IUCAA

# INTER-UNIVERSITY CENTRE FOR ASTRONOMY AND ASTROPHYSICS

(An Autonomous Institution of the University Grants Commission)

# Annual Report

(April 1, 1997 - March 31, 1998)

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# HIGHLIGHTS OF 1997-98

This annual report covers the activities of IUCAA during its Ninth year, April,1997-March, 1998. 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 11 core faculty members, 12 postdoctoral fellows and 15 Ph.D. students. The core research programmes by these academics span a variety of areas in astronomy and astrophysics.

These topics include investigations in blackhole entropy, string inspired 2D model for dilaton gravity, critical phenomenon in the collapse of scalar fields, electromagnetic analogues for gravitational fields, quasi-local mass in general relativity, alternative characterisation of blackhole horizon, structure formation in the quasi-steady state cosmology, statistical indicator to discriminate cosmological structures, nonlinear scaling relations in 2D, development of hierarchial search strategy for analysis of gravitational wave data, nature of broad emission line regions in quasars, detailed studies of the properties of quasar absorption lines, X-ray properties of active galactic nuclei, identification of optical counterparts related to FIRST sources, analysis of gamma-ray burst energetics, dynamics of clusters and superclusters, orbit structure in stellar dynamics, observations of molecular clouds, development of neural network for stellar spectral classification and development of CCD camera and imager spectograph for the IUCAA Telescope.

The publications of the IUCAA academics, numbering to about 92 in the current year are listed in pages 95 to 99. IUCAA members also take part in pedagogical activities like lectures, seminars, popularisation of science etc., the details of which are given in this Report.

The extended academic family of IUCAA consists of about 71 Associates and Senior Associates, who have been active in several different fields of research. Pages 59 to 80 of annual report highlights their research contributions spanning quantum cosmological models, exact solutions to Einstein's equations, alternative theories of gravity, gravitational waves, cosmology and very early universe, surface photometry of galaxies, solar and stellar pulsations, stellar photometry, quasar absorption systems, astronomical spectroscopy, radiative transfer, ionoshperic physics and nonlinear dynamical systems. The resulting publications, numbering to about 46 are listed in pages 111 to 113 of the report.

A total of about 899 man-days were spent by Associates and Senior associates at IUCAA during this year. In addition, IUCAA was playing host to about 845 visitors through the year.

IUCAA conducts its graduate school jointly with the National Centre for Radio Astrophysics, Pune. Among the research scholars, four have successfully defended their thesis and obtained the Ph.D. degree from the Pune University during the year 1997-98.

Apart from these activities, IUCAA conducts several workshops, schools and conferences each year both at IUCAA and at different university campus. During this year, there were 7 such events in IUCAA and 8 were held at other universities under IUCAA sponsorship. One of the major events during the year was IUCAA holding the 15 Meeting of the International Society on General Relativity and Gravitation (GR-15) which brought together more than 500 delegates from about 30 different countries for a period of six days. The meeting was a great success academically with active participation from all around. Another main component of IUCAA's activities is its programmes for Science Popularisation. On the national science day this year, several special events were organised including an interschool science festival with over 550 students from 90 schools in the region participating in it.

These activities were ably supported by the scientific and administrative staff (16 and 35 in number) who should get the lion's share of the credit for successful running of the programmes of the center. The scientific staff also looks after the major facilities like library, computer center and the instrumentation lab. You will find a brief update on these facilities.

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 sited on a hill near Giravali, about two and a half hours drive from IUCAA.

# CONTENTS

## The Council and the Governing Board

### The Council

*President*
Armaity Desai
Chairperson
University Grants Commission
New Delhi

*Vice-President*
N.C. Mathur (till 10.2.98)
Vice-Chairperson
University Grants Commission
New Delhi

*Chairperson, Governing Board of IUCAA*
R.P. Bambah
1275, Sector-19B, Chandigarh

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

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

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

G.D. Sharma
Secretary
University Grants Commission
New Delhi

V.R. Gowariker
Vice-Chancellor
University of Pune

V.K. Kapahi
Director
National Centre for Radio Astrophysics, Pune

V.N. Rajasekharan Pillai (till 31.12.97)
Vice-Chancellor
Mahatma Gandhi University
Kottayam

Hari Gautam (till 31.12.97)
Vice-Chancellor
Banaras Hindu University
Varanasi

H.L. Duorah (till 31.12.97)
Vice-Chancellor
Gauhati University
Guwahati

C.V. Vishveshwara (till 31.12.97)
Indian Institute of Astrophysics
Bangalore

S.S. Jha (till 31.12.97)
Tata Institute of Fundamental Research
Mumbai

V. Ramakistayya (from 1.1.98)
Vice-Chancellor
Osmania University
Hyderabad

R.N. Basu (from 1.1.98)
Vice-Chancellor
Calcutta University

N. Kumar (from 1.1.98)
Director
Raman Research Institute
Bangalore

A. Bhanumathi (from 1.1.98)
Andhra University, Visakhapatnam

M.S.V. Valiathan
Vice-Chancellor
Manipal Academy of Higher Education

Nirupama Raghavan
Director
Nehru Planetarium, New Delhi

N. Babu
Vice-Chancellor
University of Kerala, Thiruvananthapuram

M. Muniyamma
Vice-Chancellor
Gulbarga University

J.M. Waghmare
Vice-Chancellor
Swami Ramanand Teerth Marathwada
University, Nanded

Bimla Buti
Emeritus Professor
National Physical Laboratory
New Delhi

Ved Ratna
C-536, Saraswati Vihar
New Delhi

Arun Kumar Sen
Director
Institute of Radio Physics and Electronics
Calcutta

K. Sankara Sastry
Department of Astronomy
Osmania University, Hyderabad

S.N. Tandon (till 31.12.97)
IUCAA

N.K. Dadhich (from 1.1.98)
IUCAA

*Member Secretary*
J.V. Narlikar
Director, IUCAA

**The Governing Board**

*Chairperson*
Armaity Desai (till June 18, 1997)
R.P. Bambah (from June 19, 1997)

*Vice-Chairperson*
N.C. Mathur (till June 18, 1997)

*Members*
G.D. Sharma
V.R. Gowariker
V.K. Kapahi
V.N. Rajasekharan Pillai (till 31.12.97)
V. Ramakistayya (from 1.1.98)
Hari Gautam (till 31.12.97)
R.N. Basu (from 1.1.98)
H.L. Duorah (till 31.12.97)
N. Kumar (from 1.1.98)
M.S.V. Valiathan
C.V. Vishveshwara (till 31.12.97)
S.S. Jha (till 31.12.97)
A. Bhanumathi (from 1.1.98)
Nirupama Raghavan
S.N. Tandon (till 31.12.97)
N.K. Dadhich (from 1.1.98)

*Member Secretary*
J.V. Narlikar

## Honorary Fellows

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

2. R. Hanbury Brown
   Andover, England

3. A. Hewish
   University of Cambridge, UK

4. Fred Hoyle
   Bournemouth, UK

5. Yash Pal
   New Delhi

6. A.K. Raychaudhuri
   Calcutta

7. P.C. Vaidya
   Gujarat University
   Ahmedabad

## Statutory Committees

### The Scientific Advisory Committee

S.M. Alladin (till 31.12.97)
Osmania University, Hyderabad

S.M. Chitre (till 31.12.97)
Tata Institute of Fundamental Research
Mumbai

R. Cowsik (till 31.12.97)
Indian Institute of Astrophysics, Bangalore

Richard Ellis
University of Cambridge, England

K.C. Freeman (till 31.12.97)
Mount Stromlo Observatory, Australia

S. Mukherjee (till 31.12.97)
North Bengal University, Darjeeling

K. Sato (till 31.12.97)
University of Tokyo, Japan

G. Srinivasan (till 31.12.97)
Raman Research Institute, Bangalore

E.P.J. van del Heuvel (from 1.1.98)
University of Amsterdam, The Netherlands

K. Babu Joseph (from 1.1.98)
Cochin University of Science and Technology
Kochi

Vinod Krishan (from 1.1.98)
Indian Institute of Astrophysics, Bangalore

J. Maharana (from 1.1.98)
Institute of Physics, Bhubaneswar

Franco Pacini (from 1.1.98)
Observatorio Astrofisico di Arcetri, Italy

R. Rajaraman (from 1.1.98)
Jawaharlal Nehru University, New Delhi

Ram Sagar (from 1.1.98)
Uttar Pradesh State Observatory, Nainital

S.K. Trehan (from 1.1.98)
146, Sector 9-B, Chandigarh

J.V. Narlikar (Convener)
IUCAA, Pune

### The Users' Committee

*from 1.1.95 to 31.12.97*

J.V. Narlikar
IUCAA (Chairperson)

S.N. Tandon
IUCAA

N.K. Dadhich
IUCAA (Convener)

K.C. Pandya
Vice-Chancellor, University of Gorakhpur

J.S. Puar
Vice-Chancellor, Punjab University

R.P. Saxena
Nominee of Vice-Chancellor
University of Delhi

Pushpa Khare
Utkal University, Bhubaneswar

S.K. Pandey
Swamy Ramanand Teerth Marathwada
University, Nanded

*from 1.1.1998 to 31.12.2000*

J.V. Narlikar
IUCAA (Chairperson)

A.K. Kembhavi
IUCAA

N.K. Dadhich
IUCAA (Convener)

H.L. Duorah
Vice-Chancellor, Gauhati University, Guwahati

Asis Datta
Vice-Chancellor,
Jawaharlal Nehru University, New Delhi

D.K. Sinha
Vice-Chancellor, Visva Bharati

R.S. Tikekar
Sardar Patel University, Vallabh Vidyanagar

G. Ambika
Maharaja's College, Kochi

## The Academic Programmes Committee

J.V. Narlikar (Chairperson)
N.K. Dadhich
S.V. Dhurandhar
Ranjan Gupta
A.K. Kembhavi
T. Padmanabhan (Convener)
Varun Sahni
S.N. Tandon

## The Standing Committee for Administration

J.V. Narlikar (Chairperson)
N.K. Dadhich (till 30.07.97)
S.N. Tandon (till 30.07.97)
A.K. Kembhavi (from 01.08.97)
T. Padmanabhan (from 01.08.97 )
T. Sahay (Member Secretary)

## The Finance Committee

Armaity Desai (Chairperson) (till 31.7.97)
S.P. Gupta (till 31.7.97 )
P. Bhatia (Ex-Officio Member) (till 28.1.98)
R.P. Bambah (Chairperson) (from 1.8.97)
G.D. Sharma (Ex-officio Member) (from 1.8.97)
J.V. Narlikar (Ex-officio Member)
O.P. Nigam (Ex-Officio Member) (from 29.1.98)
R.P. Gangurde (Ex-Officio Member) (from 1.8.97)
S.N. Tandon
(Nominee of the Director, IUCAA) (from 1.8.97)
Nirupama Raghavan
(Nominee of the Chairperson, G.B.) (from 1.8.97)
Arun Nigavekar
(Nominee of the UGC) (from 1.8.97)
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)
N.K. Dadhich
S.V. Dhurandhar
R. Gupta
S. Raychaudhury
V. Sahni
R. Srianand
S. Sridhar
S.N. Tandon

### Scientific and Technical

N.U. Bawdekar
S. Bhujbal (from 11.12.97)
V. Chellathurai
S. Chitnis (from 18.11.97 to 30.12.97)
P.A. Chordia
H.K. Das
M.S. Deshpande (till 24.10.97)
D.V. Gadre
G.B. Gaikwad
S.U. Ingale
A.M. Kane (till 2.1.98)
P.A. Malegaonkar
V.B. Mistry
A. Paranjpye
H.K. Sahu (from 21.4.97)
S. Sankara Narayanan

### Administrative and Support

T. Sahay (Senior Administrative Officer)
K.M. Abhyankar (till 3.11.97)
N.V. Abhyankar
V.P. Barve
S.L. Gaikwad
B.R. Gorkha
B.S. Goswami
R.S. Jadhav
B.B. Jagade
S.M. Jogalekar
A.N. Kamnapure
S.N. Khadilkar
M.A. Mahabal
S. Mathew
S.G. Mirkute
E.M. Modak
K.B. Munuswamy
K.C. Nair
R.D. Pardeshi
N.S. Pargaonkar
N.S. Parkhe
R. Parmar
B.R. Rao
M.A. Raskar
M.S. Sahasrabudhe
V.A. Samak
S.S. Samuel
B.V. Sawant
S. Shankar
D.R. Shinde
D.M. Surti
V.R. Surve
A.A. Syed
S.R. Tarphe
S.K. Waghole (from 15.4.97)

### Post-Doctoral Fellows

S.K. Banerjee (from 1.8.97)
S. Bose
V. Faraoni (from 22.9.97)
R.K. Gulati (till 10.4.97)
S. Kar
R. Misra
A. Mangalam (from 12.8.97)
B. Nath (till 11.4.97)
S.K. Sethi (till 4.4.97)
S. Surya (from 22.9.97)
S. Sinha (till 11.4.97)
R. Wichmann (from 20.1.98)

### Research Scholars

R. Balasubramanian (till 22.8.97)
V. Chickarmane (till 19.8.97)
S. Engineer

K. Harikrishna
A.A. Mahabal
S.D. Mohanty (till 15.9.97)
A. Nayeri
A. Pai
A.N. Ramaprakash
T.D. Saini
N.R. Sambhus
S. Shankara Narayanan (from 4.8.97)
K. Srinivasan
L. Sriramkumar (till 17.10.97)
Y.G. Wadadekar

**Project Appointments**

T. Deoskar
(Trainee Engineer, Instrumentation Laboratory, from 23.12.97)
S.R. Kulkarni
(Trainee Engineer, Instrumentation Laboratory, from 15.12.97)
V. Joshi
(SILFID Project work, from 1.10.97)
V. Mahabal
(DOE-ERNET Project work, from 1.4.97)
M.N.S. Nair
(Accounts work)

**Visiting Scientist**

Anuradha Bhagwat
(Science Popularization, from 15.12.97)

**Part-time Consultants**

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

M.N. Anandaram
Department of Physics
Bangalore University

A. Banerjee
Department of Physics
Jadavpur University, Calcutta

S. Banerji
Department of Physics
University of Burdwan

Pradip K. Bhuyan
Department of Physics
Dibrugarh University

D.K. Chakraborty
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Pt. Ravishankar Shukla University, Raipur

Suresh Chandra
School of Sciences
Indira Gandhi National Open University
New Delhi

S. Chatterjee
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New Alipore College, Calcutta

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Department of Physics and Electronics
Sri Venkateswara College, New Delhi

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NERIST, Arunachal Pradesh

A.D. Gangal
Department of Physics
University of Pune

Ashok K. Goyal
Hans Raj College, Delhi

V.B. Johri
Department of Mathematics and Astronomy
Lucknow University

K.N. Joshipura
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Sardar Patel University, Vallabh Vidyanagar

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Department of Physics
Bangalore University

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

V.H. Kulkarni
Department of Physics
University of Mumbai

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Department of Physics
Cochin University of Science and
Technology

Daksh Lohiya
Department of Physics and Astrophysics
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Udit Narain
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P.C. Vinodkumar
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P. Vivekananda Rao
Department of Astronomy
Osmania University, Hyderabad

Zafar Ahsan
Department of Mathematics
Aligarh Muslim University

**... till June 30, 1997**

B. Chakraborty
Department of Mathematics
Jadavpur University, Calcutta

M.C. Durgapal
Department of Physics
Kumaun University, Nainital

Asim K. Ray
Department of Physics
Visva Bharati, Santiniketan

T. Singh
Department of Applied Mathematics
Banaras Hindu University, Varanasi

S.G. Tagare
School of Mathematics and CIS
Hyderabad University

**from July 1, 1997...**

Raj Bali
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Renuka Datta
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S.S. De
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University College of Science, Calcutta

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

N. Ibohal
Department of Mathematics
Manipur University, Imphal

B. Ishwar
Department of Mathematics
B.R. Ambedkar Bihar University
Muzaffarpur

S.N. Karbelkar
Department of Physics
College of Engineering and Technology
Akola

Manoranjan Khan
Centre for Plasma Science
Jadavpur University, Calcutta

P.S. Naik
Department of Post-graduate Studies and
Research in Physics, Gulbarga University

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

Asoke Kumar Sen
Department of Physics
Assam University, Silchar

D.C. Srivastava
Department of Physics
University of Gorakhpur

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

**Associates**

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

N. Banerjee
Department of Physics
Jadavpur University, Calcutta

Indira Bardoloi
Department of Physics
Handique Girls' College, Guwahati

S.P. Bhatnagar
Department of Physics
Bhavnagar University

S. Chakrabarty
Department of Physics
University of Kalyani

S. Chakraborty
Department of Mathematics
Jadavpur University, Calcutta

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

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

R.V. Saraykar
Department of Mathematics
Nagpur University

A.K. Sharma
Department of Physics
Shivaji University, Kolhapur

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

T. Subba Rao
Department of Physics
S.V. University P.G. Centre, Kurnool

S. Sreedhar Rao
Department of Astronomy
Osmania University, Hyderabad

Sarita V. Vaishampayan
Department of Mathematics
North Maharashtra University, Jalgaon

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

G. Yellaiah
Department of Physics
Kakatiya University, Warangal

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

Santokh Singh
Deshbandu College, Delhi

**...till June 30, 1997**

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

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

S.C. Mehrotra
Department of Physics
Dr.B. Ambedkar Marathwada University
Aurangabad

R.R. Rausaria
Distance Education Council
Indian Gandhi National Open University
New Delhi

**from July 1997...**

Moncy V. John
Department of Physics
St. Thomas College, Kozhencheri

# The Eighth batch of Senior Associates and Associates of IUCAA, who were selected for a tenure of three years, beginning July 1, 1997

Moncy V. John

G.P. Singh

Raj Bali

Renuka Datta

N. Ibohal

M. Khan

B. Ishwar

A.K. Sen

The photographs of the following Senior Associates and Associates from the Eighth batch are not available

Santokh Singh
V.K. Gupta
S.N. Karbelkar

Appointments of the following Senior Associates and Associates from the fifth batch were extended for three years:

Satya Sankar De
P.S. Naik
V.M. Nandakumaran
Udit Narain
Ramakrishna Reddy
D.C. Srivastava
S.K. Srivastava
P.C. vinodkumar

# Organizational Structure of IUCAA's Academic Programmes

**The Director**
*J.V. Narlikar*

**Dean, Core Academic Programmes**
*(S.N. Tandon - till July 31, 1997)*
*(T. Padmanabhan - from August 1, 1997)*

**Dean, Visitor Academic Programmes**
*(N.K. Dadhich - till July 31, 1997)*
*(A.K. Kembhavi - from August 1, 1997)*

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

**Head, Associates & Visitors**
*(N.K. Dadhich - till July 31, 1997)*
*(A.K. Kembhavi - from August 1, 1997)*

**Head, Computer Centre**
*(A.K. Kembhavi)*

**Head, Recreation Centre**
*(S.V. Dhurandhar)*

**Head, Library & Documentation**
*(T. Padmanabhan)*

**Head, Guest Observer Programmes**
*(A.K. Kembhavi)*

**Head, Publications**
*(T. Padmanabhan)*

**Head, Workshops & Schools**
*(V. Sahni)*

**Head, M.Sc. & Ph.D. Programmes**
*(V. Sahni)*

**Head, Science Popularization and Amateur Astronomy**
*(Somak Raychaudhury)*

**Head, Instrumentation Laboratory**
*(S.N. Tandon)*

## Director's Report

This is my and (IUCAA's) tenth Report, which comes as a reminder that IUCAA now crosses into double figures of existence. We are celebrating 1998-99 as our Decennial Year.

IUCAA has thrived on its visitor programme. Faculty members and students from universities and colleges in India, resource persons, post-docs and students from research institutions and observatories in India as well as abroad have visited us for our academic programmes and made this a vibrant campus. We thank them all and renew our invitation to visit us particularly during the coming year.

1997-98 saw a major academic event hosted by IUCAA: GR-15, the Fifteenth Meeting of the International Society on General Relativity and Gravitation. It was hosted by India for the first time. In fact, it was the first time that a GR Conference was hosted in the Asia-Pacific region. As around 500 GR-specialists descended on the campus during December 16 to 21, the IUCAA staff went on a work-overdrive. But they coped with the occasion very well judging by the very favourable feedbacks received from delegates from all parts of the world. I thank all my colleagues for this achievement.

In 1993 IUCAA had hosted the VIth IAU Asian-Pacific Regional Meeting, (again for the first time in India for such a meet) which brought in 350 delegates. The experience gained in its successful management had provided the stepping stone for making a bid for GR-15.

What do such meetings do for the growth of research in India? Our experience has shown that the excellent and varied menu of review talks on frontier level work done in different branches of the field is itself inspiring, while the discussion-oriented workshops provide workers an opportunity to see and participate at first hand in ongoing research. So such large international meets can be beneficial to our universities.

This report highlights both the research work done during 1997-98 at IUCAA by its core faculty, post-docs and students as well as by associates and senior associates from universities and colleges who use its facilities. Experts may judge for themselves the quality of research. But objective assessment is provided by the participation of IUCAA members in important meetings at the national and international level as invited speakers and workshop coordinators. Thanks to the letters written by the Chairperson, UGC to vice-chancellors and heads of colleges, we hope that the associateship programme will be used even more vigorously in the future.

The IUCAA Telescope is still in its design stage. The delay has been caused by the relocation of the concerned technical staff and experts consequent on the UK Government decision to wind up and reorganize most of the activities of the Royal Greenwich Observatory. At the time of writing this report, dust has still to settle down so that the project can move ahead. In the meantime a Memorandum of Understanding has been signed with Copenhagen University for the fabrication of an imager spectrograph for use on the telescope as the 'first light' instrument. We are grateful to CSIR and DST for research grants to cover nearly two thirds of the cost of the instrument. Progress has been slow and steady on acquiring the Giravali site for the telescope from the Forest Department. We are still hopeful, however, that the telescope will be sited during 1999.

Apart from GR-15, IUCAA had organized a number of small scale schools and workshops in different subjects as seen from the Calender of Events. Many of these were organized on the campuses of colleges and universities from Tezpur in the North East to Kozhencheri, Kerala in the south.

The highlight of the Foundation Day (29 December, 1997) was, of course, the 9th Foundation day Lecture by Professor Sir Michael Berry on Geometric Phases and the Separation of the World. The lecture (see abstract on page 47) was delivered extempore with the remarkable demonstration of a spinning top that stayed in mid-air, an effect of 'geometric magnetism'.

IUCAA's programmes for science popularization continue in full swing with lectures to school students on the 2nd (and now, also on the 4th) Saturday of the month. The projects during summer vacation see more than hundred and fifty students of Standards 8-10 on the campus. It is interesting to see how a research institution can keep a school student busy on a project for a week. This year the National Science Day was celebrated in a big way and the response from the schools and the townspeople was overwhelming. Encouraged by this, somewhat more ambitious activities are planned for the National Science Day of 1999.

