CASS	:	Centre for Astrophysics and Space Sciences
CAT	:	Centre for Advanced Technology
CCD	:	Charge Coupled Device
CMB	:	Cosmic Microwave Background
COBE	:	Cosmic Background Explorer
CSIO	:	Central Science Instruments Organisation
CTS	:	Centre for Theoretical Studies
CWKB	:	Complex Wentzel-Kramers-Brillouin
DSP	:	Digital Signal Processor
EFOSC	:	ESO Faint Object Spectrograph and Camera
ERNET	:	Educational Research Network
ESO	:	European Southern Observatory
FIRST	:	Faint Images of the Radio Sky at Twenty Centimetre
FOS	:	Faint Object Spectrograph
FRW	:	Friedmann - Robertson - Walker
GBD	:	Generalised Brans-Dicke
GMRT	:	Giant Metrewave Radio Telescope
GR	:	General Relativity
HDFS	:	Hubble Deep Field - Source
HST	:	Hubble Space Telescope
IAGRG	:	Indian Association for General Relativity and Gravitation
IIA	:	Indian Institute of Astrophysics
IISc	:	Indian Institute of Science
IIT	:	Indian Institute of Technology
IMPOL	:	Imaging Polarimeter
IPR	:	Institute for Plasma Research
IR	:	Infra - Red
IRAS	:	Infra-Red Astronomy Satellite
ISM	:	Inter Stellar Medium
IUE	:	International Ultraviolet Explorer
JNCASR	:	Jawaharlal Nehru Centre for Advanced Scientific Research
LIGO	:	Laser Interferometric Gravitational Wave Observatory
LISA	:	Laser Interferometric Space Antenna
MACHOS	:	Massive Compact Halo Objects
MHD	:	Magnetohydrodynamics
MRI	:	Mehta Research Institute of Mathematics and Mathematical Physics
NCRA	:	National Centre for Radio Astrophysics
NERIST	:	North Eastern Regional Institute of Science and Technology

PICT	:	Pune Institute of Computer Technology
PRL	:	Physical Research Laboratory
QCD	:	Quantum Chromo Dynamics
QSO	:	Quasi Stellar Object
QSSC	:	Quasi - Steady State Cosmology
RGO	:	Royal Greenwich Observatory
RRI	:	Raman Research Institute
SAC	:	Scientific Advisory Committee
SINP	:	Saha Institute of Nuclear Physics
SNR	:	Signal to Noise Ratio, Supernova Remnant
STIS	:	Space Telescope Imaging Spectrograph
SUSY	:	Super Symmetric
TIFR	:	Tata Institute of Fundamental Research
VLA	:	Very Large Array
VLBA	:	Very Large Baseline Array
VLBI	:	Very Large Baseline Interferometer
VSP	:	Vacation Students' Programme
WKB	:	Wentzel-Kramers-Brillouin