A major development on the organizational side was the modification of the Rules of IUCAA which passed on the Chairpersonship of the Governing Board (formerly called 'Governing Body') to a distinguished scientist appointed by the Chairperson, UGC, who continues to be the President of the Council of IUCAA. We are indeed very happy to welcome the first Chairperson under the new Rules, Professor R.P. Bambah, a distinguished mathematician and formerly Vice-Chancellor of Punjab University, Chandigarh.

We record our grateful thanks to Professor (Miss) Armaity Desai who, as our President and Chairperson, UGC, has always provided support and encouragement. We will miss Professor Naresh Mathur who retired this year as the Vice-Chairman, UGC. It was a pleasure to interact with him on various scientific and infrastructural matters. We also thank the Secretary, UGC and the IUC Bureau for prompt attention to IUCAA's problems.

**Jayant V. Narlikar**

## Awards and Distinctions

**S.V. Dhurandhar**

Elected Member of the International Astronomical Union, Commission 47.

**J.V. Narlikar**

Degree of Doctor of Science (Honoris Causa) at the 79th Convocation of the Banaras Hindu University, June 13.

Mohamed Sahabdeen Award for Science Popularisation, Sri Lanka.

Literature Award for a novel on "Virus" by the Maharashtra Government, November 21.

Degree of Doctor of Science (Honoris Causa) at the Annual Convocation of Roorkee University, November 26.

C.V. Raman Birth Centenary Award by the Indian Science Congress Association, Hyderabad, January 3-4.

**Somak Raychaudhury**

Elected Member of the International Astronomical Union, Commission 28.

Elected Science Popularization Officer, Astronomical Society of India.

**V. Sahni**

Elected Member of the International Astronomical Union, Commission 47.

**R. Srianand**

INSA young scientist award, 1997.

**S. Sridhar**

Elected Member of the International Astronomical Union, Commission 28.

## Calendar of Events

### 1997

April 14 - May 23
**School Students' Summer Programme**
at IUCAA

May 14 - June 3
**Refresher Course in Astronomy and Astrophysics for College/University Teachers**
at IUCAA

June 2 - July 11
**Vacation Students' Programme**
at IUCAA

August 10-11
**Astronomy Camp**
at Hubli, Karnataka
(jointly organized by IUCAA and Chinmaya Seva Samiti Trust, Hubli)

August 18
**IUCAA-NCRA Graduate School**
First Semester begins

September 8-9
**Lecture/Demonstration on Astro-photography in CCD Era**
at IUCAA

September 12-13, 1997
**Mini School on Introductory Astronomy and Use of Computers**
at St. Thomas College, Kozhencheri, Kerala

September 29 - October 3
**Workshop on Modern Trends in Gravitation and Cosmology**
at Cochin University of Science and Technology

September 29 - October 3
**Level 1 Workshop on Astronomical Photometry**
at IUCAA

October 13-14
**Workshop on Introductory Astronomy and Astrophysics**
at Raman School of Physics, Pondicherry University

November 3-14
**TIFR-IUCAA School on Cosmic Ray Astrophysics**
at Ootacamund

December 16-21
**15th Meeting of the International Society on General Relativity and Gravitation**
at IUCAA

December 21
**XIX Meeting of the Indian Association for General Relativity and Gravitation (IAGRG)**
at IUCAA

December 27
**IUCAA-NCRA Graduate School**
First Semester ends

December 29
**The 9th IUCAA Foundation Day**

## 1998

January 12-26
**5th Workshop on High Energy Physics Phenomenology (WHEPP-5)**
at IUCAA

January 12
**IUCAA-NCRA Graduate School**
Second Semester begins

January 16-20
**Workshop on the Physics of Stars**
at University of Tezpur

February 9-13
**Workshop on Stellar Structure and Evolution**
at IUCAA

February 9-23
**School on Basic General Relativity and Cosmology**
at Mangalore University

February 26
**National Science Day**

March 2-6
**Introductory School on Astronomy and Astrophysics for College Teachers**
at Bangalore University

# Academic Programmes

## Research at IUCAA

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 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

*Event horizon: Magnifying glass for Planck length physics* : It is generally believed that the spacetime continuum will give way to a more fundamental level of description at length scales smaller than Planck length $L_P \equiv (G\hbar/c^3)^{1/2}$, corresponding to energy scales larger than $E_P = L_P^{-1}$. Approaches to quantum gravity based on strings or Ashtekar variables strengthens such a belief. If this is the case, then spacetime continuum — described by a solution to Einstein equations — is an approximate, coarse grained concept, similar to the continuum description of a fluid or gas. Einstein equations have a status similar to that of equations of fluid mechanics and are of limited validity.

If the spacetime has certain quantum mechanical micro-structure at Planck scales, and the continuum description based on Einstein's equations is a coarse-grained one, then the *necessary* criterion for the breakdown (or otherwise) of the continuum description should not be based on the approximate theory. An analogy might make this point of view clearer. In the study of a fluid system, one can obtain solutions to hydrodynamic equations describing the coarse-grained behaviour. In special circumstances, like in the case of shock waves, one can also obtain a *sufficient* condition for the breakdown of hydrodynamic description by studying these solutions. But if a very high energy beam of photons propagates through the fluid probing length scales comparable to those of constituent particles, then the smooth fluid description will necessarily breakdown around the region where the external influence interacts with the microscopic structure of the fluid. Similarly, if the modes of an external field can probe scales comparable to Planck length in some region of spacetime, then one cannot describe physics around that region using Einstein's equations. Normally, virtual modes of arbitrarily high energy of matter fields do interact strongly with the quantum micro-structure of spacetime; but this is of no consequence unless such a virtual process can manifest as a real one in some way. This is exactly what happens in spacetimes with an event horizon, like that of a black hole.

Based on this idea, *T. Padmanabhan* has made an attempt to describe the 'thermodynamics' of semiclassical spacetime without specifying the detailed 'molecular structure' of the quantum spacetime, using the known properties of black holes. He has given detailed arguments, essentially based on the behaviour of quantum systems near the event horizon, which suggest that the event horizon acts as a magnifying glass to probe Planck length physics even in those contexts in which the spacetime curvature is arbitrarily low. The quantum state describing a black hole, in any microscopic description of spacetime, has to possess certain universal form of density of states. It turns out that, this form can be ascertained from general considerations. Since a black hole can be formed from the collapse of any physical system with a low energy Hamiltonian $H$, it is suggested that when such a system collapses to form a black hole, it should be described by a modified Hamiltonian of the form $H^2_{\rm mod} = A^2 \ln(1 + H^2/A^2)$ where $A^2 \propto E^2_P$. He also shows that it is possible to construct several physical systems which have the black hole density of states and hence, will be indistinguishable from a black hole as far as thermodynamic interactions are concerned. In particular, black holes can be thought of as one-particle excitations of a class of *nonlocal* field theories with the thermodynamics of black holes arising essentially from the asymptotic form of the dispersion relation satisfied by these excitations. These field theoretic models have correlation functions with a universal short distance behaviour, which translates into the generic behaviour of semiclassical black holes. Several implications of this paradigm are being explored.

*Quantum black holes in dilaton gravity* : Since Hawking's discovery in 1974 that black holes radiate thermally, physicists have not yet been able to ascertain the ultimate fate of black hole evaporation. It is known that Hawking's semiclassical analysis (where one quantizes only the matter fields on a fixed classical background spacetime) breaks down before the evaporating black hole reaches Planck-size. Hence, an attempt to study the final fate of such an evolution necessarily entails a complete quantization of gravity, which is still an unsolved problem in four dimensions.

One can, however, attempt to answer this question in a string - inspired two-dimensional (2D) model of dilaton gravity of black hole formation/ evaporation. Recently, Kuchař, Romano, and Varadarajan have partially succeeded doing so in a canonical framework. However, it still remains to study the quantum geometry that emerges from their work. *S. Bose* is involved in investigating this problem, especially to see if the black hole singularity survives this quantization. This issue is likely to bear on the ultimate fate of black hole evaporation.

*Quantization of two-dimensional dilaton-gravity models* : In the past couple of years, different approaches to quantizing two-dimensional dilaton - gravity models have been proposed. Of particular interest are, (i) the path-integral quantization method, which is perturbative, and (ii) Dirac constraint quantization, which is exact. Given this pair of different approaches, it is important to ask if they are consistent with one another wherever their domains of validity overlap. This question attains special significance in the light of the fact that two of the principal approaches to quantizing gravity, namely, superstring theory and non-perturbative quantum general relativity, form one such pair. Thus, lessons learnt from studying different quantizations of the two-dimensional model may provide guidelines for comparing theories of quantum gravity. In this regard, *S. Bose* has initiated a study of different approaches to quantizing two-dimensional (2D) dilaton-gravity models. He finds that the anomaly in the commutator algebra of the matter stress-tensor operator arising in the Dirac constraint quantization is related to the Polyakov-Liouville term traditionally associated with the path-integral quantization. Furthermore, the "gauge"-degree of freedom associated with the choice of the anomaly potential (which is dependent only on the embedding variables) is shown to lead to different realizations of the vacuum of the matter fields. He also argues why the "large N" approximation, where N is the number of matter field species, is not required in the Dirac constraint quantization approach, as opposed to the path-integral one, where it is essential in obtaining a one-loop action.

*Critical phenomenon in collapse of scalar fields* : In 1993, using numerical techniques, Choptuik studied the collapse of a spherical shell of massless scalar matter fields in an initially flat spacetime. He found that, as the matter fields evolve in time, they subsequently either disperse away to infinity (this is called the subcritical case) or collapse to form a black hole of certain mass (this is called the supercritical case) depending on the strength of the initial matter configuration. More interestingly, he found that the mass of the black hole exhibits a critical scaling law in the parameter space of the matter configuration such that the critical exponent is a universal constant. One of the consequences of this scaling law is that a black hole of arbitrarily small mass can form in such a classical collapse.

In realistic stellar collapses, however, there exists a lower bound on the masses of black holes formed, namely, the Chandrasekhar limit, which arises because of the degeneracy pressure. Although, such a pressure will not come into play in the collapse of massless scalar fields, it is interesting to ask whether any other relevant quantum effect can prevent the formation of infinitesimally small black holes or even alter the classical scaling law observed by Choptuik. It is known that quantum gravitational effects can not be neglected for black holes of Planckian size. In fact, in a two-dimensional model of dilaton gravity, which has many similarities with spherically symmetric four-dimensional Einstein gravity, Y. Peleg, *S. Bose*, and L. Parker have shown that Choptuik's scaling law breaks down when quantum effects are included. They also showed a strong possibility for the existence of a lower bound (of Planckian order) on the mass of black holes formed from such a collapse. *S. Bose* is currently working on extending this calculation to the more realistic and involved scenario of such collapses in general relativity.

*Exact solutions in superstring cosmology with back reaction* : The Standard Cosmological Model (SCM) successfully explains many features related to the observed universe. However, it does not offer a solution to the initial singularity problem or account for the homogeneity and isotropy of the universe unless one invokes an ad hoc inflation field and fine-tunes the initial conditions. Superstring cosmology appears to be more promising in this regard. First, it is known to be well behaved at ultraviolet energy scales or at the most have mild singularities. Second, apart from the graviton, it has a naturally occurring dilaton field whose kinetic energy can be used to drive the universe through an inflationary phase. The solutions to the tree level effective action depict an FRW phase as well. Unfortunately, the tree level solution does not describe a smooth singularity-free transition from the inflationary phase to the FRW phase. This is called the "graceful exit" problem in superstring cosmology.

Recently, *S. Bose* found a new string - inspired two-dimensional cosmological model in which the graceful exit problem is solved for any number of matter field species. The exact solutions of this model were obtained subsequently by *S. Bose* and *S. Kar*. One of these solutions exhibits a graceful exit from the inflationary to the FRW phase and is nonsingular everywhere. A duality-related second solution is found to exist only in the pre-big-bang phase and is singular at the epoch of big-bang. In either case, back reaction is shown to play a crucial role in determining the specific nature of these geometries. A future project that they propose to work on is to study whether quantum corrections can induce a graceful exit even in cosmological solutions of the four-dimensional string action, coupled to the usual gauge fields, but in the absence of ad hoc dilaton potentials.

*The Einstein equation in string theory* : It is a well-known fact in string theory that the consistency conditions on the background massless fields, necessary to impose quantum conformal invariance in the nonlinear sigma model, turn out to be the Einstein equations. One of the methods used to arrive at this result is based on equating the beta-function(al)s of the sigma-model to zero. However, *S. Kar* has shown, using purely classical considerations and logical extrapolation of results belonging to point particle theories, that the metric background field in which a string propagates must satisfy an Einstein or an Einstein-like equation. This analysis is based on the recently obtained Jacobi and Raychaudhuri equations for string worldsheets. Restrictions on the worldsheet curvature, which seems to act as a source for spacetime gravity, even in the absence of other matter fields, also emerge. A class of backgrounds in which classical strings can propagate are also identified through a condition on the Bach tensor.

*Toy model in quantum mechanics* : The physics of a particle on a vertical rotating circle in the presence of constant gravitational/magnetic fields is explored in detail by *S. Kar* and A. Khare (IOP). After an analysis of the classical mechanics of the problem, they discuss the quantum mechanics from both exact and semiclassical standpoints. Exact solutions to the Schrodinger equation are obtained in some cases by different methods. Instanton-like bounces are constructed and semiclassical, leading order, tunneling rates are obtained. They also investigate qualitatively the nature of small oscillations around the bounce solution. Finally, the connections of these toy examples with field theoretic and statistical mechanical models of relevance are pointed out.

*Role of topological fluctuations*: Topology is expected to play as important a role in any theory of quantum gravity as it does in flat space field theories. *S. Surya* and S.M. Vaidya found that, on certain spaces, when gravity is coupled to an SU(2) field and a single Weyl fermion the theory is free of global anomalies. This analysis was done within the so called "frozen space" formulation of quantum gravity. H.F. Dowker and *S. Surya* investigated spacetimes where the spatial topology was allowed to fluctuate and found that these spacetimes can be classified according to their causal structure. Currently, they are working to construct a proof relating the causal structure to a topological invariant.

*Classical paradigms for black hole evaporation* : Moving mirrors radiate. This strange phenomenon, predicted within the framework of quantum field theory in flat spacetime in the '70s, and is usually thought to arise from a disturbance of the vacuum in the vicinity of the moving mirror which gives rise to a production of photons. Only for certain kinds of accelerated trajectories, the radiation is thermal in nature. In fact, there are non-trivial trajectories where no energy is radiated though there is a local flux of particles created. The trajectory for which thermal radiation is observed (for late times when the mirror is near the event horizon) is of special importance because, there is a close connection between radiating mirrors and radiating black holes. The process of radiation as well as the structure of the horizon in both the cases is mathematically very similar. In the case of the moving mirrors, it is the exponential Doppler redshift of the quantum modes that causes particle production while in the case of the black hole, it is the exponential gravitational redshift that does the same.

Though both these effects are similar, they occur in rather different contexts. Radiation from a black hole is a quantum effect with a spacetime that is curved. Since there is no viable quantum theory of gravity, this radiation is derived using the simpler semiclassical theory which describes quantum fields propagating in curved classical fixed background spacetimes. There is no direct experimental evidence in support of this semiclassical theory. In contrast, however, the theory explaining radiation from moving mirrors is the well established quantum field theory in flat spacetime.

The results described above, namely, radiation from black holes and moving mirrors, are all well known quantum field theoretical results. However, it is interesting to ask whether it is possible to construct classical models that give *similar* results. In the framework of classical field theory and classical general relativity, Planck's constant is zero. There is no concept of photons and no production of particles can take place. Further, there is no classical analogue of quantum statistical physics which is used to derive Planck's radiation formula and to quantify the notion of fluctuations which is important in quantum field theory. However, in classical field theory, the power spectrum gives quantitative information regarding the frequency content of any classical field like the electromagnetic field. Therefore, to construct viable classical models, we consider the reflection of classical electromagnetic waves of the objects to be studied and analyse the power spectrum of the reflected wave. This power spectrum is regarded as the classical analogue to the radiation spectrum in quantum field theory.

*K. Srinivasan and T. Padmanabhan* use the above ideas to construct classical models analogous to radiation from black holes and moving mirrors in their present work. For moving mirrors, light is reflected off a mirror moving along the trajectory (that produced a thermal spectrum in the quantum case) and the power spectrum of the reflected wave is constructed. In the case of a black hole, a collapsing star of given mass with a totally reflecting surface is considered close to its event horizon. Light is reflected off the star's surface and the reflected light is Fourier analysed and its power spectrum is obtained. It is shown that the thermal nature of the radiation discovered in the quantum versions can be recovered here with the classical analogue having a "thermal" form. In fact, the power spectrum is composed of three terms. The first is a constant equal to 1/2, which is reminiscent of the zero point energy of a quantum harmonic oscillator. The second term is a Planckian in the *frequency* which is analogous to the Planckian in the *energy* that is obtained in the quantum case. The third term represents the fluctuations around the Planckian. It is because of the presence of this fluctuation term that the power spectrum can be regarded to have a "thermal" nature.

It must, however, be stressed that the classical systems they have studied have no fluctuations or temperature in the sense of statistical physics. But these terms can be interpreted in a natural way using notions like thermal spectrum and its fluctuations.

In this connection, it is also of interest to study the motion of charged particles classically and ask if there are any trajectories for which the radiation field has a Planckian power spectrum. *K. Srinivasan* has constructed physical trajectories which do indeed have radiation fields having the above property. The power spectra of these trajectories is not isotropic, though the Planckian form is retained for certain range of frequencies.

*Tunneling interpretation of black hole radiance* : It is a well known result in quantum field theory that a uniform electric field produces particles. Though this result is gauge invariant, when using the tools of standard quantum field theory, however, it appears that particle production is gauge dependent. In a time dependent gauge, the particle production is obtained because the "in-vacuum" in the infinite past is not the same as the "out-vacuum" in the infinite future. But, in a space dependent gauge the "in-vacuum" and the "out-vacuum" are found to be the same. Hence, according to the tenets of quantum field theory in flat spacetime, no particles should be produced. But, the above gauge gives the same uniform electric field as the time dependent gauge. This paradox is resolved by invoking the tunneling interpretation. In this approach, the problem is reduced to an effective Schrodinger equation and the transmission and reflection coefficients are calculated. The coefficients are then suitably interpreted to recover particle production. Therefore, the tunneling interpretation gives a useful explanation when dealing with the time independent gauge.

In the present work, *K. Srinivasan* and *T. Padmanabhan* examine the validity of a similar tunneling interpretation as applied to black hole radiation. Particle production from black holes can be derived in many ways. In one of the approaches, a collapsing star is studied when it is on the verge of forming a black hole. In such a time dependent case, the relation between the in-vacuum and the out-vacuum determines the particle production rate and the resulting spectrum is thermal. In an another approach, external black holes are studied. This is an explicitly time independent case. In such a case, it is found that the relevant Green's function for the field is periodic in the time co-ordinate but with a imaginary period. Since this periodicity is a characteristic of thermal Green's functions, Hawking radiation is immediately inferred. But, in this case, unlike the previous system which studied a collapsing star, the system actually corresponds to an equilibrium situation with the black hole being immersed in a thermal bath of radiation at the same temperature. The actual radiation process from the eternal black hole is usually described as a tunneling process involving the event horizon. In this work, a scalar field propagating in the usual Schwarzchild spacetime is considered and this problem is reduced to an effective Schrodinger equation with an effective potential which reduces to $(-1/x^2)$ near the event horizon. The transmission and reflection coefficients are calculated for this quantum mechanical problem. Re-interpreting these coefficients does not produce the known result unlike in the electric field case. This difficulty with the tunneling interpretation can be traced to the fact that the effective potential is symmetric with respect to both sides of the horizon. This means that the fundamental property of asymmetry that the horizon possesses (it is classically a one-way membrane) is lost. However, by using a suitable semi-classical ansatz in which the asymmetry of the horizon is taken into account, the standard result can be obtained.

## Classical Gravity

*Naked singularities in low energy limit of string theory*: *S. Kar* has constructed the solutions to the equations of motion of the low energy, effective field theory emerging out of compactified heterotic string theory by making use of the well-known duality symmetries. Beginning with four-dimensional solutions of the Einstein-massless scalar field theory in the canonical frame, he first rewrites the corresponding solutions in the string frame. Thereafter, using the T and S duality symmetries of the low energy string effective action, one can arrive at the corresponding uncharged, electrically charged and magnetically charged solutions. Several of the metrics are shown to possess naked singularities although the energy conditions are obeyed. Dual solutions exhibit a duality in the conservation/violation of the null and averaged null energy conditions (NEC/ANEC), a fact demonstrated earlier in the context of black holes and cosmologies. Additionally, those backgrounds which preserve the energy conditions in spite of possessing naked singularities serve as counter examples to cosmic censorship in the context of low energy, effective string theory.

*Aspects of the Raychaudhuri equation* : A couple of results on the Raychaudhuri equation for geodesic congruences are obtained by *S. Kar* who has studied the covariance and invariance properties of the Raychaudhuri equation for curves under an $SL(2, R)$ transformation of the expansion. He has also developed an alternative approach to geodesic focusing using integral equations as opposed to differential equations. By assuming the existence of a focal point, he derives the conditions under which such effects do occur. A more general condition is obtained, of which the usual energy condition is a special case.

*Conformal invariance of quasilocal mass* : Recently, the Brown-York formalism of finding the quasilocal mass has been extended to the case of a generic scalar-tensor theory of gravity in spacetime dimensions greater than two by Chan, Creighton, and Mann. Since solutions of two conformally related scalar-tensor theories will themselves be related by a conformal transformation, it is interesting to ask if the quasilocal masses of these solutions are also related. In the past, it has been suggested that the quasilocal mass should be a conformal invariant, since a conformal transformation is merely a local reparametrization of the fields, which is supposed to leave the mass of a system unchanged. However, such a claim was verified to hold only for the special case of asymptotically flat, static, spherically symmetric solutions, and for a particular choice of reference action (which is subtracted from the gravitational action to renormalize the quasilocal mass).

*S. Bose* and D. Lohiya have now shown that in spacetime dimensions larger than two, the quasilocal mass of a spatially bounded region (in a classical spacetime solution of a generic scalar-tensor theory of gravity) is indeed invariant under conformal transformations of the metric under more general conditions and asymptotic behaviour of the fields.

This conclusion is based on a well defined prescription for calculating the quasilocal mass of bounded regions of spacetime solutions in scalar-tensor theories of gravity. In this prescription, the reference action is obtained by generalizing the recent proposal of Hawking and Horowitz, which was made in the context of general relativity. The proof of conformal invariance of quasilocal mass is illustrated by applying their prescription to specific cases of black hole spacetimes, which are either asymptotically flat or anti-de Sitter, in conformally related theories.

*Alternative characterization of black hole horizons* : The concept of a black hole horizon has played a monumental role, not only in the understanding of the structure of various spacetimes, but has also been associated with several general relativistic theorems and laws, e.g., the singularity theorem of Penrose, the black hole area theorem of Hawking, and the classical laws of black hole mechanics, not to mention the important role it plays in Hawking's semiclassical calculation of black hole evaporation and its association with the entropy of a black hole.

Although, the horizon does not have any special significance in the frame of a freely falling observer, it behaves very much like a physical membrane with respect to an asymptotic inertial observer. An apparent horizon is a local construct that is topologically defined to be the outer boundary of the union of trapped surfaces in a spacetime. On the other hand, the event horizon is a globally defined surface; it is the boundary of the causal past of the future null infinity. That is, from beyond this surface, null rays cannot escape to the future null infinity without violating causality. These definitions implicitly depend on the behaviour of families of null geodesics in a given spacetime and the properties of such a family are affected by the matter stress tensor through the Raychaudhuri equation. This fact had earlier prompted *N. Dadhich* to ask if there exists a direct characterization of the black hole horizon in terms of quasilocal energy of bounded regions embedded in such spacetimes. In a recent work, *N. Dadhich* and *S. Bose* have now proven that a black hole horizon can be characterized by the fact that at the horizon, the quasilocal energy becomes equal to the sum of the ADM energy and the gravitational charge of the spacetime, which is the Komar integral evaluated at the horizon.

*Electromagnetics of gravity* : Electromagnetic field could in general be resolved into electric and magnetic parts. It is the electric charge that produces electric field, while its motion produces magnetic field. In gravitation, the analogue of charge is the mass energy which should produce the gravo electric field and the front of mass energy could produce the gravo magnetic part of the field. Since gravitation is described by the curvature of spacetime, this suggests that one should resolve the Riemann curvature tensor relative to a timelike unit vector.

There is, however, an additional and unique property of gravity that gravitational field itself produces more gravity. This is because, energy in any form must link to gravity. Since gravitational field, like any other field, possesses energy, it should also produce gravity. This is precisely the reason for non-linearity of the Einstein field equation. In the context of electromagnetic decomposition, the electric part will have further decomposition, the one due to matter-energy distribution ("active") and the other due to field itself ("passive"). The Riemann curvature has 20 components, of which 12 will refer to electric part (6 each for active and passive, and the each being represented by a second rank symmetric 3-tensor orthogonal to the resolving timelike unit vector) and 8 to magnetic part which is represented by a second rank trace-free 3-tensor. It consists of the Weyl magnetic symmetric part and an antisymmetric part that represents energy-flux.

*N. Dadhich* has been investigating several features of this formalism. The interesting question to ask is what happens when we interchange the active and passive electric parts? It turns out that this interchange amounts to interchange of the Ricci and the Einstein tensors. Thus, under the duality transformation a fluid spacetime maps onto another fluid spacetime with density and pressure transforming appropriately. The important point to note is that the duality transformation takes one fluid solution to another fluid solution. On the other hand, the vacuum equation is invariant under duality. The most interesting vacuum solutions are the black hole solutions, and they are all unique.

A closer look at derivation of black hole solutions demonstrates that there exists one free equation which is implied by rest of the equations. Since black hole solution is unique, the modified equation will also characterize vacuum in this situation. It turns out that the modified equation is not duality-invariant. Then, what does solution of the dual set represent? Remarkably, the dual solution represents the original black hole field with a global monopole charge. This works for all black holes, stationary as well as rotating including the NUT solution as well. One can thus find solutions dual to the well-known black hole solutions and the duality transformation amounts to generating a global monopole in the original spacetime.

What they have done to vacuum could be done to flat spacetime as well and FRW model with the equation of state $\rho + 3p = 0$, which characterizes global texture and zero mass global monopole (Schwarzschild mass put to zero) are the spacetimes dual to flat spacetime. That is, they are dual-flat.

Global monopoles and textures are the stable topological defects that are supposed to be produced when global symmetry is spontaneously broken in phase transitions in the early universe. The remarkable property of the gravitational field is that their spacetime description is incorporated automatically by the electrogravity duality. This is, a new and interesting property of the gravitational field.

## Cosmology and Structure Formation

*The Quasi-Steady State Cosmology* : Work on the QSSC has continued on two fronts : (i) The relationship of predictions of the theory to cosmological observations and (ii) The development of large scale structures in the QSSC. Progress made on these fronts is as follows :

*(i) Interpretation of cosmological observations* : *S.K. Banerjee* and *J.V. Narlikar* have been examining the prediction of QSSC with regard to the variation of angular size with redshift for ultracompact radio sources. It has been argued by K. Kellermann that such sources being shielded from extragalactic environment are less likely to be subject to evolution of linear size with epoch compared to the large scale radio sources. Using this argument, K.I. Kellermann, J.C. Jackson and M. Dodgson investigated the fit between the predictions of standard models and the data. Although, Kellermann found a satisfactory fit with the $k = 0, \Lambda = 0$ model, Jackson and Dodgson found

the fit unsatisfactory with a larger database, and concluded that models with $\Lambda < 0$ provided better fit. *S.K. Banerjee* and *J.V. Narlikar* investigated the question and found that the fit provided by a range of QSSC models with the Jackson-Dodgson database is quite satisfactory.

*(ii) Structure formation* : Standard cosmology relies on gravitational effects as the main agent for forming large scale structure in the expanding universe. *S.K. Banerjee* and *J.V. Narlikar* showed that gravitational perturbations of the QSSC do not grow systematically, but oscillate. Thus, other effects are required for making large scale structures.

In fact, as has been argued by F. Hoyle, G. Burbidge and *J.V. Narlikar*, the main agent in structure formation is matter creation through mini-creation events. A toy model based on Hoyle's initial ideas along these lines has been explored further by *Ali Nayeri, Sunu Engineer* and *J.V. Narlikar*.

In this model a randomly distributed set of N points over a unit volume ($N \sim 10^5 - 10^6$) is augmented by the creation of an additional point in the neighbourhood (within a distance less than $xN^{-1/3}$ of a fraction $\alpha$) of the original set of points. The volume is then scaled up to $1 + \alpha$ times the original volume. The inner unit volume of the expanded one is then taken for further processing. This will have on an average $N$ points. The same 'creation' exercise is repeated around $\alpha N$ of these. This process can be repeated $n$ times ($5 \leq n \leq 10$). Very soon the set of points begins to show clusters, filaments and voids. A 2-point correlation function analysis shows a slope of $-1.8$ for $\xi(r)$ over an extended range before dropping sharply to show a void.

The toy model underscores the crucial role of creation process in forming inhomogenous structures. This model is currently being developed further within the framework of the QSSC.

*Structure formation in standard big bang model* : The real universe contains inhomogeneous structures like galaxies, clusters, etc. In any theory of the formation of these structures, it is essential to understand the evolution of small inhomogeneities in the early universe. For that, on scales larger than Hubble radius ($\lambda > d_H$), a general relativistic analysis is usually needed. In principle, it is straightforward to work out the general relativistic theory of linear perturbations. One can linearize Einstein's equations to obtain a second-order differential equation of the form involving a linear differential operator depending on the background spacetime.

In practice, there are many complications and conceptual difficulties which make this analysis highly nontrivial. One problem is the so-called "gauge problem", which arises due to non-uniqueness of splitting of all metric and matter quantities into a homogeneous and isotropic zeroth order and small, first-order perturbation about the FRW metric. In other words, by the re-labeling of coordinates $x^\alpha \rightarrow x^{\alpha'}$, one can make a small $\delta T_{\alpha\beta}$ large or even generate a component which was originally absent. Thus, when analyzing relativistic perturbations, one must take care to factor out effects due to coordinate transformations. There are two different ways of handling this kind of problems in general relativity. One approach is to analyze a perturbation in a particular gauge, say, synchronous gauge. In this case, one specifically identifies the points of fictitious background spacetime with those of real spacetime, i.e., one can treat $\delta T^0{}_0$ to be the perturbed mass density. In this method, however, we cannot fix the gauge completely and the residual gauge ambiguities create some problems. The second method is to construct the perturbed physical variables in a gauge-invariant manner. The gauge-invariant approach is conceptually more attractive, since there is no need for specific identification of the points between the two spacetimes, though it is more complicated and the physical meaning of variables do not, in general, possess any simple interpretation and becomes obvious only for specific observers.

In principle, cosmological perturbations can be divided into two subclasses: (i) Perturbations with wavelengths larger than Hubble scale ($\lambda > d_H$), i.e., large-scale perturbations for which we have to use some form of a general relativistic perturbations and (ii) small-scale perturbations ($\lambda < d_H$) for which the evolution of mass density can be studied using Newtonian theory. All physical quantities can be defined in this context, unambiguously. In general, however, the application of Newtonian equations is restricted and cannot be used for relativistic component even in scales much smaller than Hubble radius ($\lambda \ll d_H$).

Recently, Lima, et al., re-examined the basic equations describing a Newtonian universe with *uniform pressure* and found out the same density contrast evolution equation as could be obtained by the full relativistic approach. They achieved this goal by modifying the continuity equations in an expanding background. The equation which they have derived for evolution of density contrast matches exactly with the relativistic one in the imposing synchronous and co-moving gauge. With this result, in fact, they argued that one can extend the domain of validity of Newtonian cosmology in order to analyze some problems of formation of structures even in the radiation dominated phase.

*Ali Nayeri* and *T. Padmanabhan* extend the result of work done by Lima and his collaborators to a multi-component universe with different equations of states. They consider a two fluid universe in the context of an effective Newtonian cosmology. Comparison with the fully relativistic two-component universe reveals the high accuracy of density contrast equations in this approach.

*New shape-statistics for large scale structure* : The large scale structure of the Universe is remarkably rich in visual texture. At different density thresholds, the clustering pattern has been variously described as 'meatball-like', 'sponge-like', 'bubble-like', 'network of surfaces', etc. Attempts to quantify this pattern, in redshift surveys of galaxies and in N-body simulations, have been made using topological discriminators such as the genus curve and percolation statistics and also by applying minimal spanning trees and statistics sensitive to 'shape'.

In earlier work, *V. Sahni*, together with B.S. Sathyaprakash and Sergei Shandarin, suggested using percolation and shape morphology to study the large scale structure of the Universe. The morphology of superclusters and voids is likely to differ for different scenarios of structure formation and a study of supercluster-void shapes could help distinguish between radically different alternatives such as gravitational instability, seed models of structure formation and models based on explosions or 'mini-bangs'.

Percolation theory provides a definite clue to the *morphology* of the supercluster-void network. As shown by *Sahni*, Sathyaprakash and Shandarin, systems evolving under gravitational instability percolate at progressively higher density thresholds corresponding to lower values of the filling factor. This means that during later epochs a smaller volume fraction is in the percolating phase immediately suggesting that structures in the percolating phase are more likely to be sheet or filament-like, since sheets and filaments occupy a larger surface area than a sphere at a given volume, and therefore percolate more easily. For a fluid that has evolved as a result of gravitational instability, a low filling factor at percolation is also suggested by the Zeldovich approximation, which predicts that the first singularities to form are pancake-like. However, it is unlikely that these pancakes will be strictly planar objects. Instead, it is more natural that they will resemble, in a manner of speaking, the curved two-dimensional surface of a cup. Recent work suggests that soon after pancake formation, the density distribution becomes a web-like structure dominated by filaments which act as bridges connecting neighbouring clusters with pancakes remaining statistically significant.

Observationally, most galaxy catalogues reveal structures with typical scales about 50 Mpc., some such as the Great Wall, appear to be even bigger. The present finite size of surveys, together with the fact that most of them are limited to surveying galaxies within a wedge shaped region, prevents us from establishing whether the visual structures we see are truly filamentary (one-dimensional) or whether they appear filamentary because the geometry of the survey prevents us from acquiring a fully three-dimensional perspective (filaments in a wedge type survey could, for instance, be slices of two-dimensional 'sheets'). Upcoming large redshift surveys such as the 2dF survey at the Anglo-Australian Telescope and the Sloan Digital Sky Survey promise to reveal large scale structures in their full glory and shed more light on their three-dimensional shapes.

The importance of trying to quantify shapes of clusters and superclusters, in galaxy surveys and in simulations has, in recent years, led to a discussion of different statistical tools which may be sensitive to 'shape'. While such statistics have had a measured amount of success, it is fair to say that none of them is entirely satisfactory. A central feature of some shape indicators is that they describe the shape of a collection of points (equivalently – an overdense region) by evaluating its moment of inertia tensor, which is similar to fitting by an ellipsoid. The ratios of the principal axes then provide a means of ascertaining whether the structure is oblate or prolate. This method has been widely used in determining the luminosity profiles of galaxies and remains a powerful tool for classifying the projected shapes of ellipticals. Its efficacy as a discriminator for large scale structure is, however, not quite as obvious. Indeed, results of N-body simulations show that, when viewed at different density thresholds, shapes of compact surfaces can vary widely, ranging from approximately ellipsoidal (at high densities), to topologically complicated 'spongy' shapes at moderate density thresholds.

An example of a multiply-connected surface often seen at moderate thresholds in simulations is a torus. Clearly, a statistic which attempts to describe the shape of a torus by fitting with an ellipsoid would be widely off the mark since it would lead us to conclude that the torus has a pronounced oblate shape and would miss completely its tubular form – which is more like a one-dimensional filament. A tendency to model shapes using pre-defined 'eikonal' forms, can lead to an exaggerated emphasis of oblateness or sphericity over filamentarity and could easily bias our understanding of the morphology of large scale structure. *Sahni*, Sathyaprakash and Shandarin introduce a *new shape statistic* 'Shapefinders' which are free from the above drawbacks, and probe the shape of an object without any preordained reference to an eikonal shape.

This shape-statistic is constructed out of four fundamental properties of a surface : (i) Volume $V$, (ii) surface area $S$, (iii) integrated mean curvature: $C = \frac{1}{2}\int(\kappa_1 + \kappa_2)dS$, (iv) integrated Gaussian curvature (genus): $\mathcal{G} = -\frac{1}{4\pi}\int \kappa_1\kappa_2 dS$, where $\kappa_1 \equiv 1/R_1$ and $\kappa_2 \equiv 1/R_2$ are the principal curvatures of the surface. Multiply-connected surfaces have $\mathcal{G} \geq 0$, while simply connected have $\mathcal{G} < 0$. Out of these four quantities, three *Shapefinders* are constructed: $V/S$, $S/C$ and $C$ or $C/\mathcal{G}$. In addition, a pair of dimensionless Shapefinders: $\mathcal{K} \equiv (\mathcal{K}_1, \mathcal{K}_2)$ is also constructed.

The Shapefinders have dimensions of *length* and can be thought of as describing the spatial dimensions of an object. Thus an ideal pancake (having vanishing thickness but not necessarily planar) has one characteristic dimension much smaller than the remaining two, so that $V/S \ll S/C \simeq C$ and $\mathcal{K} \simeq (1,0)$. An ideal filament (an one-dimensional object, but not necessarily straight) has two characteristic dimensions much smaller than the third so that $V/S \simeq S/C \ll C$ and $\mathcal{K} \simeq (0,1)$. All three dimensions of a sphere are equal, resulting in $V/S \simeq S/C \simeq C$ and $\mathcal{K} \simeq (0,0)$. In addition, an interesting surface to consider is a 'ribbon', for which $V/S \ll S/C \ll C$ and $\mathcal{K} \simeq (1,1)$.

Thus $\mathcal{K}$ can be regarded as a two-dimensional vector whose amplitude and direction determine the shape of an arbitrary three-dimensional surface. Combined with the genus, we get the dimensionless triad $(\mathcal{K}_1, \mathcal{K}_2, \mathcal{G})$ giving information about shape as well as topology.

The shape-statistic so constructed has been applied to a number of shapes, both topologically simple and complicated with excellent results. The values of $(\mathcal{K}_1, \mathcal{K}_2)$ for extreme deformations of a torus having an elliptical cross-section are shown in Figure 1.

The statistic suggested by *Sahni*, Sathyaprakash and Shandarin could also be used to study more general shapes than those appearing in large scale structure. For instance, one could use them to study the shapes of concentrated cosmic magnetic fields which might have important astrophysical consequences. Finally, a two-dimensional shape-statistic developed along similar lines by *Sahni*, Sathyaprakash and Shandarin could be useful for studying shapes and topologies of two-dimensional contours defining 'hot and cold spots' in the Cosmic Microwave Background, or isodensity surfaces in projection data. At present, statistical tools based on percolation theory and shape analysis are being applied to the IRAS $1.2Jy$ redshift survey, the Las Campanas redshift survey and also to N-body simulations of galaxy clustering.

*Nonlinear scaling relations : S. Engineer, T. Padmanabhan* and J.S. Bagla have continued the investigations into scaling relations describing gravitational clustering. They explore the existence of scaling relations in two dimensional simulations of gravity and conclude that such scaling relations exist in 2D as well as 3D. It is found that the slope at the intermediate regime matches with the index obtained from spherical collapse model earlier used by *Padmanabhan* to explain the N5R in 3D. In the nonlinear end, instead of slope of 1 (which arises

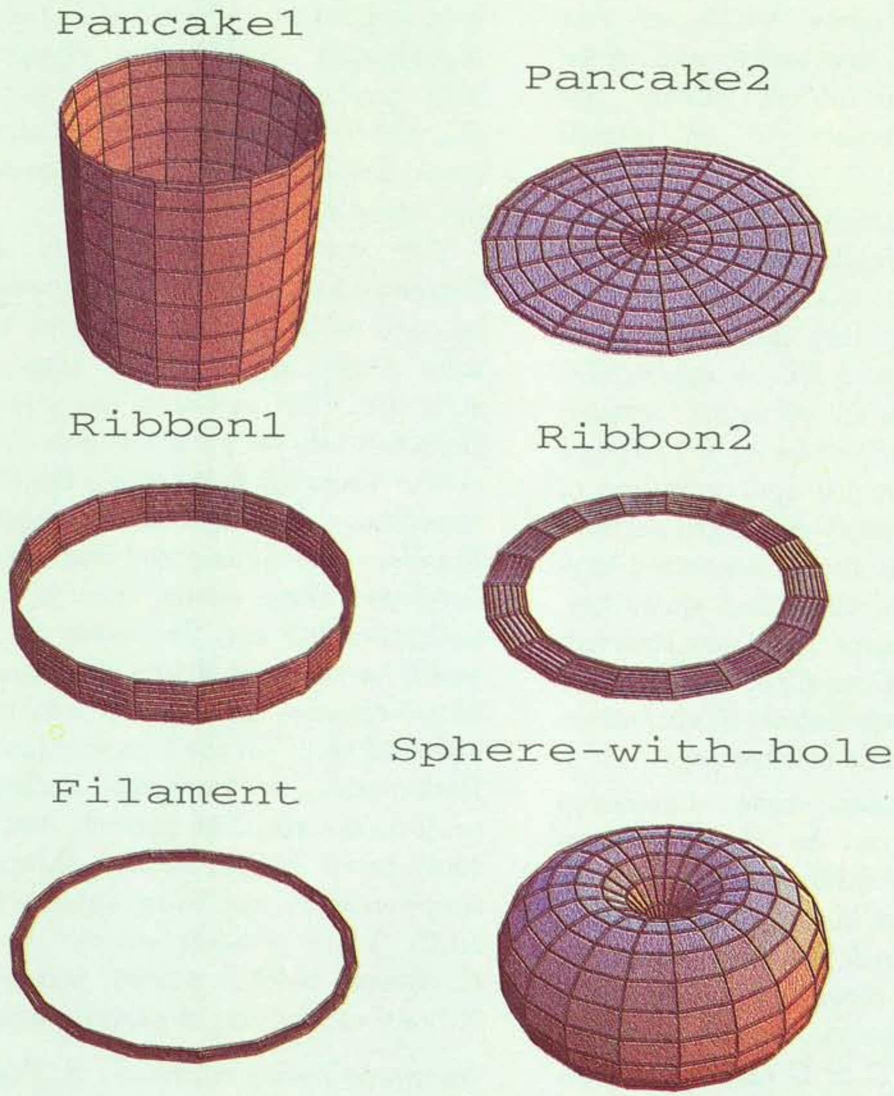


Figure 1: The *Shapefinder* statistic proposed by Sahni, Sathyaprakash and Shandarin can effectively discriminate between the geometrically distinct shapes shown above for which the dimensionless shape statistic $\mathcal{K} \equiv (\kappa_1, \kappa_2)$ has values : Pancake1, $\mathcal{K} = (0.90, 0.03)$; Pancake2, $\mathcal{K} = (0.88, 0.20)$; Ribbon1, $\mathcal{K} = (0.70, 0.80)$; Ribbon2, $\mathcal{K} = (0.70, 0.80)$; Filament, $\mathcal{K} = (0.14, 0.93)$; Sphere-with-hole, $\mathcal{K} = (0.14, -0.09)$. This example demonstrates the discriminating power of this new shape statistic.

from stable clustering) they obtain a value of 3/4 which in turn indicates that the $h$ function (the ratio between pairwise peculiar velocity and Hubble flow, Peebles 1980) reaches an asymptotic value of 3/4 in the nonlinear end.

In order to understand the issues involved in 2D simulations better, *S. Engineer, K.Srinivasan* and *T. Padmanabhan* undertook a rigorous investigation into ways of doing 2D simulations. They began by deriving the 2D equations from Einstein's equations and reached the conclusion that it is not possible to define a self consistent picture of structure formation in two dimensions, starting from Einstein's equations. One is thus led to the conclusion that the only way to do a 2D simulation in the study of structure formation is to simulate infinite needles in a 3D expanding background, and to define the 2D particles as intersections of an orthogonal plane with these needles.

*An improved model for spherical collapse :* *S. Engineer*, N. Kanekar and *T. Padmanabhan* also suggested an improved spherical collapse model for structure formation which attempts to alleviate the problem of *ad hoc* virialization argument of standard spherical collapse model. Starting from the functional form of dimensionless pair velocity given by Hamilton, et al. one can derive a functional form for the dependence of rotational term (which is usually put to zero in spherical collapse model), as a function of the density contrast $\delta$. The solution of the resulting differential equation for $R$ shows a smooth transition from the maximum value to a constant value at late times.

*Inflationary models of universe :* The inflationary models of the universe are based on a self-interacting scalar field. The coupling constant of the scalar field to the Ricci curvature is usually neglected for economy of calculations, or considered as a free parameter that can be adjusted at will to reduce certain fine-tuning problems of inflation. However, definite prescriptions for the value of the coupling constant exist in many theories of gravity and of the scalar field. Particularly important is the case of general relativity, in which the value of the coupling is dictated by the Einstein's equivalence principle. The success of an inflationary scenario is deeply affected by the value of the coupling constant, and it is important to establish the consequences for the known inflationary scenarios of the prescriptions for the coupling forced upon us by the theory.

This work has been started by *V. Faraoni* and certain scenarios do not survive the consistency check. Work in progress aims at selecting the inflationary scenarios which are theoretically consistent. The non-minimal coupling of the scalar field, which cannot be avoided according to many arguments, entirely changes the problem of the reconstruction of the field potential from the observations that can be performed with the next generation of satellites.

## Gravitational Waves

Over the next decade, several large-scale interferometric gravitational wave detectors will come on-line. These include LIGO, composed of two Laser Interferometer Gravitational-wave Observatories situated in the United States each with baselines of 4 km, VIRGO, an Italian/French project located near Pisa with a baseline of 3 km, GEO600, a British/German interferometer under construction near Hannover with a baseline of 600 m, TAMA in Japan, a medium-scale laser interferometer with a baseline of 300 m, and with funding approval AIGO500, the proposed 500 m project sponsored by ACIGA. Notably, funds for a 12 m advanced research interferometer, as a corner station for the AIGO500, have already been obtained. There are also separate proposals for space-based detectors which could be operational twenty-five years from now (e.g., LISA: the Laser Interferometer Space Antenna, a cornerstone project of the European Space Agency). In the meantime, a number of the existing resonant bar detectors will have had their sensitivities further enhanced.

The key to gravitational wave detection is the very precise measurement of small changes in distance. For laser interferometers, this is the distance between pairs of mirrors hanging at either end of two long, mutually perpendicular vacuum chambers. Gravitational waves passing through the instrument will shorten one arm while lengthening the other. By using an interferometer design, the relative change in length of the two arms can be measured, thus signaling the passage of a gravitational wave at the detector site. Long arm lengths, high laser power, and extremely well-controlled laser stability are essential to reach the requisite sensitivity, since the gravitational waves will be faint and will interact only weakly with matter in the detector.

Although, the initial design of several of the interferometers currently under construction has already been set, it is universally recognised that more technologically advanced detector designs, in a globally distributed network, will be essential to locate and characterise sources of gravitational waves. A southern hemisphere advanced detector, with its large separations from all northern hemisphere interferometers, is an essential component of this network.

Although, existing resonant bar detectors have several years of detector output which is still largely unanalysed, very little output from working interferometers is currently available. Recent coincidence runs between bar detectors located in Australia, Italy and the USA have highlighted the potential pitfalls that must be avoided to extract a reliable event with 100% confidence. Interferometer analyses have focused on the data from the 100 hour coincidence run on the Glasgow/Garching prototype interferometers and more recently on the existing small body of interferometer output from the 40 metre instrument located at Caltech. Importantly, the Caltech data is now being distributed to interested research groups around the world so that intense work can begin on algorithm development.

Gravitational wave detectors produce an enormous volume of output (e.g., of the order of 16 MB/sec for the LIGO instruments) consisting mainly of noise from a host of sources both environmental and intrinsic. Buried in this noise will be the gravitational wave signature. Sophisticated data analysis techniques will need to be developed to optimally extract physical data. Experience in handling large volumes of data and the development of appropriate analysis algorithms will, therefore, play a vital role in the eventual success of gravitational wave detection. Prior to these instruments becoming fully operational, data analysis is also an essential diagnostic tool. In this world wide effort, IUCAA has contributed handsomely in the theoretical aspects of the experiment, especially, in gravitational wave data analysis. The details of the IUCAA involvement has been given in the last annual report.

During the current year the following results have been obtained :

*(i) Hierarchial search strategy : S.D. Mohanty* has extended the earlier work on hierarchial strategy to include post-Newtonian corrections. The problem in this case is more involved and the previous (essentially one dimensional) analysis needed to be extended to a two-dimensional parameter space (basically corresponding to the two masses of the stars). The saving in the computational cost now jumps to a factor of about 25 or 30. The cost saving factor is basically the ratio of the widths of the ambiguity function at the two thresholds.

*(ii) Pulsars :* A rotating, asymmetrical neutron star is a source of continuous gravitational waves. An important problem in this context is the construction of a filter bank for pulsar signals. *A. Mangalam* is studying this problem. A related problem is a filter bank in the ellipticity parameter which quantifies the non-axisymmetry of the pulsar. Since the pulsar wobbles depending on its ellipticity. S. Sahay (Gorakhpur University) is developing a code for assessing the number of filters required.

Although, a lot of work has gone into the problem of estimating parameters and the inverse problem, the problem of detection by the maximum likelihood method has not been applied for a network of detectors. This method is optimal in the sense that it maximises the detection probability for a given false alarm probability (Neyman-Pearson Lemma). *S. Bose* and *S.V. Dhurandhar* have laid down the formalism for detecting coalescing binary signals with a network of detectors. The formalism has been kept quite general in that it can be applied to other detectors such as resonant bars or spheres and it also applies to any number of detectors. More detailed results and simplifications are being obtained for two and three detectors. The final aim is to obtain quantitative results for the actual network that is being constructed around the globe.

*(iii) Analysis of data from prototype detectors and bars :* 100 days of data from the Perth bar is available from the Indo-Australian collaboration. Data from the 40 metre Caltech detector will also be available. The data will be tested for colour, stationarity, Gaussianity, periodicity, etc. One of the primary objectives is to characterise the noise and determine the probability distribution of the noise. This is important for computing false alarm and detection probabilities and thus setting up thresholds to optimally extract the signal out of the noise. Signals will be embedded in the noise and it is proposed to test the algorithms of Sathyaprakash and *Dhurandhar*, *Mohanty* and *Dhurandhar* for performance when real data from the detectors is used. Coincidence between detector data can also be done using cross-correlations. The main point here to note is that the cross-correlation statistic should be carefully analysed for its statistical distribution in order to draw accurate inferences from the data.

*(iv) Modeling the interferometer :* The Indo-French project on the stability of giant high power laser cavities under the IFCPAR programme was successfully completed on August 31, 1997. The total duration of the project was 3 years and 3 months. The investigators on the Indian side were *S.V. Dhurandhar* and B.S. Sathyaprakash and on the French side were J.Y. Vinet and P. Hello. As a part of the collaboration, students were encouraged to work on this project and *V. Chickarmane* has contributed handsomely. Although, the project is formally over, the collaboration still continues and *A. Pai* is continuing the

work on radiation pressure instabilities in the nonlinear regime of the operation of the Fabre-Perot cavity.

At present, *A. Pai* and *S.V. Dhurandhar* along with the Orsay group are investigating the pumping of the cavity due to the delay effect, which now has been modeled in a closed form for the first time. The closed form facilitates in studying the dynamics of the Fabre-Perot cavity with suspended mirrors. Two modes have been studied: one is the longitudinal mode which decides the resonance condition of the cavity and the other is the centre-of-mass mode which is important from the point of view of the optics of the full interferometer. The modes typically show a steady increase in amplitude as the cavity gets pumped by the laser, which one can think of in terms of a negative Q-factor. The negative Q depends on the input power and suggests that the Q for the active damping must be chosen sufficiently large so that it prevails over the negative Q. Alternatively, the gain and other characteristics of the servo must take into account this important instability in order to counter it. With the present design of the servo given by the Annecy group, work is in progress for examining the over all stability of the system.

*(v) The network problem :* Techniques have been developed to analyse the data output of gravitational wave detectors, such as LIGO and VIRGO, to detect the presence of signal and estimate the parameters of the source of that signal. The network problem deals with how to optimally use a set of N detectors to achieve the same purpose. This is expected to lead to a decrease in the threshold. The computation time might increase, but the increase in the probability of detection for a given false-alarm probability will be enough of a compensation. The first part of this project, involving *S. Bose* and *S.V. Dhurandhar*, will deal with only the detection problem in the presence of N = 3 detectors. They hope to deal with the estimation of parameters using N detectors later.

In this project, they formulate the data analysis problem in the case of the coalescing binary signal for a network of laser interferometric gravitational wave detectors that have arbitrary orientations and are located around the globe. Their formalism is general enough to be extended in a straightforward way to other types of detectors, e.g., bars or spheres. They use the maximum likelihood method for optimising the detection problem. A complete set of eight independent parameters, which define the likelihood ratio, are identified. They call these the 'basic' parameters, which are usually the observed parameters, e.g., the location of the binary. Then a new set of eight parameters is defined that are functions of the basic ones; this set of new parameters not only allow them to express the likelihood ratio for the network in a very simple and compact form but also is at the basis of giving a novel geometric interpretation to the detection problem. They assume that the noise in each detector is Gaussian and that the noises in different detectors are independent of one another. They formulate the problem by writing down a single likelihood ratio for the entire network. The formulation involves the use of product data-trains and product templates. Due to the assumptions on the noises mentioned above, the maximum likelihood method leads to a simple surrogate statistic, that is, just the sum of the correlations over all the detectors. The formalism turns out to be quite simple and elegant and easy to apply in practice. The threshold, false-alarm probabilities can be calculated now in a manner similar to the single detector case. It just implies, applying the usual techniques to the product space. They explicitly work out the details of maximisation of the likelihood ratio in the cases of networks comprising of two and three detectors. Their aim is to apply the formalism to the LIGO/VIRGO network and compute detection rates, range of the network, etc. In particular, they would like to estimate the advantage of constructing a detector in Australia far from the other detectors in the network.

*Lensing by gravitational waves* : Gravitational waves deflect light rays and can act as gravitational lenses; this possibility has been studied by *V. Faraoni* for waves generated by astrophysical sources, and also scintillation effects have been considered. It was found that the creation of multiple images of a cosmic object and the high amplification events associated with the crossing of caustics by the light source are possible at a level detectable with present technology, although they are very rare. This is in contrast with previous results derived using the optical scalars formalism, which is inadequate for the study of multiple images and high amplification events.

VLBI observations are already being carried out and are proposed by different groups in order to detect the scintillation effect; although, it appears doubtful that these efforts can be successful, we lack a detailed study of the amplification/scintillation effect for realistic sources of gravitational waves. A study of the deflection and modulation of light by astrophysically generated gravitational waves in relation to the ground and space-based VLBI experiments is in progress. There are also observational/theoretical implications for scalar-tensor theories of gravity and for the issue of which conformal frame is physical in generalized theories of gravity.

## Quasars, Active Galactic Nuclei and Absorption Systems

*Do the central engines of quasars evolve by accretion?* : According to a currently popular paradigm, nuclear activity in quasars is sustained *via* accretion of material onto super-massive black holes located at the quasar nuclei. A useful tracer of the gravitational field in the vicinity of such central black holes is available in the form of extremely dense gas clouds within the broad emission-line region (BLR) on the scale of $\sim$ 1 parsec. Likewise, the radio sizes of the lobe-dominated radio sources are believed to provide a useful statistical indicator of their ages. Using two homogeneously observed (and processed) sets of lobe-dominated radio-loud quasars, taken from literature, *R. Srianand* and Gopal-Krishna (NCRA) have shown that a positive correlation exists between the radio sizes of the quasars and the widths of their broad $H\beta$ emission lines, and this correlation is found to be significantly stronger than the other well known correlations involving radio size. An important inference from this correlation is that over the lifetime of a typical powerful double radio source, the FWHM of the $H\beta$ emission line from the BLR undergoes an increase by roughly a factor of 3–4. This broad line is presumed to arise from the vicinity of the central super-massive blackhole (SMBH) and its width is commonly attributed to the gravitational influence of the SMBH.

If the matter is accreting on to the black hole at the Eddington accretion rate, the increase in the mass of the central blackhole with time would result in a similar increase in the luminosity.

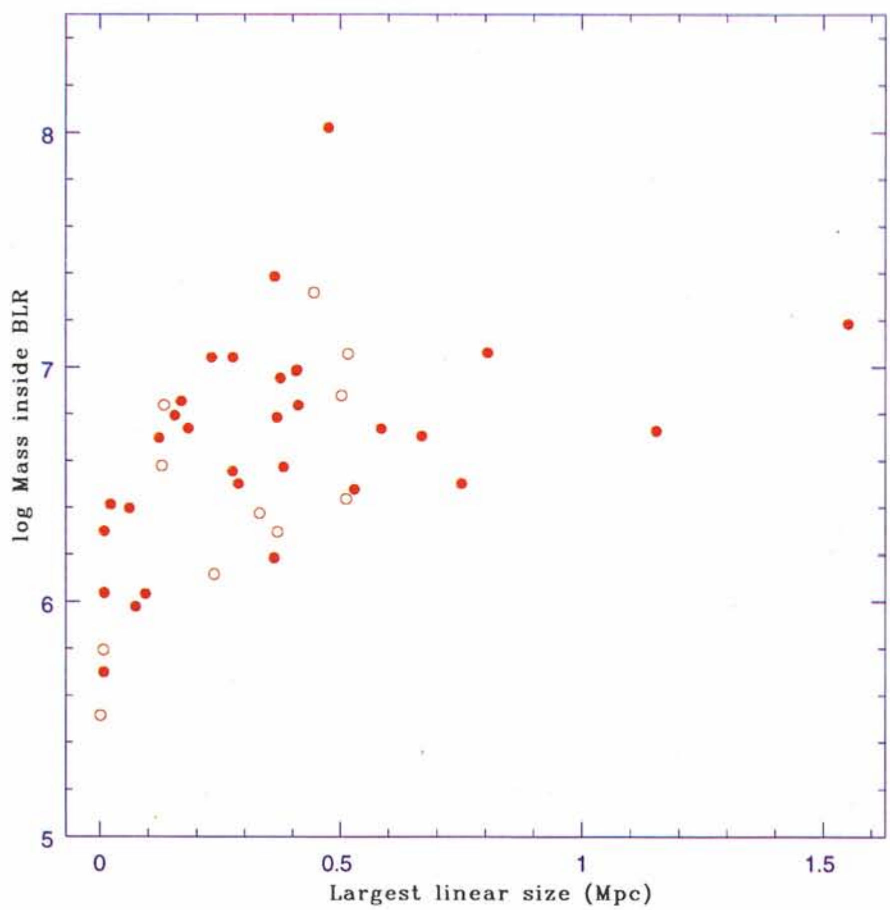


Figure 2: : Plots of radio size $(l)$ *versus* the mass of the central engine for the combined data set of *R. Srianand* and Gopal-Krishna(1998)

As a result, one would expect a positive correlation between luminosity and radio size, which is not evident in their combined data set. This weakens considerably the case for a persistent accretion at the Eddington rate. Using the well know relationship between the radius of the BLR and the bolometric luminosity one can write the mass of the central engine to be $M \propto v^2\sqrt{L_{46}}$ where $L_{46}$, is the bolometric luminosity expressed in the units of $10^{46} ergs^{-1}$.

The Figure 2 shows a plot of $M$ *versus* linear size, $l$, which is a measure of age of the quasar. A positive correlation between $M$ and $l$ at a $4.5\sigma$ level is evident in the figure. This suggests that over the life time of a typical radio quasar, the mass of the region inside the BLR does go up by about an order-of-magnitude. Thus, this preliminary investigation by *Srianand* and Gopal-Krishna suggests that there is a matter flow across the BLR into the central regions of the quasars. Also, the accretion onto the central black hole is not at a steady Eddington accretion rate throughout the life time of the quasars. Their study also suggests that in principle, using the bolometric luminosity of all the quasar, one can get the relationship between the mass accretion rate into the quasar and the mass flow across the BLR. This will be very important for understanding the formation and evolution of AGNs.

*Quasar absorption lines* : QSO absorption line systems probe the baryonic matter over most of the history of the Universe ($0 < z \leq 5$). The so-called damped Ly$\alpha$ (hereafter DLA) systems are characterized by a very large HI column density ($N(\mathrm{H\ I}) \geq 2\times 10^{20}$ cm$^{-2}$), similar to the one usually seen in local spiral disks. Though, some of the available observations tend to favour the damped systems to be produced by proto-galactic disks, hydro-simulations have shown that the progenitors of present day disks of galaxies could look like an aggregate of well separated dense clumps at high redshift. Although, the nature of the DLA systems is unclear, they trace the densest regions of the universe where star formation occurs. *Srianand* and his collaborators are investigating different properties of the damped Ly $\alpha$ systems using high resolution echelle spectra of quasars.

*(a) Molecules in the $z_{\rm abs}$ = 2.8112 damped system toward PKS 0528-250* : *Srianand* and Petitjean (IAP, Paris) have analysed a high resolution spectrum of the damped Ly$\alpha$ system at $z_{\rm abs}$ = 2.8112 toward PKS 0528-250 for which absorption redshift is slightly larger than the emission redshift of the quasar. This is one of the two high redshift damped Ly $\alpha$ systems in which the $H_2$ molecule is detected. They have identified and fitted all absorption lines due to different rotational and vibrational levels and estimated the column density of $H_2$ molecules to be $N(H_2) \sim 6\times 10^{16}$ cm$^{-2}$ and the fractional abundance of $H_2$ to be $f = 5.4\times 10^{-5}$ (Figure 3). The excitation temperature derived for different transitions suggests that the kinetic temperature of the cloud is about 200 K and the density in about $n \simeq 1000$ cm$^{-3}$. The cloud, therefore, has a dimension of about 1 pc along the line of sight. Since it obscures the broad-line emission region, its transverse dimension should be larger than 10 pc.

They have also obtained upper limits on the column densities of CI($< 10^{12.7}$ cm$^{-2}$) and CO ($< 10^{13.2}$ cm$^{-2}$; $N(\mathrm{CO})/N(\mathrm{H\ I}) < 7\times 10^{-9}$). They suggest that the ratio $N(H_2)/N(\mathrm{C\ I})$ is a useful indicator of the physical conditions in the absorber as the photoionization of CI and photo dissociation of $H_2$ are due to UV photons in the same energy range. They have constructed self

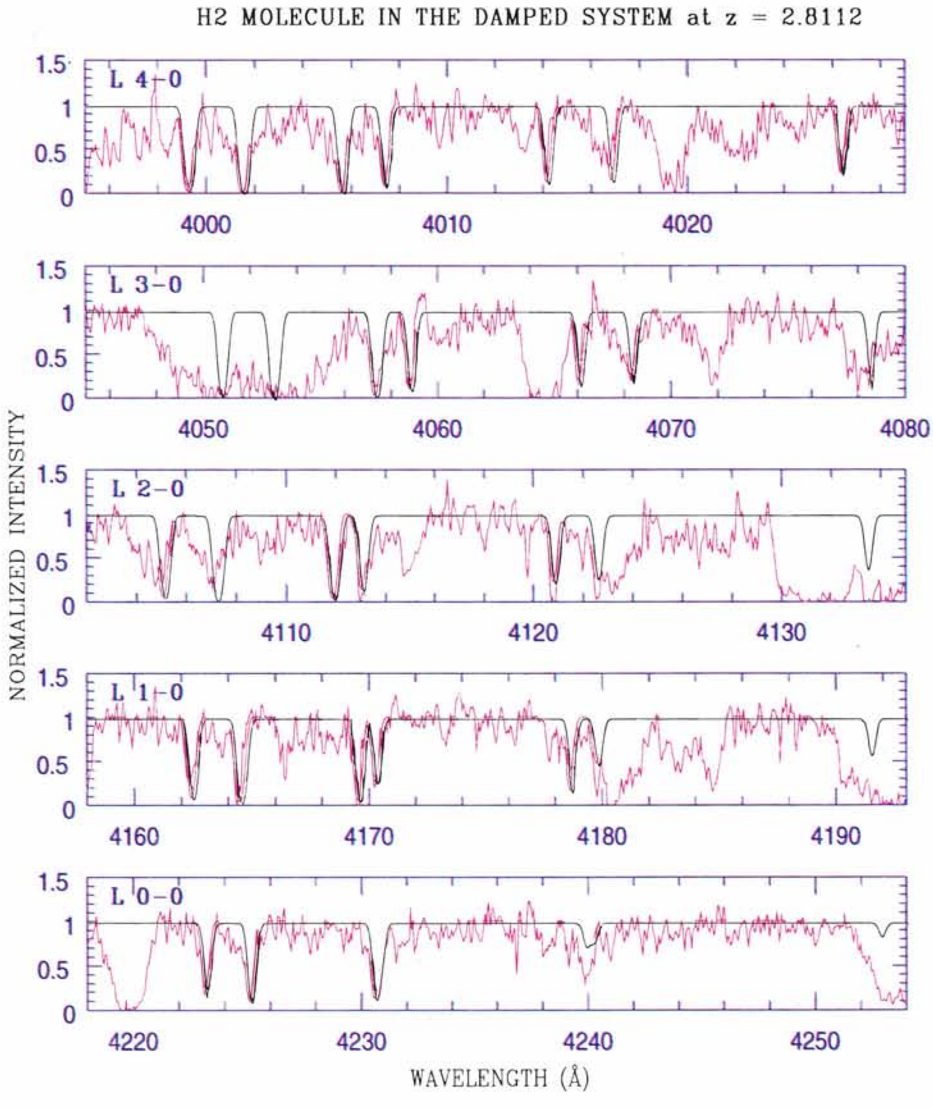


Figure 3: Fit results for a few rotational transitions of the $H_2$ Lyman absorption bands in the $z_{\rm abs} = 2.8112$ damped system towards PKS 0528–250 (*Srianand* & Petitjean 1998)

consistent models taking into account the ionization equilibrium of the gas and the formation and destruction of $H_2$ molecules simultaneously. Their models, assuming solar relative abundances, show that radiation field with spectra similar to typical AGNs or starbursts are unable to reproduce all the constraints and, in particular, the surprisingly small $N(\mathrm{CI})/N(\mathrm{H_2})$ and $N(\mathrm{MgI})/N(\mathrm{H_2})$ ratios. In view of the models which are explored, the most likely ionizing spectrum is a composite of a UV-"big bump" source (possibly a local starburst) and a power-law spectrum from the QSO that provides the X-rays. Dust is also needed to explain the production of molecules in the cloud. The amount of dust is broadly consistent with the [Cr/Zn] abundance determination.

*(b) Kinematic properties of damped Ly α absorption galaxies* : *Srianand* and his collaborators (Ledoux, Petitjean, Bergeron and Wampler) have investigated the line velocity profiles and the element abundances in five damped absorption systems. Nitrogen is found to have abundance less than silicon by an order of magnitude in three out of the five systems studied by them. It is important to recall that the ionization correction factor for nitrogen is always close to unity for log N(HI)> 20. Thus, the deficit of nitrogen could imply that the metal production in these systems are dominated by the massive stars. They found that an absorption system with $z_a = 2.6184$ system toward Q 0913-072 is characterised by low metallicities and simple kinematical structure. This system has [C/H]$\simeq$[O/H]$\simeq$ −2.7 and [Fe/H]$\leq$−3.5. If their estimates are not affected by saturation effects, which they believe is the case, then this system would be the one with lowest metallicity among all the known damped Ly$\alpha$ systems. By combining their sample with similar data available in the literature they studied the kinematics of the low and high ionization phases in a sample of 26 damped Ly$\alpha$ absorbers in the redshift range 1.17–4.38. They noted a strong correlation between the velocity broadenings of the Si II(1808) and Fe II(1608) transition lines irrespective of the line optical depth, implying that the physical conditions are quite homogeneous in the sample. Statistically, this shows that the large variations of abundance ratios and thus large variations of depletion onto dust grains are unlikely. The velocity broadening is correlated with the asymmetry coefficient for the velocities less than 120 km s$^{-1}$ indicating that the broader the line the more asymmetric. However, this correlation does not hold for larger values indicating that the evidence for rotational motions is restricted to velocity broadenings less than 120 km s$^{-1}$. The systems with velocity broadenings greater than 200 km s$^{-1}$ are peculiar with kinematics consistent with random motions and they show subsystems as those expected if their objects are in the process of merging. They noted a weak trend for the mean velocity broadening of the low ionization lines to decrease with redshift from 80 km s$^{-1}$ at $z < 2.2$ to 50 km s$^{-1}$ at $z > 2.2$. If confirmed with high statistical significance, this will provide a vital tool to distinguish between the models of damped Ly$\alpha$ systems. The kinematics of the low ionization and high ionization species are found to be correlated, though the high ionization phase has a much more disturbed velocity field than low ions.

*X-rays from AGN* : Recently, the detection of broad iron emission line has generated considerable interest. It has been proposed that the line is produced close to the central black hole and the line is broadened due to gravitational redshift. If this interpretation is correct, this would be the first direct observation of the effect of a strong gravitational field near a black hole. However, *R. Misra* and *A.K. Kembhavi* point out that the evidence is still not conclusive. They have shown that a high density cloud surrounding the source could also give rise to a similar line profile. Present observations do not rule out the presence of such a cloud.

Presently, there are several different models which predict similar X-ray spectrum of black hole systems. However, high resolution broad band observations of bright black hole systems (like Cygnus X-1) may be able to rule out some of these models. A step in this direction has been taken by *R. Misra*, V. Chitnis, and F. Melia, who show that the transition disk model fits the broad-band Cygnus X-1 spectrum better than the standard external photon Comptonization model.

One of the convincing observational evidence for black holes in AGN is that, unlike a regular compact star the thermal energy associated with matter accreting on to a black hole can be advocated (i.e., not radiated away from the surface). Generally, the presence of advective flow is inferred from modeling the X-ray spectrum. *R. Misra* has shown that multi-wavelength observations (i.e., optical/UV and X-ray) can also indicate the presence of an advective flow. Evidence for such an advective flow is presented for the black hole system, Nova Muscae.

*Formation of quasar black holes* : An interesting problem in the physics of active galactic nuclei is, how supermassive black holes needed in the standard model form. Cosmological simulations predict the formation of potential quasar sites at redshifts as high as $z = 8$. The corresponding density peaks involve massive self-gravitating clouds of cold gas that have collapsed to a scale below the spatial resolution ($\sim$ 1 kpc) of the simulations. It is not yet certain, how the gas further collapses beyond the centrifugal barrier and forms a massive black hole.

*A. Mangalam*, in collaboration with K. Subramanian (NCRA), has developed a model for formation of quasar black holes from a magnetized accretion of a collapsed disk which occurs in the three stages. In the first stage, an overdense region of mass $10^{10} M_\odot$ and $\Omega_b/\Omega \simeq 0.1$, collapses at $z = 8$. In the second stage, a gaseous disk forms with a radial extent of about one kpc and is spun up by tidal torques. An extensive star formation activity in the disk is assumed that provides turbulence and magnetizes the disk. It is shown that about $10^8 M_\odot$ accretes via small magnetic stresses in background potential of the dark halo, into a compact region of about one parsec in size. In the final stage, this self-gravitating compact region is unstable and excess angular momentum is removed due to braking by a field amplified by a dynamo.

The evolution of the disk gas is described by the usual accretion disk equations with the viscosity provided by magnetic fields. The first phase of accretion that occurs in the gravitational potential of the halo is calculated in some detail, whereas the second phase of the core collapse, caused by instabilities induced by self-gravity or by magnetic braking by large-scale fields, is treated approximately. The large-scale residual seed field in the initial magnetized gas can be about $10^{-9}$ $G$. For typical values of the parameters involved in the model, a supermassive black hole forms about $10^8$ yr after the initial collapse. This mechanism also provides a simple explanation of the observed mG field strengths in galaxies at redshifts $z \sim 2$.

## Radio Galaxies

One of the enduring mysteries of contemporary astronomy has been the reason, why a small fraction of elliptical galaxies become highly luminous and spectacularly endowed radio sources. These "radio galaxies" emit as much, or more, energy in the radio region of the spectrum than in the optical region. The radio power is emitted from a compact source located at the centre of the galaxy, and from two very large lobes situated on either side of the galaxy, with their size and distance from the galactic centre often being far larger than the galaxy itself. The energy for the radio emission is believed to arise in an active galactic nucleus (AGN), through accretion of matter onto a supermassive black hole. The energy, converted to the form of highly energetic particles is transported, to the distant radio lobes, by two narrow, relativistic beams, one towards each radio lobe.

Powerful radio emission arises in galaxies as well as in quasars. The latter are believed to be galaxies as well, except that the AGN is so bright that it outshines the galaxy. Radio galaxies are always observed to be ellipticals, even though powerful AGN also exist in spiral galaxies. A combination of a spiral and an AGN is called a Seyfert galaxy. This has all the properties of radio galaxies, but the radio emission present is nowhere near as powerful as in the radio ellipticals. The questions then are, what is it that makes the elliptical galaxies host of the radio sources, and in what way are the properties of radio ellipticals different from those of the normal elliptical galaxies?

*A. Mahabal* and *A.K. Kembhavi*, in collaboration with Patrick McCarthy have been studying a sample of radio galaxies with these questions in mind. They have obtained optical and near-infrared images of the radio galaxies using telescopes of the Carnegie Observatories situated in Chile. Using sophisticated image processing studies, simple mathematical models which describe the distribution of light in the galaxies and statistical analysis, a number of very interesting results have been obtained. They have found that in spite of harbouring a powerful AGN, radio galaxies have regular large scale structures, like normal galaxies, even when they are rather distant. But superposed on the regular features are signs of disturbance which occur much more often in radio galaxies than in the case of normal galaxies. The radio galaxies are found to have blue colours in their central regions, which indicates that there are bursts of star formation going on here, with young energetic stars contributing the blue light. Clouds of dust have been seen in different regions of the galaxy, particularly the central regions. The dust is discovered through the red colour that it endows the galaxy with, because it absorbs some of the blue light that is present.

While, there have been indications in the past of these properties of radio galaxies, the novelty with the approach here has been the use of a new criterion as the indicator of blue or red colours. This criterion depends on the overall distribution of light in the galaxy when viewed at different wavelengths. It provides a much more sensitive separation, than available before, between objects which are blue or red towards the centre. Using the new criterion, it is possible to show convincingly that radio galaxies are subtly different from normal galaxies, even when such a separation is not indicated by conventional techniques.

Through very careful modeling, it has

been found that several of the galaxies have a disk component to the structure. Such disks are not associated with elliptical galaxies, and these would be amongst the very few known examples of disky radio galaxies. The presence of such disks means that the host galaxy could be intermediate between an elliptical and a disk galaxy which has prominent spiral arms. While such arms are not directly visible, detailed image processing has indeed revealed spiral structure in a few cases.

The techniques adapted have made it possible to probe the inner regions of galaxies, generally not accessible to ground based telescopes because of the image spreading effects of the atmosphere. It has been found that starbursts as well as dust cohabit in the centres in different proportions, affecting the colours of the galaxies. The relationship of these features with the radio properties is under investigation.

*Optical content of the FIRST survey* : All galaxies are radio emitters at some level, but only a small fraction of them have strong radio emission of the kind described above. This is also true with quasars, and only about 10 percent of them emit significant amounts of radio emission. Attempts have been made several times in the past to detect weak radio emission from galaxies and quasars, to see where the boundary between weak and strong sources lies, and how the physical processes operating in the two kinds of sources are different.

A useful way to find and study faint radio sources is to survey the sky at radio wavelengths with high sensitivity so that faint radio sources are observed, and then to identify these with different kinds of optical objects. Some of the faint sources will correspond to intrinsically weak galaxies and quasars, while others will be powerful sources which are very far away. Such surveys, therefore, provide a means of finding very distant galaxies and quasars, which are difficult to find by other means.

The most sensitive radio survey which covers a large area of the sky is the FIRST survey. This covers 1/8th of the whole sky and has about a quarter of a million radio sources which reach a level as faint as one milli Jansky. *Y Wadadekar* and *A.K. Kembhavi*, in collaboration with Patrick McCarthy have undertaken a programme of identifying FIRST sources in a small part of the sky with optical counterparts. They have so far covered about seven square degrees with V and R filters, which correspond approximately to wavelengths of green and red light, with telescopes of the Carnegie Observatory situated in Chile, as well as a telescope of the Kitt Peak National Observatory. From this data, they have identified about 150 radio sources with galaxies and quasars. Identifications have also been carried out by matching positions of the FIRST radio sources with the positions of known quasars and active galaxies. In the process, they have discovered radio emission from 21 quasars which were previously not known to have radio emission. Detailed studies of the samples, as well as comparison with the predictions of models of the luminosity distribution of different classes of objects, is in progress.

## Gamma Ray Bursts

Recently, major advances have been made in our understanding of the over thirty year old enigma of gamma-ray bursts (GRB). These can be attributed mainly to the launching of the Italian-Dutch satellite BeppoSax in mid-1996. This satellite has the ability to provide accurate (3-5 arcminutes) positional information of a GRB within hours of its occurance. It then became possible to make follow up observations of relatively long-lasting afterglows in X-ray (lasting few hours), optical (few days) and radio (few weeks) wavelengths leading to a new era of GRB observations. Two among the major results of these observations are the extra-galactic nature of these bursts (and the implied extreme energetics) and the smallness of the burst sources ($\sim$ 100 km). Models based on coalescence of two neutron stars (or a neutron and black hole) existing as close binary systems in star-forming galaxies became very popular. Though, most of the energy released in such a coalescence will be carried away by neutrinos, a fraction of these neutrinos will produce electron-positron pairs which will expand into the surrounding interstellar medium as an ultra-relativistic fireball. Once the fireball sweeps up matter from the interstellar medium comparable in mass to the ejecta itself, shocks are produced.

This provides the mechanism for converting the electron energies to photons, thus resulting in the gamma-ray burst event. The afterglow is believed to be due to synchrotron emission from the electrons accelerating relativistically in the magnetic field tangled with the swept-up matter. The energy fractions in electrons and post-shock magnetic fields are assumed to be close to their equipartition values.

A turning point in the understanding of GRBs occured with the observations of the burst event of December 14, 1997, called GRB971214. This was the third GRB for which an optical afterglow was discovered and the first one for which a homogeneous set (same telescope and instruments) of observations could be made for the afterglow. Most of the observations were made with the Low Resolution Imaging Spectrograph (LRIS) on the Keck-II telescope on Mt. Mauna Kea in Hawai.

*A.N. Ramprakash* collaborated with the Caltech GRB team during his visit at Caltech between November 1997 and March 1998. The following is a summary of the results obtained in this collaboration :

The results of I-band and R-band photometric observations are illustrated in Figure 4. The I-band light curve closely follows a power-law and the best fitting curve is given by the equation $I(t) = 22.22(\pm 0.18) + 3.09(\pm 0.52)\log(t/\text{day})$ where I(t) is the I-band magnitude between epochs December 15-17 and it is the time elapsed in days since the burst event. This implies a power-law index for I-band flux decay equal to $-1.2$, allowing for the factor 2.5 involved in converting to the magnitude scale. Such a decay is quite consistent with the synchrotron emission models and has been observed in the case of earlier GRBs.

Afterglow models based on synchrotron, also predict that the flux should decay with the same power-law index at all wavelengths. Based on this assumption and using the R-band observation of December 16 to fix the zero-point, it was possible to obtain a fitting equation for the light curve in R-band. As seen in Figure 4, this curve fits the other R-band data very well till December 17. However, the last two R-band points deviate significantly from the extrapolation of this curve. These observations which were made on January 10 and February respectively, indicate that the light curve has stopped decaying as a power-law and is constant at $R = 25.6$ during these epochs. Besides, this source appears slightly extended when compared to nearby stars in the R-band image. Comparison of the positions of the I-band optical transient (OT) and the R-band constant source, relative to several nearby stars show that

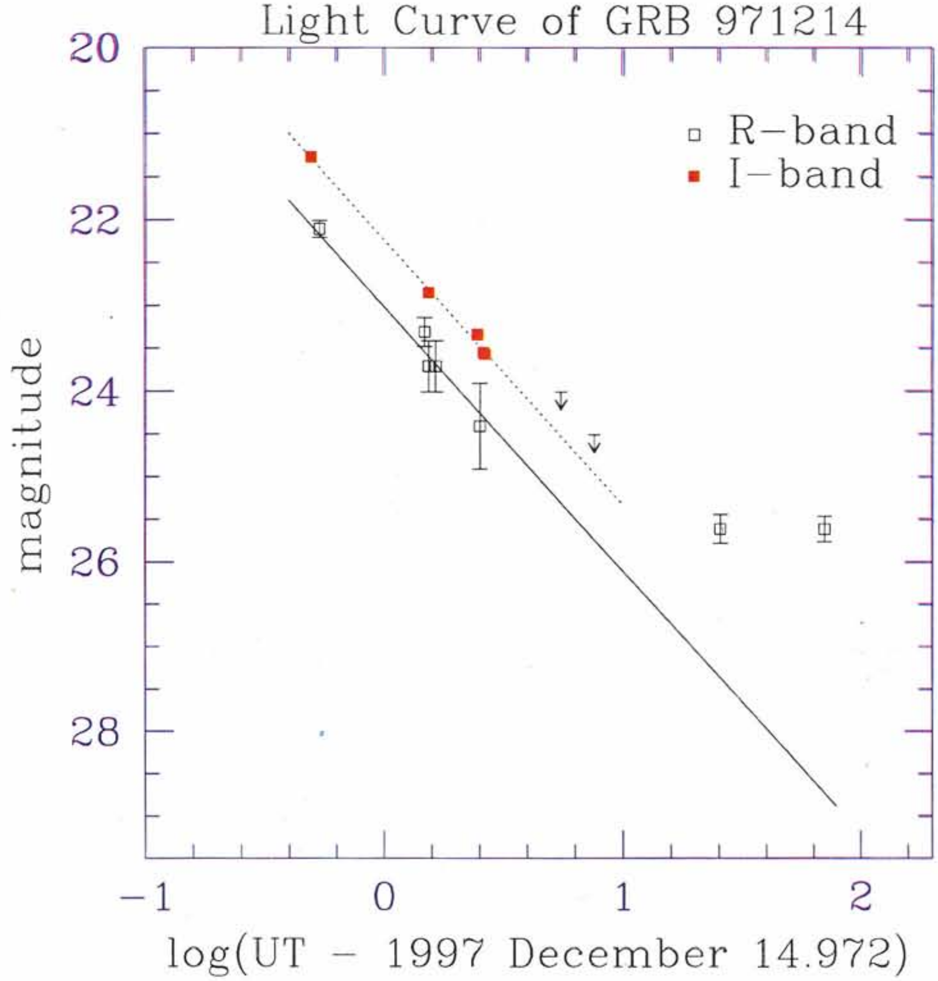


Figure 4: The R- and I-band light curve of the optical transient (OT) of GRB 971214. The OT is identified in Figure 1. The x-axis is $\log(t - t_0)$ where $t$ is the UT date of the observation and $t_0$ is the UT date of the gamma-ray burst. All times are measured in units of days. The GRB took place on UT 1997 December 14.9727. At I-band the OT is well detected for the first three nights. Upper limits exist for the night of UT 1997 December 20 and December 22. The dotted line is a linear least squares fit to the I-band data but restricted to these first three nights. The assumed model is $\mathrm{I}(t - t_0) = \mathrm{I}_1 + s\log(t - t_0)$; here I is the magnitude at time $t$ and $s$ is the slope and $\mathrm{I}_1$ the offset. The fits yield $\mathrm{I}_1 = 22.22 \pm 0.18$ and $s = 3.09 \pm 0.52$. For reasons discussed in the text it is reasonable to assume that the R-band light curve has the same slope, $s$. The solid line is parallel to the dotted line but goes through our R magnitude of UT 1997 Dec. 16.63. This line does an adequate job of describing the R light curve for the first three nights. clearly, the Dec. 15.50 point of Henden et al. is not well accounted by this model. The R-band measurements of 1998 January 10 and February 24 10 January lie well above the extrapolation of the dotted line. We attribute this excess over the decaying optical transient as arising from galaxy K shown in Figure 1. In both the January 10 and February 24 images, the full width at half maximum (FWHM) of K is 1.07 arcseconds which is larger than the same estimated from stars in the vicinity of K. The rough size of K is thus about 0.65 arcseconds.

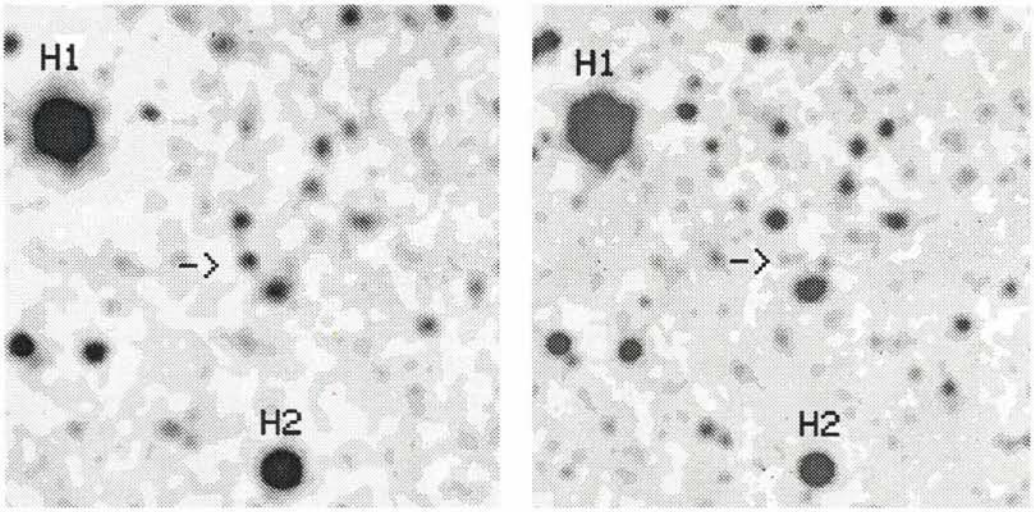


Figure 5: **Left:** I band image of the field of the optical transient. I band image of the field of the optical transient (OT) of GRB 971214. The image is 3.5 arcmin by 3.0 arcmin and has been smoothed by a Gaussian of full-width at half maximum of 0.53 arcseconds. The numbered stars are "secondary" stars used for achieving consistency within our various data sets. Stars H1 and H2 allow us to link our photometry with that of Halpern et al. and Henden et al. The "rays" are light from the bright star (6.7 mag.) SAO 15663 diffracted by the telescope structure; this bright star (6.7 mag.) is about one arcminute NE of the optical transient. The rays rotate as the telescope tracks the source. Image of the OT in I-band obtained from data taken on December 16, 1997 UT. The image is a square of size 1 arcminute. The image has been smoothed by a Gaussian with FWHM of 0.53 arcseconds. The OT is marked. (*Right*) Image of the field of OT in R-band obtained from data taken on January 10, 1998 UT. The image is a square of size 1 arcminute.
**Right:** The image has been smoothed by a Gaussian with FWHM of 0.53 arcseconds. An extended object is seen at the position of the OT. We suggest that this is the host galaxy of GRB 971214. For all three images North is to the top and East to the left. We have also obtained the spectrum of of the galaxy about 4.5 arcsecond to the NE of the OT. m the OT. The spectrum shows a prominent [O II] 3727 emission line and the usual absorption features at a redshift of 0.5023.

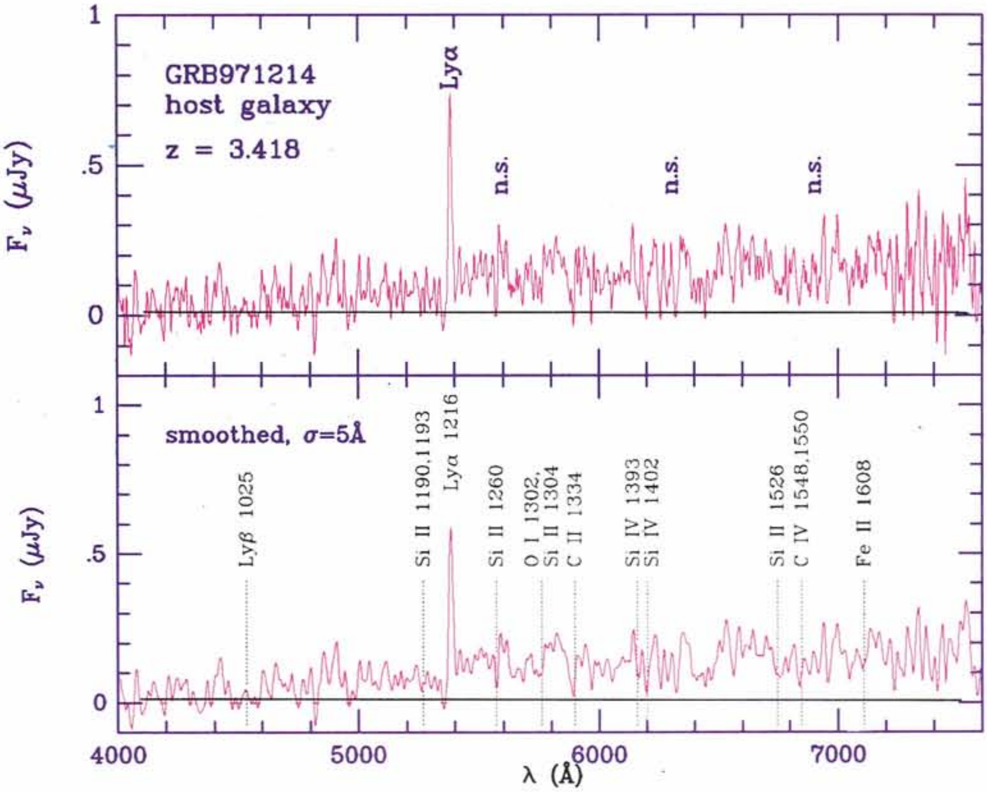


Figure 6: The composite Keck spectrum of the host galaxy of the GRB 971214. The top panel shows the original data, with the locations of the prominent night sky (n.s.) emission lines as indicated. The bottom panel shows the same spectrum smoothed with a Gaussian with $\sigma = 5$ Å, which is approximately equal to the effective instrumental resolution. Locations of several absorption features commonly seen in the spectra of $z \sim 3$ galaxies are indicated. The redshift, $z = 3.418$, has been derived from the mean point of the Ly$\alpha$ emission and absorption features, as described in the text. The "lower" resolution data were reduced completely independently by two of the authors (SGD and KLA), using independent reduction packages. The results are in an excellent mutual agreement. The "higher" resolution data are also fully consistent with them, showing essentially the same spectroscopic features. The useful wavelength range spanned by the lower resolution data is approximately 4000 to 7600 Å, and of the higher resolution data approximately 4900 to 7300 Å. All of the spectra have been averaged with the proper signal-to-noise weighting, after the suitable resampling.

they are at the same position in the sky; relative offset between the OT and the constant source is about $0.06 +/- 0.06$ arcsec (see Figure 5). It is to be noted that the probability of finding a $R < 25.6$ galaxy by chance, within even 0.35 arcsec of the OT, is only about $10^{-3}$. Thus, it is concluded that the R-band source is actually the host galaxy of GRB971214.

In the upper part of Figure 6 is shown the spectrum of the host galaxy obtained on February 24. The presence of only a single prominent emission line, the continuum drop immediately blueward and the slowly rising continuum redward of this line, suggestive absorption dips at the expected locations of interstellar gas absorption lines, all indicate that the single emission line is redshifted Ly-alpha at a rest-frame wavelength of 1215.7 A. The redshift of the galaxy can then be estimated as $3.148 +/- 0.010$ after correcting for Ly-alpha self-absorption effects and air to vacuum conversion.

Assuming a standard Friedman cosmological model with $H_0 = 65$ km per s per Mpc and $\Omega_0 = 0.3$, this redshift gives a luminosity distance of $9.7 \times 10^{28}$ cm. An extrapolation using the observed red continuum slope (index $-0.7$) and the observed R-band magnitude, gives a rest-frame B-band absolute magnitude of $-20.9$ for the galaxy. This is quite similar to the absolute magnitude of a typical star-forming galaxy today. Besides, estimates of star-formation rate from the observed Ly-alpha flux provide a lower limit of about $1.0 +/- 0.5$ solar mass per year. Thus, on the whole, the properties of this galaxy are typical of the known systems at comparable redshifts.

The gamma-ray fluence of GRB971214 as observed by the Gamma-ray Burst Monitor on board BeppoSax is about $1.0 \times 10^{-5}$ erg cm$^{-2}$. Thus, the isotropic energy loss in gamma-rays alone at the distance to the host is about $3 \times 10^{53}$ erg. The currently favoured neutron star coalescence model for GRBs predict that about $10^{51}$ ergs will be released in the form of electromagnetic waves which turns to be true in the case of GRB971214. Thus, the measured fluence of GRB971214 when combined with the estimated redshift for the GRB appears to be inconsistent with the expectations of the neutron star merger models in their simplest incarnations. However, more elaborate versions of this model or beaming effects of the afterglow may potentially reduce the strain on the energy budget.

According to the models discussed here, the afterglow emission is supposed to arise from non-radiative shocks; that is, the efficiency of the shock in converting the total energy of the burst to afterglow radiation is low. Thus, the evidence presented by GRB971214 favours GRB models which produce energy vastly in excess of $10^{51}$ erg, usually assumed by many practitioners in the field. The afterglow emission is similar in nature to the emission from supernovae, but is more energetic by two orders of magnitude. Following the naming sequence, nova and supernova, it is only appropriate to refer to GRB afterglow as hypernova.

## Observational Cosmology

*Gravitational lensing*: Most studies of the large-scale distribution of matter in the universe rely on observations of galaxies, i.e., conglomerations of light-producing stars. To probe the distribution of matter, which is overwhelmingly dark, one needs to directly map the gravitational field that matter generates. 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. The study of gravitational lensing, therefore, has become one of the most valued tools in surveying the universe and understanding its constituents and its evolutionary history.

*Tarun Deep Saini* and *S. Raychaudhury* have been working on several problems related to gravitational lensing. They have suggested the use of supernovae in the giant arcs magnified by gravitational lensing to measure distances to distant supernova-bearing galaxies. This can serve as a further step in the distance ladder. They have also cast the lensing formalism in a complex notation, which brings new insight into the effects produced by lensing. This formalism enables one to obtain equations which are useful in connection with weak lensing, which is the effect produced by matter on light far away from the high concentration of matter. In addition, it seemingly gives us a new way of deriving several other useful results (e.g., bending angle) in a simple manner and possibly can be used to generalize a few of them.

*Studies of clusters and superclusters* : The abundances of richest clusters, which represent rare large fluctuations in the distribution of visible matter in the universe, can be used to provide a stringent constraint on cosmological models. In particular, upper bounds to the average mass density $\Omega_0$ can be obtained if the value for mass fluctuations in a sphere of radius $8h^{-1}$ Mpc is known.

*S. Raychaudhury* and Mridula Chandola (University of Pune), together with Andrea Prestwich (Center for Astrophysics), have been analyzing optical CCD photometry, X-ray observations, redshift data and other observations of the richest optically-selected clusters to determine their mass, luminosity function, velocity structure and status of dynamical equilibrium and relate them to similar parameters for a sample of poorer clusters.

*S. Raychaudhury* has also been involved in the study of the two of the richest superclusters of galaxies within $z = 0.1$, the Shapley supercluster and the Horologium supercluster, through optical and x-ray observations. Together with Bill Forman and Christine Jones (Center for Astrophysics), he has obtained and analysed ROSAT and ASCA images of several clusters of galaxies in these superclusters. Using the x-ray images of these clusters, they are studying the evolution of the hot intergalactic medium in the densest environments, where clusters and subclusters are known to be merging at the present epoch. They have been relating these data to the optical observables and dynamical information to investigate several aspects of galaxy and cluster formation.

## Galactic Dynamics

*Stellar dynamics around black holes in galactic nuclei* : The centres of some galaxies display strikingly non symmetric distributions of stars, in particular, M31 and NGC4486B possess double nuclei. Other galaxies might also exhibit similar structures, if only we could view them with sufficient angular resolution. Most galaxies probably harbour central, supermassive black holes, and it is likely that these non symmetric features lie within the region where the gravitational influence of the central black hole dominates over the self-gravity of the stellar cluster—this seems to be hold for M31 and NGC4486B. *S. Sridhar* and J. Touma have developed an "averaging" technique to classify orbits of stars that are bound to central black holes in galactic nuclei. The stars move under the combined gravitational influences of the black hole and the central star cluster. Within the sphere of influence of the black hole, the orbital periods of the stars are much shorter than the periods of precession. Averaging over the fast orbital motion produces an extra integral of motion for slow, precessional dynamics, which is the product of the black hole mass and the semi-major axis of the orbit. Thus, the black hole enforces some degree of regularity in its neighbourhood. Well within the sphere of influence, planar, as well as three dimensional, axisymmetric configurations, both of which could be lopsided, are integrable; further, fully three dimensional clusters with no spatial symmetry whatsoever must have semi-regular dynamics with two integrals of motion. Similar considerations apply to stellar orbits when the black hole grows adiabatically. *Sridhar* and Touma introduce a family of planar, non-axisymmetric potential perturbations, and study the orbital structure for the harmonic case in some detail. In the centered potential, there are essentially two main families of orbits: the familiar loops and lenses, which were discussed by them. Resonant loops emerge when the potential is lopsided; these might be the orbits needed for the construction of lopsided, eccentric, discs around black holes, such as in M31 and NGC 4486B.

*Dynamical model of violently relaxed spherical systems* : Elliptical galaxies are expected to have undergone violent relaxation, a process wherein the energy and angular momenta get redistributed by strong potential fluctuations in a central core in such a way that it depends mainly on the macroscopic quantities of the initial conditions, which could be merging galaxies. This is indicated by N-Body experiments where under a variety of initial conditions, the final state has the observed $R^{1/4}$ surface density profile. Several interesting attempts to guess at this final state using ideas of phase mixing have been made. However, the relaxation process does not proceed to completion and it has been recognized that the dynamics of the relaxation process picks out the final state.

Motivated by Scott Tremaine's suggestion, *A. Mangalam*, in collaboration with *S. Sridhar* and R. Nityananda (Raman Research Institute) have developed a model using a distribution function, which is a function of radial period including a strict pericenter cutoff. This is based on an expectation from dynamical arguments that only orbits whose pericenters lie inside a certain core radius remain bound and this population is proportional to the number of crossings within the cutoff radius during the time that the relaxation process lasts.

A good testing ground for such a hypothesis are spherical systems which are the simplest realisations of elliptical galaxies. Calculations using the distribution $(-E)^{3/2}$ as an approximation to the radial transit frequency with a pericenter cutoff radius yields the asymptotic behaviour of $\rho \simeq r^{-4}$ in agreement with the results from simulations. This initial model served as a good guess to an iterative numerical scheme for obtaining the final density distribution.

*Statistical mechanics of two-dimensional gravitating systems* : The statistical behaviour of $N$ particles interacting through Newtonian gravitational force differs significantly from the behaviour of the other many body systems such as neutral gases and plasmas. The central feature of gravitating system, in contrast of normal many body systems, is the non-extensive nature of the energy. This, in turn, requires the physical description for the gravitating systems to be microcanonical.

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

*Ali Nayeri* has studied some properties of this two dimensional system by introducing a toy-model which was originally introduced by *T. Padmanabhan* in three dimension based on a simple Hamiltonian, describing two particles of finite size, confined inside a box. This system shows several important properties of more complicated systems. The very interesting feature of this $2D$ system is that the thermodynamic functions are all calculable analytically which contrasts the thermodynamical behaviour of $3D$ confined binary system. The *"isothermal cylinders"* for these systems are remarkably similar to a simple toy model and one can show that the system cannot exist at $T < T_c$ where $T_c$ is given by $T_c = (1/2)Gm^2$. *Ali Nayeri* also found that by putting the short distance cutoff, in contrast to $3D$ case, the specific heat of the system would become negative in some intermediate temperatures.

*Stellar and galactic dynamics* : At least ten dwarf spheroidal galaxies are known to orbit the Milky Way galaxy at distances ranging from few tens to a few hundred kpc. On the sky they represent barely discernible enhancements in stellar density, but some have internal substructure and appear flattened. Much theoretical argument about the formation of galaxies rely crucially on the supposed existence of dark matter in these systems. The evidence for this rests on the measured velocity dispersion of stars belonging to these dwarf galaxies.

Measuring redshifts of hard-to-resolve stars in galaxies that are barely visible compared to the background, is a difficult job. These velocity dispersions thus have to depend on the measured redshifts of a few stars per galaxy, the errors on individual measures being not very different from the values of the dispersions themselves (about 10 km/s). Together with Rajesh Deo, *S. Raychaudhury* has been attempting to assess the evidence for dark matter in two of these dwarf spheroidal galaxies, Draco and Ursa Minor, using a maximum likelihood technique, using the measured redshift data and some information about the orbits of stars in these systems.

## Galaxy and Interstellar Medium

*Interstellar dust and extinction by porous grains* : It is now well established from observations by space probes, etc. that the interstellar dust grains are of porous and fluffy nature. *Ranjan Gupta* and Vaidya over past two years have been using Discrete Dipole Approximation (DDA) method to study the effect of light scattering by porous graphite and silicate particles and have been applying their extinction properties to explain the observed interstellar extinction curve. Recent results of this study (see Figure 7) show that the observed extinction curve agrees well with a best fit obtained from a linear combination of a mixture of graphite and silicate dust grains over the large wavelength region extending from $0.10\mu$m in the UV to $3.40\mu$m in the near-NIR. The shape of the dust grains is assumed to be prolate spheroid with 4088 number of dipoles, as shown in the Figure 8.

*Observations of dark molecular clouds by imaging polarimeter* : It is believed that some of the dark molecular clouds (also called Bok Globules)

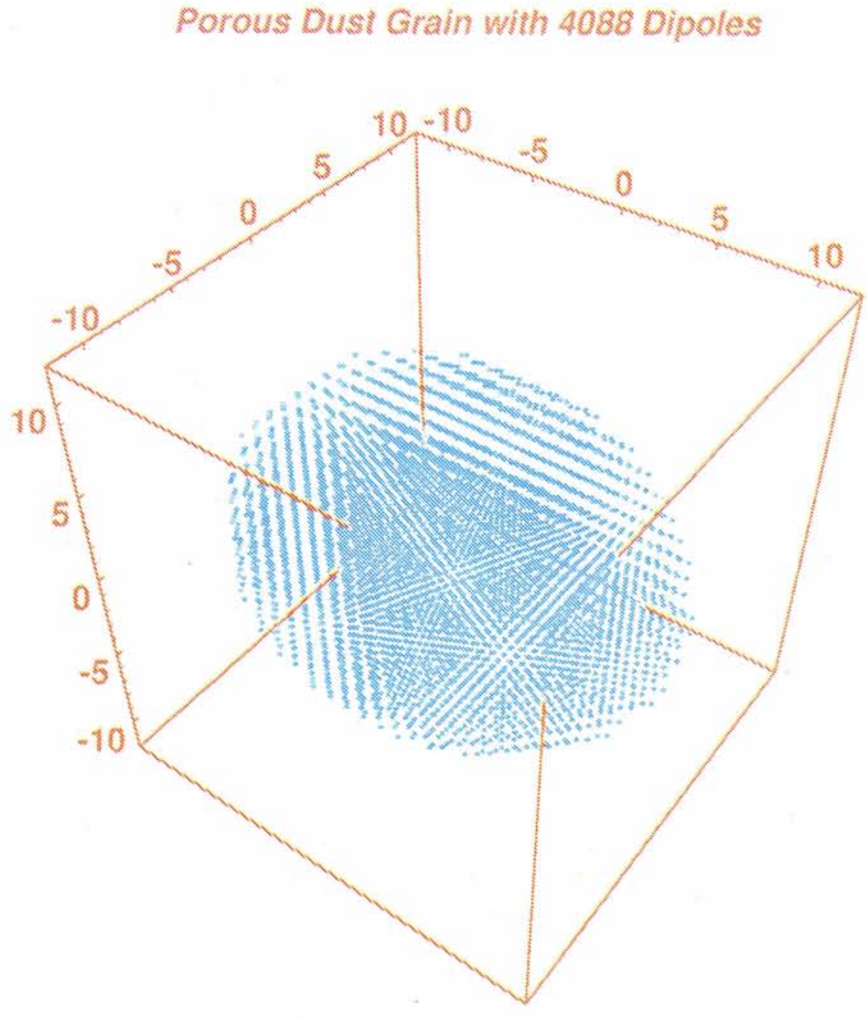


Figure 7: A 3-D view of the shape of the dust grain with 4088 dipoles.

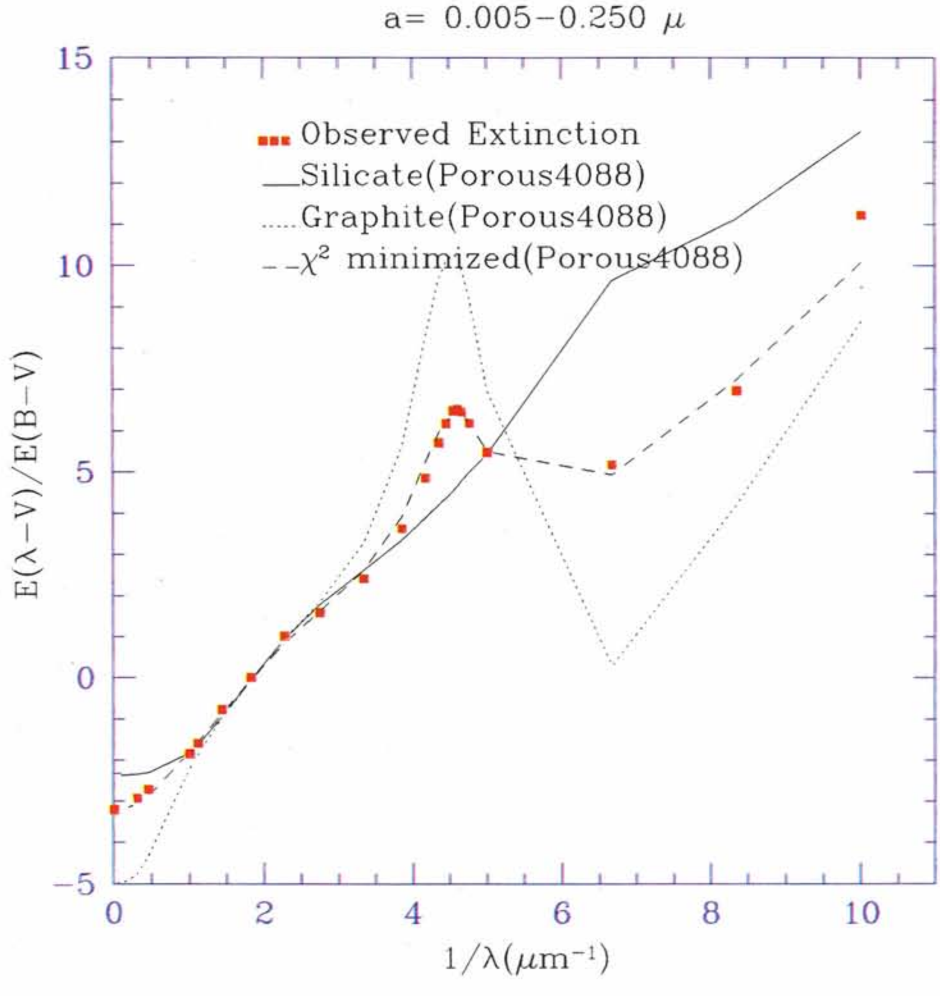


Figure 8: Comparison of interstellar extinction curve with the best fitted model combination curve of porous Graphite and Silicate grains with n=4088 dipoles.

are promising sites for star formation. The clouds collapse gravitationally and the ambient magnetic field plays an important role in the star formation process. These clouds themselves do not radiate in the optical band but making polarimetric observations of the stars in the background of the clouds has been found to be a powerful tool to investigate the magnetic field in the regions. The light of the background stars passes through the cloud and gets scattered by the magnetically aligned non-spherical dust grains present in the cloud. This scattering causes linear polarization and thus, can be measured to give information on the magnetic field structure, its role in the cloud collapse and star formation and the nature of the dust grains.

*Ranjan Gupta, A.N. Ramaprakash*, A. Sen and *S.N. Tandon* have undertaken an observing programme to cover various such small molecular clouds from the published catalog of Clemens and Barvainis, using the IUCAA imaging polarimeter IMPOL. (The details of this instrument were reported in the last year's annual report). The instrument is now permanently kept at Infrared Observatory, Guru Shikhar, Mt. Abu, where a 1.5 metre telescope is run by Physical Research Laboratory, Ahmedabad. Around a dozen clouds from this catalog have been already observed in the past observing runs.

## Fluid Mechanics

*Dynamics of fluids* : The mixing of passive tracers by a turbulent velocity field is a problem that arises in many fields. The physical context could, for instance, be the mixing of entropy fluctuations in the earth's atmosphere, or electron density fluctuations in the interstellar medium. A new formulation of the problem of advection and diffusion of a passive tracer by an arbitrary, incompressible velocity field has been developed by *S. Sridhar.* A Wiener path integral is employed to prove that the problem is *identical* to the diffusive dynamics of a charged particle in electromagnetic fields constructed from the velocity field. In the limit of small diffusion (WKB), classical paths offer a graphic description of tracer dynamics; the optimal paths, obtained in the limit of zero diffusion, are the integral curves of the velocity field. For the simple case of tracer advection–diffusion in the flow field of a time–independent, straight vortex line, the optimal paths are shown to be unstable to diffusive fluctuations. Generalisation of the path–integral principle to the case when tracer sources/sinks are present is also possible. When the velocity field obeys the Navier–Stokes equation, the associated electromagnetic fields satisfy the equations of magnetohydrodynamics for a fluid with resistivity equal to the viscosity of the (real) fluid.

## Stellar Physics

*Neural network for stellar spectral classification* : Over the past few years, *R. Gupta* and R. Gulati have evolved schemes based on artificial neural network (ANN) for classifying large stellar spectral database. Recently, applications of ANN have been extended by this group to newer areas viz. obtaining effective temperature of dwarf stars and E(B-V) determination of O and B type stars which were reported in the last year's annual report. In the past year, *Gupta*, Singh and Gulati have further explored these schemes and used principal component analysis (PCA) method as a preprocessor before applying ANN to the optical data base. The Figure 9 shows that the original spectra

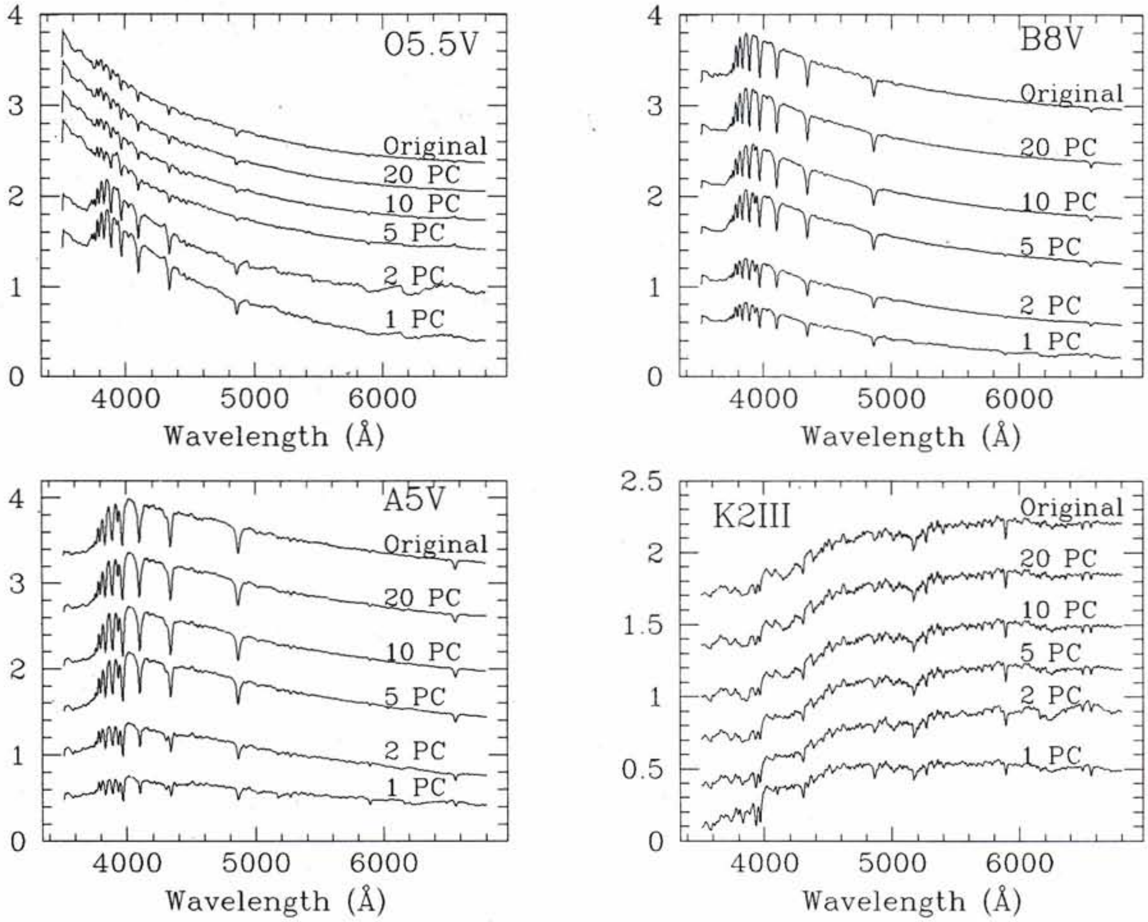


Figure 9: Reconstruction of four different spectral types out of the test spectra using the first twenty, ten, five, two and one principal components (PCs).

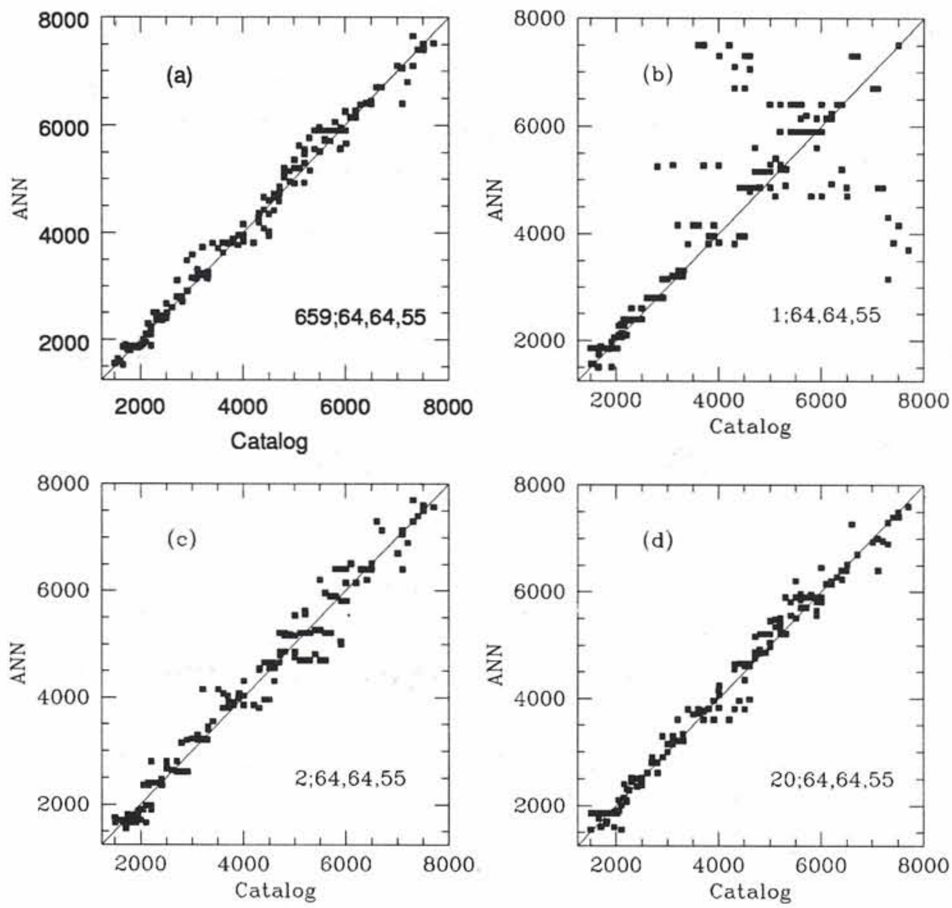


Figure 10: Scatter plots of spectral classification for four different cases viz.(a) original 659 wavelength points, (b) 1 PC, (c) 2 PCs and (d) 20PCs.

of four different spectro-luminosity classes can be reconstructed effectively by 20 principal components (PCs). Thus, using a much reduced data set (consisting just 20 components per spectrum), the classification accuracies show an improvement in the overall performance as compared to the original work where full spectra were used (see Figure 10).

## Instrumentation

*CCD Camera* : CCD cameras cooled by liquid nitrogen are the most common detectors used for optical astronomy. During the last year, two designs of controllers for CCD cameras have been developed. The second of these designs uses fibre-optic link with the host computer, in order to give trouble free communication over a distance of upto hundreds of metres between the computer and the camera at the focal plane of the telescope. *P. Chordia, D. Gadre, T. Deoskar*, and *S.N. Tandon* have continued the development of a more versatile CCD controller.

A controller is being developed which uses DSPs for communication with the host controller as well as for setting the clocking for the CCDs in real time; this setting of the clocking allows optimal reading of the CCDs for the specific conditions and use. For example, in order to save time and storage space, only a small part of the CCD could be read; or a faster read out could be carried out at the expense of an increased read noise; or one could try to optimise the operating voltages. The design also allows for simultaneous reading of upto eight outputs from a single or multiple CCDs.

*Imager Spectrograph for IUCAA Telescope* : The weather during the observations always has some uncertainty, and hence it is not possible to predict in advance if the conditions would be good enough for a particular kind of observations. In particular, it is hard to be sure that photometric conditions would prevail during an entire night. Therefore, there is some 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). Therefore, *H.K. Das, R. Gupta* and *S.N. Tandon* have been working to develop an efficient imager spectrograph for the optical band, in collaboration with the CSIO at Chandigarh, and Copenhagen University Observatory at Copenhagen.

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 design of the optics has been developed as an adoption of the original design provided by Bernard Delabre of ESO. The optics would be fabricated at CSIO and the mechanical structure and the controls of the spectrometer would be made by the Copenhagen University Observatory. The Council of Scientific and Industrial Research, and the Department of Science and Technology are providing financial support for this project.

# (II) RESEARCH BY ASSOCIATES

This account is based on the reports received from 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 responded in time and so this account is unavoidably incomplete.

## Solar and Stellar Pulsations

### M.K.Das

The internal structure and dynamics of a star results in a desecrate sets of frequencies of normal modes of oscillation. The observed global oscillations of Sun have led to the development of helioseismology to probe the Solar interior. This is made possible because the spectrum of solar oscillations is rich and complex. Recently, a stochastic mechanism for Solar modes has been proposed as the modal amplitudes are very small. Das extended the stochastic nonlinear oscillation study made earlier (Ap. J, 1996, **463**, 694) to the case of nonlinear nonradial Solar p-modes. Estimates of the mean square displacement (MSD) of nonlinear nonradial p-modes of various degree were made for different values of the stochastic excitation parameter.

Recently, the problem of ordering chaos with disorder has been extended to stellar pulsations. The basic idea came from the pioneering work of Braiman, et al. (Nature, 1995, **378**, 465) wherein a random disorder is shown to induce regularity in a dynamical system. Since, the outer convective region of a variable star affects the pulsation characteristics, it could be shown that the basic effect of convection as modelled by a Lorenz model, results in various windows or domains where the pulsation could be regular and chaotic.

### G. Ambika

The light intensity curves of certain variable stars show irregular behaviour which, in a few cases, has been shown to be low dimensional chaos. In collaboration with A.K. Kembhavi, Ambika has started a research program to look into this problem in an exhaustive way by choosing variable stars in different stages of evolution. The magnitudes of such stars form a time series that can be used for computing all the usual quantitative measures of complexity like entropy, embedding dimension, Lyapunov exponents, etc. The required data for a few stars have been obtained from the American Association for Variable Star Observation (AAVSO) and the early analysis regarding dressing up of data are done and the computation of the various measures is in progress.

### Harinder P. Singh

The region of vigorous convective motions beneath the solar surface has been a dominant source of uncertainty in the modelling of the structure and oscillations of the Sun. The discrepancy between the frequencies of the standard Solar models and the observed frequencies arises mainly because of the inaccurate treatment of convection. There is no agreement also on the amount of overshooting of these convective motions into the radiative interior at the bottom of the convection zone. H.P. Singh with his co-workers I.W. Roxburgh and K.L. Chan performed full three dimensional simulations of turbulent compressible convection with a view to study the amount of overshooting at the bottom of a stellar-type convective envelope. Scaling relations between the overshooting distance and the vertical velocity were examined. Initial models were tested on the DEC Alpha 3000 at IUCAA before running on the CRAY J90 at RAL, UK and Origin 2000 at UST, Hong Kong.

## Quasars

### P. Khare

P. Khare with S. Das studied the intensity of the intergalactic ultraviolet (UV) radiation background at high redshifts by performing proximity effect analysis of the high and low resolution data of absorption lines in quasi-stellar objects (QSOs). They calculated the decrease in the expected number of Lyman alpha lines near the QSOs due to the increase ionization by the QSO flux, taking into account the detailed frequency and redshift dependence of the background. The effect of resolution, the detailed shape of the column density distribution of Lyman alpha lines and the error in system redshift of the QSOs was studied. They concluded that the estimated intensity of the background is consistent with that contributed by the observed QSOs and an additional, dust extinct, population of AGNs may not be necessary. P. Khare with S. Ikeuchi studied the ionization and abundance of silicon (SI) and carbon (C) at high redshifts. They did not find any evidence for a systematic or abrupt change in the ratio of column densities of CIV and SiIV, in the heavy element absorption systems in QSOs, with high redshifts. They compared the results of photo-ionization models, constructed for different expected shapes of the background, with the observed column density ratios in different classes of the QSO absorption lines. They concluded that no overabundance of Si relative to C is present in the intervening absorbers if the stellar sources contribute significantly to the background. An overabundance is, however, present in the Lyman alpha forest lines and in systems associated with the QSOs.

## Spectroscopy

### R. Ramakrishna Reddy

Spectroscopy happens to be the most versatile remote sensing tool of astronomers. Spectroscopic investigators have revealed the existence of YO in various astronomical sources. Davis (1947) and Lin (1949) have reported YO bands in the star $\beta$-Pegasi and in the spectrum of $\xi$-Cygni. Band head measurements have established the presence of CrO in $\beta$-Pegasi which belongs to the spectral class $M_2$. The disc spectra of Sun spots show the bands of CrO. The bands of ScO are observed in M-type stars as well as in disc and spot spectra (Babcock, 1945). Different bands of A-X system of the AIO have been found in the Umbral spectrum and in M-type stellar spectra. In view of the astrophysical importance of these molecules, R. Ramakrishna Reddy has obtained the potential energy curves for the electronic ground states of YO, CrO, BN, ScO, SiO and AiO using the RKRV method. The dissociation energies were determined by curve-fitting techniques using the five-parameter Hulburt-Hirschfelder function. The estimated $D_0$ values were found to be in reasonably good agreement with values in the literature. The r-Centroids and Franck-Condon factors for the bands of $B^2\Sigma^+ - X^2\Sigma^+$ of YO, $B^5\Pi X^5\Pi$ of CrO, $A^3\Pi - X^3\Pi$ of BN, $B^2\Sigma^+ - X^2\Sigma^+$ of ScO, $E^1\Sigma^+ - X^1\Sigma^+$ of SiO and $D^2\Sigma^+ - X^2\Sigma^+$ and $B^2\Sigma^+ - X^2\Sigma^+$ of AiO molecules were determined. The Franck-Condon factors were evaluated by the approximate analytical method of Jarmain and Fraser. The absence of the bands in these systems was explained.

## Radiative Transfer

### Suresh Chandra

Suresh Chandra along with his research students, A.K. Sharma and Rashmi has been working on transfer of radiation in Interstellar Molecular Clouds. This group is mainly interested in cyclic molecules observed in cosmic objects. Out of about 100 molecules observed in the cosmic objects, three molecules, $SiC_2$, $C_3H_2$ and $C_3H$, were found having ring structure. Suresh Chandra and Rashmi have recently calculated Einstein A-coeffcients for rotational transitions in the ground vibrational state of $SiC_2$. These coeffcients are now being used in the investigation of transfer of radiation in $SiC_2$ molecules in specific astronomical objects.

## Dust Grains

### D.B. Vaidya

It has long been established that the ratio R of total to selective extinction is anomalously large, i.e. $> 5$, in certain regions of the interstellar medium. These large values of R have been attributed to large grain sizes; i.e. $\geq 0.2\mu$m, in these regions of anomalous extinction. These grains could have grown larger than normal size due to coagulation in which a single grain consists of an assembly of small particles stick together loosely. The particles are, therefore, porous and fluffy. Using discrete dipole approximation (DDA) D.B. Vaidya, in collaboration with Ranjan Gupta, has calculated the extinction efficiencies of porous silicate grains at several wavelengths between $0.30\mu$m and $3.4\mu$m. They applied these results to the interpretation of the observed extinction in Orion and found that the porous grain models with about 40 percent porosity reproduce the observed extinction reasonably well. Further work with other compositions and grain size distributions is in progress.

## Geometric Formalism

### Renuka Datta

Bergmann, Penrose, and Newman, amonst others, have shown that the spinor language provides a powerful tool for the investigation of exact solutions of the Einstein equations, dealing with problem of the classification of Petrov types and the analysis of gravitational radiation. The spinor formalism simplifies Cartan's structural equations. By introducing a compact, index-free version of spinor formalism of Cartan's structural equations, Chinea has derived a set of equations whose integrability conditions are satisfied by the Einstein gravitational field equations in vacuum. Furthermore, Chinea has shown that the Clifford algebra-valued differential forms provide a natural formalism for the description of gravitational field in vacuum. Renuka Datta, B.K. Datta and V. de Sabbata expressed Einstein's gravitational field equations as a compact exterior system of spinor-valued forms, which may be derived in a natural way from Clifford algebra-valued forms. They introduced a geometric product, emphasized the importance of eliminating the imaginary unit and worked in a real spacetime. One important point made was the multivector concept in Clifford algebra from which follows the interpretation of spin as generator of rotations.

### Ng. Ibohal

Ng. Ibohal has classified the Killing - Yano (KY) bivectors according to their nullity in electrovac spacetimes. He has shown that the non-null (or null) electromagnetic field implies the existence of non-null (or null) KY tensor. Thus, Collinson's theorem on the existence of the KY tensors on vacuum spacetimes have been generalized on electrovac spacetimes. Ibohal has also generalized Chandrasekhar's theorem on vacuum type D spacetimes. Chandrasekhar's theorem is based on the existence of the first integral constant generating a Killing vector field in a type D vacuum spacetime. The generalized Chandrasekhar's theorem is based on the existence of the second quadratic integral constant along the charged particle orbits, generating a symmetric Killing tensor field in type D non-vacuum spacetimes filled with non-null electromagnetic field or dust particles. Ibohal has strengthened the generalized Chandrasekhar's theorem by giving examples in Kerr-Newman solution as well as in Kantowski-Sachs metric having different sources of gravitational fields.

Ibohal has also shown that Kantowski - Sachs metric admits one eigen-KY-bivector whereas the KY tensor in Kerr-Newman metric is not an eigen-KY-bivector. Robertson-Walker cosmological model admits four eigen-KY-bivectors. In collaboration with J.V.Narlikar, Ibohal has found that a rotating Robertson-Walker cosmological metric and non-static Godel model have no creation field.

## Exact Solutions

### S. Mukherjee

S. Mukherjee has been working on a model for a class of cold star-like objects. Considering a spherically symmetric spacetime, he has obtained (in collaboration with B.C. Paul and N.K. Dadhich) a general solution for a class of relativistic stars in hydrostatic equilibrium having a spheroidal geometry for the 3-space embedded in the 4-Euclidean space. The parameter $\lambda$, a measure of this spheroidal character, determines the physical properties of the star. Physical constraints give a lower bound, $\lambda > \frac{3}{17}$. Stars with smaller mass to radius ratio can occur for all $\lambda > \frac{3}{17}$, while ultra-compact stars need $\lambda > 0.9$. General features of the model have been studied.

S. Mukherjee, in collaboration with T.R. Sharma and S.D. Maharaj has extended the method of obtaining general solution to the case of a static charged spherically symmetric star. Einstein - Maxwell equations were solved for a perfect fluid with a charge distribution and matched to an exterior Reissner-Nordstrom solution. Physical properties of the star were studied. The stability of the star (with as well as without charge) under radial perturbations have also been studied following the technique given by Chandrasekhar.

### L.K.Patel

Many investigators have shown interest in finding exact solutions of Einstein field equations in higher dimensions. These solutions may prove useful in the unification of gravitation with other forces of nature. L.K. Patel, N.P. Mehta and S.D. Maharaj constructed some exact higher dimensional solutions of Einstein equations which describe interior fields of perfect fluid spheres. L.K. Patel, R. Tikekar and N.K. Dadhich have obtained many inhomogeneous cosmological models incorporating the dissipative effects of heat flow. These models contain a family of cylindrically symmetric singularity-free models with heat flow as particular cases. In recent times, considerable attention has been given to the solutions of Einstein equations that represent metrics embedded in a cosmological background. L.K. Patel, N.K. Dadhich and H.M. Patel have obtained the solutions of Einstein equations describing the fields of a radiating system in the cosmological background of Einstein universe and de Sitter universe. L.K. Patel has been able to express higher dimensional bonnor-Vaidya metric in the cosmological backgrounds of Einstein static universe and de Sitter universe.

### Ramesh Tikekar

Relativistic models of compact fluid spheres based on analytic, easily surveyable closed form solutions of Einstein's field equations are expected to provide deeper insight into the structure of the spacetime in the interior of the superdense stars in equilibrium. The core regions of such stellar configurations are likely to contain fluids with anisotropic pressure. Accordingly, the study of spacetimes of anisotropic fluid distributions has received considerable attention. Ramesh Tikekar and his students V.O. Thomas and M.C. Sabu have developed schemes for constructing relativistic models of compact anisotropic fluid spheres in equilibrium. These models have the noteworthy aspect that at the boundary separating the interior from the empty exterior, all the pressures vanish, distinguishing them from the models found in the literature. The scheme is extended to describe core-envelope models of superdense stars, wherein the core region contains an anisotropic fluid distribution in equilibrium surrounded by an envelope of perfect fluid with isotropic pressure, a salient feature of these models being the continuity of matter density and both the radial as well as the transverse pressures at the core boundary. The physical plausibility of these models is also critically examined.

R. Tikekar, N. Dadhich and L.K.Patel have shown that the presence of anisotropic pressure in a spherical distribution of matter, accompanied with heat flux along radial direction can give rise to spherical singularity-free cosmological model satisfying the energy and causality conditions. Further, it is shown that presence of null radiation can replace the heat flux without disturbing the singularity-free nature of the model. The work is being generalized to a general family of spherically symmetric singularity-free models.

## Alternative Theories of Gravity

### Sujit Chatterjee

Depending on the nature of the scalar field it can be shown that spontaneous symmetry breaking can give rise to permanent topological defects like monopoles, which are important as regards their gravitational influence. As Brans-Dicke theory is now considered seriously for its applications to inflationary models, Sujeet Chatterjee has studied the monopole solution in the above formalism. This extends earlier work of Barriola and Vikenkin in GRT.

Physical theories formulated on spacetime backgrounds of dimensions greater than four have been the object of intensive studies in recent years in the context of the unification gravity with all other forces of nature. Chatterjee has obtained cosmological solutions in multidimensional spacetimes and starting from a vacuum solution in higher dimensions and has tried to interpret matter in an effective 4D universe.

### G.P. Singh

Scalar - Tensor Theories of gravity have an interesting physical embodiment which makes them a natural generalization of General Relativity (GR). The Brans-Dicke Theory, one of the best known case of scalar-tensor theory, play an important role in studying early stages of evolution of the universe. G.P. Singh has studied the effect of bulk viscosity on the evolution of cosmological models in the context of open thermodynamic system, which allow for particle creation within the framework of Brans-Dicke theory.

The fundamental conservation laws are related to the universal invariance properties of physical laws. The conservation laws in general relativistic theories differ from those in non-relativistic theories, due to wider scope of coordinate transformations in general relativity. The covarient conservation law of energy momentum expressed by a tensor, results in a global continuity equation valid in a preferred subclass of geodesic coordinates. Recently, a number of authors have considered different pseudo-tensor approach to show that the total energy of the universe is zero. All these results, based on the pseudo-tensor approach, lack covariant character. Thus, it is worthwhile to investigate by alternative techniques whether the vanishing of the total energy has any invarient meaning in the expanding universe. G.P. Singh and V.B. Johri are studying these problems within framework of general relativity and Brans-Dicke theory.

### A. Banerjee

It is widely accepted that the topological defects such as cosmic strings, domain walls and monopoles are formed during inflation and hence, in the context of Brans-Dicke theory must interact with the Brans Dicke scalar field. Some interesting results different from those existing in Einstein's theory have been obtained. A. Banerjee along with A.A. Sen and N. Banerjee has shown that Vilenkin's prescription for a gauge string are inconsistent with Brans-Dicke classes of static solutions and were obtained outside the core and one of them has been found to be nonsingular at any finite distance, the result which is unlike that in Einstein's theory. It has also been clearly demonstrated that similar to Einstein's theory the static thin domain in general, and also thick walls under certain circumstances, do not exist in the Brans-Dicke theory.

### Daksh Lohiya

Whenever the standard big bang model has been confronted with a crisis, a resolution has been sought for by taking recourse to some novel equation of state of matter and associated properties of exotic particle states. There is reluctance to give up the basic framework of the standard model as little work, in comparison, has been accomplished in alternate cosmologies. Daksh Lohiya and his co - workers in the University of Delhi have embarked upon a whole class of scalar - tensor theories as viable alternatives. These theories have a vanishing effective gravitational constant outside spherical domains. The value in the interior is retained at its universal canonical value. These domains occur very naturally in variations of a class of non - topological - soliton solutions known as Lee - Wick solitons. The resulting cosmology has no horizon and flatness problems. There is extremely good agreement with the standard cosmological tests currently being reported in the type 1A supernovae observations. The universe has a vanishing decceleration parameter. For a given value of the Hubble parameter, the universe is 1.5 times older than the corresponding age inferred in the standard model. The nucleosynthesis programme goes through rather well.

## Gravity Waves

### D.C. Srivastava and S.S. Prasad

*Gravitational Wave Data Analysis:* Pulsars are one of the important sources of continuous gravitational radiation (GR). The signal is extremely weak, but a long observation time may yield enhancement in Signal to Noise ratio, proportional to the square root of the observation time. But this introduces amplitude modulation due to the qudrapole nature of the detector. In addition, there arise frequency modulation due to the translatory motion of the detector acquired from the motion of Earth around Sun. Srivastava and Prasad are engaged in this field in collaboration with S. Dhurandhar. They have taken up the following two aspect of the above problem.

*Fourier transform of frequency modulated gravitational waves from pulsars:* In order to calculate frequency modulation of a monōchromatic wave, one needs to calculate Doppler shift due to rotational and orbital motion of Earth. Even under some simpifying assumptions viz., circular orbit of Earth around Sun, the phase of the wave is a involved one. Besides the analytical methods, there are other methods like (i) Discrete Fourier transform and (ii) Gaussian quadrature. An analysis for a suitably chosen location of the detector and under assumption of a short time observation, so that the orbital motion of Earth can be neglected, has been carried out by Kanti and Dhurandhar (1994). This analysis has been genearlised by Srivastava and Prasad for arbitary location of the detector and taking into account Earth's orbital motion. The qualitative nature of the transform is similar to that obtained by Kanti and Dhurandhar. The application of these results to gravitational wave data analysis is under investigation.

*Gravitational waveform from a spinning spheriod:* The gravitational waveform emitted by a pulsar of spheroidal shape whose axis of rotation is misaligned with its angular momentum has been obtained by Zimmermann (1979). Srivastava with his student S. Sahay has developed a numerical code for small wobble angle and oblateness of the pulsar to obtain the gravitational waveform. The results of this investigation will be used to see the number of the filters required in gravitational wave data analysis of the pulsar. Prasad has been engaged with U.S. Pandey in studying distribution and stability of self gravitating nuclear gaseous disk as proposed by Kundt as a model of AGN.

## Cosmological models

### Raj Bali

The distribution of matter can be satisfactorily described by perfect fluid due to the large scale distribution of galaxies in our universe. However, in the early stages of the universe when neutrino decoupling occurs, matter behaves like a viscous fluid. Thus, a realistic treatment of the problem requires the consideration of material distribution other than the perfect fluid. Bali and Jain have investigated two viscous fluid non-static cosmological models in general relativity, in which the expansion is only in two directions, i.e., one of the Hubble parameters $H_1$ is zero. In the first model, the coefficient of shear viscosity is assumed to be constant while in the second model, the coefficient of shear viscosity is proportional to the rate of expansion in the model. The first model isotropizes, although, $\lim_{T\to\infty} \sigma/\theta \to 0$. The second model does not approach isotropy for large values of T. For large values of T, the spacetime is Petrov Type D. In the second model, it has been investigated that viscosity is due to the expansion in the model. It has been found that there is a singularity in the models at T=0. The expansion in the models stop at $T = \infty$.

**A. Banerjee**

The study of cosmological implications for a space time with more than four dimensions has recently attracted the interest of many researchers, particularly from the point of view of unifying gravity with other gauge type interactions in the early stage of the universe. Senovilla in a recent publication has shown that a general family of explicit inhomogeneous cosmological models exsist, which contain all the spatially homogeneous isotropic cosmologies together with all the G2 diagonal and separable perfect fluid cosmologies. A. Banerjee, Ajanta Das and A. Sil have shown that such a general class exists also in five dimensional spacetime, where all the previous five dimensional nonsingular solutions with an equation of state $p = \alpha\rho$ are recoverable.

**S. Banerji**

In the past S. Banerji and his coworkers have considered a two- component model of the void consisting of a sphere of low density conducting fluid surrounded by a thick spherical shell of radiation. This was embedded in a Robertson-Walker (RW) universe with flat space section. Recently, they have generalised it to the case where the spatial curvature of the RW universe is nonzero. The matching conditions indicate as before that if the time coordinate in each region is future directed, then the void appears to contract in all cases to a comoving observer in the universe as the latter expands. The rate of collapse is fastest for the spatial curvature K = +1, medium for K=0 and slowest for K= −1. If, however, the Universe is mass dominated as at present (i.e., zero pressure), the size of the void remains unaltered.

**Moncy V. John**

Complex numbers have found many interesting applications in the theory of relativity since its inception. For example, it is well known that open and closed FRW models, de Sitter and anti de Sitter spacetimes, Kerr and Schwarzchild metrics, etc. are related by complex substitutions. The latest in this tally are the applications in Ashtekar formalism and twistor theory. Another intriguing use of complex variables in relativity is in connection with a possible signature change of the metric in the early universe in the quantisation programme of Hartle and Hawking. In the context of classical relativity, signature change is a matter of hot debate in the current literature. It is argued that the conventional Lorentzian signature of the metric in the usual solutions occurs not because it is demanded by the field equations, but because it is a condition we impose on the solutions. Some authors have even used a complex lapse and obtained signature changing features. Moncy V. John and K. Babu Joseph, by replacing the real scale factor in the FRW metric with a complex one, obtained a signature changing cosmological model, which has a direct bearing on several observed phenomena. This coincides with an old model by Ozer and Taha which happens to be the first among a class of 'decaying vacuum cosmological models'. In these models, the cosmological constant (which is indistinguishable from the vacuum energy density) varies with time and this provides a natural solution to the 'cosmological constant problem'. In the model with complex scale factor, the total energy momentum tensor for the universe is obtained from first principles and is shown to have values well within the observed range. It has a nearly vanishing gravitational charge, so that the model is coasting. It has the added advantage of having no flatness problem or age problem when compared with the Ozer-Taha model. Under quantisation in a minisuperspace model, results which comply with some of the much sought after quantum cosmological ideals are obtained.

### S. Mukherjee

S. Mukherjee, in collaboration with B.C. Paul and A. Beesham has considered cosmological solutions with an imperfect fluid in a higher derivative theory in the Eckart, truncated and full causal theories. Possible scenarios for the temperature variation permitted by causal thermodynamics have been studied. The effect of viscosity, in general, is seen to increase the rate of expansion of the universe in the cases studied. The results have been found useful in describing some epochs in the early universe. Cosmological solutions in (1+1) dimensions obtained in Mann's theory of gravity have been studied in the presence of dissipative phenomena in the truncated Israel- Stewart theory and also in the full causal theory. Some exact solutions are obtained and the general features of these solutions are studied. Continuing this work, the field equations with an imperfect fluid in Mann's theory in (1+1) dimensions have been studied qualitatively by rewriting the equations as a system of autonomous ordinary differential equations and studying its critical points.

## Instrumentation

### M.N. Anandaram and B.A. Kagali

M.N. Anandaram and B.A. Kagali are in the process of buliding an fourteen inch Automated Photoelectric Telescope (APT) for Bangalore University. The work is being carried out at IUCAA Instrumentation Laboratory in collaboration with S.N. Tandon and Ranjan Gupta. Software development and testing were carried out. The APT programme commands were made more user friendly and systematic. Some errors in the older version of the software were debugged. The construction of the APT was supported by funds from the DST, and various steps were completed as per the DST project proposal. The field testing is expected to be completed in the second half of 1998, after which, the telescope would be transported to the Bangalore University.

### S.P. Bhatnagar

Bhavnagar University and IUCAA have received grants from DST for fabricating an APT. The telescope would be assembled at IUCAA and later transported to Bhavnagar. The design of this telescope is essentially similar to that developed at IUCAA. The project began in July 1997. S.P. Bhatnagar has assembled some parts of the mechanical structure of the telescope, the stepper motor drivers, and studied the mechnical structure for the accuracies in mounting. D.B. Vaidya, co-investigator on this project, has helped in the fabrication of telescope structure. Some of the electronic circuits for monitoring and control are being assembled and tested at Bhavnagar University.

### P.S. Naik

P.S. Naik and his group have used a photometer, designed and constructed, at IUCAA along with a C8 plus telescope to observe the variable star Betelgeuse and have obtained various parameters like extinction coefficient.

## Galaxy Surface Photometry

### D.K.Chakraborty

Detailed photometric analysis of elliptical galaxies have been made in last few years by various groups of workers. It is very important to understand the intrinsic nature of these objects. One of the approaches to do this is to take a model, project it with suitable viewing angles and compare the projected surface density with data, assuming a constant mass to light ratio. Adopting a model which is a triaxial generalization of Jaffee Model, D.K Chakraborty has compared models with the data on elliptical galaxies NGC 4406, NGC 5846 and NGC 2513. For dynamical studies, it is required to work out a velocity field which may be obtained as a solution of the continuity equation. The proposed velocity field may be projected and compared with kinematical data which is available for the above galaxies. This work is in progress.

**S.K. Pandey**

The study of dust properties in external galaxies is important in order to understand the mechanisms of dust formations and subsequent evolutions in the extragalactic environment. Dust constitutes an important component of interstellar matter (ISM) in the star formation process too. One expects the dust grain properties to be different from site to site as various parameters which affect the growth and destruction of the dust grain change. Early type galaxies, elliptical and lenticulars, with large scale dust are suitable targets to investigate the properties of dust in extragalactic environment, because the underlying galaxy has fairly smooth distribution of star light. Optical as well as far infra red surveys have amply demonstrated the presence of significant amount of dust in a large fraction of early-type galaxies. In fact, Hubble Space Telescope observations of these galaxies show the presence of nuclear dust in almost every galaxy. Although, the amount of dust in early-type galaxies is minute as compared to that in inspiral galaxies, it has caused a renaissance of interest in studying dust as well as other forms of ISM in these objects for the reasons explained above. With these ideas in mind, Pandey and his collaborators have started detailed analysis of broad band BVRI CCD images of the dusty early-type galaxies taken by them from Kavalur and Nainital to obtain wavelength dependence of dust extinction in these galaxies. The case of NGC 2076, an early-type galaxy with a prominent dust lane parallel to its apparent major axis, was investigated to derive the extinction curve. The extinction varies linearly with the inverse wavelength and the extinction curve runs almost parallel to the galactic extinction curve. The ratio (Rv) of total extinction Av in the V band to the selective extinction E(B-V) between B and V bands was found to be 2.7. The value of this ratio for the Milky way is 3.1. The smaller value of Rv relative to the galactic value implies that the size of the large dust grains responsible for extinction is smaller than that in our galaxy. The dust mass from total extinction is estimated to be $3.2 \times 10^6$ solar mass, where as the dust mass using FIR data gives a value of $3.67 \times 10^6$ solar mass. In absence of neutral and molecular hydrogen observations, it is very difficult to have reliable estimate of total ISM content of this galaxy. However, the estimate of dust content from FIR and optical data does indicate that it contains significant amount of ISM. Using FIR fluxes, it has been estimated that more than 50% of the IR emission in this galaxy may be attributed to the young stars. This indicates an ongoing star formation in it. A comparison of star formation rates (SFR) using some reasonable approximation for different scenarios reveals that, this galaxy is undergoing a burst of star formation in the present epoch. As far as origin of dust lane in NGC 2076 is concerned, it may be attributed to a recent merger with a gas rich galaxy. Detailed investigations, specially on its kinematics, are needed to support this view. The research article based on this has been accepted for publication in Astronomy and Astrophysics journal. The investigation of other dusty early-type galaxies is in progress.

## Stellar Photometry

### S.K. Pandey

Small aperture telescope with adequate back-end instrumentation can provide meaningful astronomical data, apart from being useful in imparting training in astronomy to M.Sc. students, even though they are situated at low altitudes and in township areas. This is particularly true for a variety of variable stars including RS CVn type which require telescope times over long time spells for their continuous monitoring. With this objective in mind, an observing programme on some bright RS CVn binary stars was started by S.K. Pandey and his co-workers. This work was carried out using the computer controlled Schmidt-Cassegrain 14" Celestron (C-14) telescope in the Physics Department of the Pt. Ravishankar Shukla University, Raipur. This telescope is equipped with stellar photometer, CCD camera and standard photometric broad band filters. B, V, R light curves of six prominently active RS CVn binaries have been traced for two observing seasons covering the period November 1995 – February 1997. The light curves of these stars are found to display remarkable changes in shapes as well as in amplitudes when compared with previously recorded observations. The traditional two star spot model has been used to reproduce the light curves and to derive spot parameters. Similar to the well known 11-year activity cycle of the Sun, these active stars too may have long term activity cycle. An extensive analysis of the light variations in some of the prominently active RS CVn has been made in the framework of star spot model with total spotted area as an indicator of the degree of activity. The study seems to indicate that the spot activity of UX Ari varies periodically with a time scale of approximately 18 years.

## Ionosphere

### P.K. Bhuyan

Radio interferometric observations are affected by tropospheric and ionospheric refraction. The effects of refraction are visible in two ways (1) as phase errors, which are to the first approximation (as long as the ionosphere remain coherent over the interferometer baseline) linearly proportional to the baseline length and (2) as Faraday rotation on polarized signals travelling through the magneto-ionic medium. Ionospheric refraction is a significant effect for connected element radio interferometry at frequencies upto about 2 Gigahertz. When the angular scale of ionospheric irregularities is less than the beamwidth of an interferometer element, diffraction occurs, because the ionospheric irregularities above the different interferometer element may not be correlated. This effect is visible in the observations as scintillations in interferometer phase and/or amplitude. To correct these errors in radio astronomical observations, it is necessary to have either real time observation or long term knowledge of ionospheric variables such as F-region peak density or ionospheric total electron content (height integrated electron density). In the absence of real time observations, empirical models are generally used to derive correction factors. Looking in the GMRT context, until some real time observational techniques are deployed, the next logical way is to derive models of electron density and electron content which should be applicable to the GMRT location. P.K.Bhuyan has worked towards the development of empirical models of electron content and electron density applicable to the Indian zone. Preliminary work on an elaborate procedure for ionosphere correction has been completed. The model will be tested against observed data either from the GMRT or ORT.

## Observing and Analysis Facilities

### R. Prabhakaran Nayar

With the help of IUCAA, S.R. Prabhakaran Nayar has set up a computer network and image processing facility at the Observatory of the University of Kerala. He has set up e-mail facility at the observatory which is used by a number of people and organizations in the region around Thiruvananthapuram. The observatory now has a 11" Celestron telescope equipped with a CCD camera. Reasearch and postgraduate students of the University, and college teachers and students from different parts of Kerala have been trained in the use of the computer network and image processing software. The observatory has entered into an agreement with the Department of Electronics and IUCAA to set up a VSAT, which will provide full internet connectivity.

## Plasmas and Dusty Plasmas

### Manoranjan Khan

The physical process in dusty plasmas are being studied intensively because of their many applications to astrophysical and space plasmas as well as in laboratory plasmas. The dust components occur naturally in space environments such as interstellar clouds, circumstellar clouds, planetary rings, characteristics of low frequency wave propagation in a cold magnetized dusty plasma. Manoranjan Khan has investigated the effect of fluctuation of charges on dust grains. Evolution of various instabilities like Stimulated Raman Scattering (SRS), Stimulated Brillouin Scattering (SBS), etc. in the interaction of intense laser radiation in a plasma is an important phenomenon in inertial confinement fusion. Khan has been carrying out a theoretical study of SBS stabilization due to induced magnetization.

### V.H. Kulkarni

It is interesting to study the effect of the charged dust grains on the neutral induced high frequency drift instability in a weakly ionised and magnetised dusty plasma. For example, the dispersion relation for the high frequency drift waves, in a partially ionised, magnetised and non-uniform electron and neutral distribution and uniform distribution of ions and charged dust shows that the growth rate depends on the dust number density. V. H. Kulkarni has shown that the neutral density gradient in the direction opposite to that of electrons reduces the growth rate. The results are useful to analyse the ionspheric instabilities. Charged dust particles in the presence of curved magnetic field lines undergo drift and can excite low frequency waves. This instability seems to be responsible for the wave activities in the cometary plasma neighbourhood. It is known that lightning discharges occur in atmosphere when the large scale electric fields are generated due to charge separation by frictional forces, winds and other forces. Recently, Kulkarni has suggested the possibility of generating large scale electric field by low frequency acoustic waves in a plasma medium having two types of charged dust grains. When the charged dust grains are included, then their charge fluctuations reduce the effective amplitudes of acoustic waves. Therefore, if these waves are responsible for the large scale electric fields so as to give rise to the lightning discharges, then their amplitudes must be much higher than those in the absence of charge fluctuation.

## Atomic Processes

### S.P. Khare

Khare and his associates have continued their investigations on the interaction of the electrons with various molecules which are to obtain integrated ionisation and dissociated ionisation cross sections of the molecules due to electron impact. The method based on the phase wave Born approximation includes exchange and relativistic effects, the longitudinal interaction through the unretarded Coulomb field and the transverse interaction through the emission and reabsorption of the virtual photons. Their approach utilised the optical oscillator strength (OOS) as the input instead of the generalised oscillator strengths (GOS), which are difficult to evaluate for the molecular targets. The evaluated cross section are in good agreement with the available experimental data. To examine the effect of the replacement of the GOS by the OOS, Khare utilised the above method to obtain the ionisation cross section of the silver atom from its three L-subshells due to electron impact for the energies varying from the threshold of ionisation ($\sim$ 3 Kev) to 100 Mev. A comparison of these cross sections with those obtained with the use of GOS shows that the ratios of these two sets of the cross sections do not differ by more than 10% for the impact energies greater than 20 keV.

## Dynamics

### Sarita Vaishampayan

Sarita Vaishampayan has derived the Euler Lagrange equations of motion for the classical Lagrangian functions with non-holonomic constraints linear in generalized velocities. A new Lagrangian functions L* was used to construct the Hamiltonian function and its motion equations. Equivalence of Euler-Lagrange equations and Hamilton's equations of motion was established. Euler-Lagrange equations of motion were derived for the general Lagrangian function with general non-holonomic constraints. Forces of constraints were obtained with the help of least square approximation. Though the number of equations of motion is same as the generalised co-ordinates, the motion takes place on a submanifold of dimension(n-r) where r is the number of constraint equations. The presence of constraint forces keeps the motion on (n-r) dimensional subspace of the full space.

## Non-linear dynamics

### G. Ambika

G. Ambika has analysed the chaotic behaviour of pendulum systems with different types of damping. For one such system with Froude type of damping, parametric perturbation is found to be an effective mechanism for control of chaos. The work, mostly analytical in nature, leads to expressions for the width of the window of modulation amplitudes that can suppress chaos. Numerical calculations support these views. A few 2-parameter 1-d maps were chosen to investigate the bubble structure formation in the bifurcation scenario. Numerical work could establish the basic features common to them, the mechanism and the reason for the same.

This is important since, such a structure takes the system once again to regions of low periodic states and hence can avoid chaos.

### V. M. Nandakumaran

V.M. Nandakumaran has worked on the numerical study of chaos in a multimode laser system with a coupling among the different modes. The coupling is brought about by an intra cavity KTP crystal. It was found that for certain range of values of the coupling constant, there is a chaotic transfer of energy between orthogonally polarised modes as is evident from the positive values of the Lyapunov exponent. Further work is in progress. Nandakumaran has also studied the bifurcations in a piece-wise continuous logistic map with a discontinuity at the centre. This map shows many interesting features which are not exhibited by the ordinary logistic map. The study is partly analytical and party numerical and is in progress.

## Three-body problem

### B. Ishwar

Singh, Jagdish and B. Ishwar started research work on stability of triangular equilibrium points in the generalised photo gravitational restricted three body problem. The problem is generalised in the sense that both primaries are taken as a oblate spheroid. Also, they have supposed both primaries are radiating. They have obtained the equations of motion of the problem and found the location of triangular equilibrium points. The co-ordinates are different from the classical case. They have examined the linear stability of motion at the triangular equilibrium point. They have found the condition of stability in terms of oblateness and radiation pressure. Non-linear stability of the problem is an open question which will be addressed in the future.

### L.M.Saha

L.M. Saha has been engaged with the problem of restricted three body motion and its applications. He has been mainly considering the problem of obtaining the trajectory of a third body moving under the gravitational influence of two primaries. For different initial conditions, the dynamics could evolve from regular to chaotic motion which could be deciphered by using the tools of dynamical system theory. Recently, Saha along with M.K. Das and Y. Tanaka has studied the problem of spatio-temporal chaos in connection with stellar pulsation problem. The idea is to find the domain where the chaos or stochasticity present in the system results in inducing regular behavior of the system.

## Early universe

### Narayan Banerjee

Dissipative process in the fluid distribution, such as viscous effects or heat conduction, are likely to have played an important role in the evolution of the early universe. N. Banerjee has investigated the effects of viscosity using causal non-equilibrium thermodynamics by allowing a finite relaxation time. Different models have been considered, particularly along with minimally or non-minimally coupled scalar fields. He also continues his work on the gravitational field of cosmic strings and their consistency in the context of various scalar tensor theories.

## Hadronic and quark matter

### Somenath Chakrabarty

The investigation of dense matter in a strong magnetic field is interesting both from a theoretical point of view and for possible applications in cosmology and astrophysics. Large magnetic fields are known to be present in neutron stars, where the field strength are $\sim 10^{14} - 10^{15}$ Gauss at the surface (as follows from pulsar observations), and it is expected from the scalar virial theorem that for a newborn protoneutron star, the field inside reaches a value as large as $10^{18}$ Gauss. The properties of dense nuclear matter/quark matter are considerably modified with respect to the fieldfree case in presence of such strong magnetic fields. Recently Somenath Chakrabarty, his Ph.D. student and two of his collaborators have studied the properties of dense hadronic and quark matter of astrophysical importance in presence of strong magnetic fields. They have considered $\sigma - \omega - \rho$ meson exchange type of mean field model for dense astrophysical hadronic matter in presence of a strong magnetic field, and could be the first to solve relativistic Hartree equation in presence of a strong magnetic field. The solutions of the equation were used to study the properties of interacting dense nuclear matter. The stability of the matter and the effect of strong magnetic fields on the abundances of various species is also studied. The matter becomes energetically stable enough in presence of a strong magnetic field if the field strength $B_m$ is $< 10^{19}$ and $> 10^{14}$ Gauss. Above this field strength, the magnetic energy density dominates and the system becomes energetically unstable. The proton fraction increases in presence of such strong magnetic field. It may go up to 90% of the total baryon content. The magnetic field also affects the equation of state of dense hadronic matter and makes it much softer, as a consequence, the mass-radius relation of neutron stars is modified significantly.

Chakrabarty and collaborators have also studied the effect of strong magnetic field stability and equation of state of dense quark matter which is expected to be present at the core of a neutron star if the density exceeds a few times normal nuclear matter density. They have considered an interacting quark matter system at $T = 0$ in presence of strong magnetic fields. The interaction is mediated by single gluon exchange. They have solved relativistic Harteee-Fock equation in presence of a strong magnetic field. The gross properties of dense interacting quark mater in presence of strong magnetic fields were studied. They have investigated the bulk properties of hybrid stars in presence of such strong magnetic fields. Chakrabarty and collaborators have also investigated weakly interacting quark matter in the presence of a strong magnetic field with quasi particle approach using the relativistic version of Landau theory of a Fermi liquid. This is the first attempt to develop this particular model in presence of a strong magnetic field. This model was applied to study the gross properties of quark matter in presence of strong magnetic fields. They have applied this model to investigate the bulk properties of magnetised quark stars. Another interesting problem, Chakrabarty and collaborators have studied recently in detail, is the neutrino transport through dense hadronic and quark matter in presence of strong magnetic fields. They have investigated the effect of strong magnetic field on the characteristic time scale of degenerate neutrino diffusion in quark matter at the core region of a compact star. The effect of magnetic field modifies the mean free path (or collision frequency) of neutrino. They have shown that effect is significant for the degenerate case. Their calculations show that the emission of neutrinos from a neutron star, in presence of a strong magnetic field, is anisotropic in nature, provided there is a deconfined phase transition at the core and the strength of magnetic field is such that the Landau levels for $u$ and $d$ quarks are also populated. The characteristic time scale of neutrino emission for such an object is a function of polar angle (they have assumed that the direction of field is also Z-axis). On the average, it takes a few seconds for the neutrinos to leave the system on the magnetic equator and on the magnetic meridian they can take as large as $10^{10}$ second. This indicates that the emission rates are minimum along (opposite to) the direction of magnetic field and is maximum along the orthogonal direction.

**Ashok Goyal**

Stars are excellent laboratories for testing fundamental physics. The existence of new modes of draining energy from the stars through the production of new weakly interacting light exotic particles or through new properties and interactions of known particles should not result in energy loss in conflict with the observed rates of cooling of stellar objects. These considerations have been used to put constraints on properties and interactions of exotic particles by demanding that the rate of energy loss from the Sun does not exceed the observed luminosity of $\sim 17$ ergs/gm/sec and from a red giant $\sim 100$ ergs/gm/sec. The observation of neutrino flux by the IMB and Kamiokande groups from Supernova 1987A confirmed the standard model of the supernova and any additional process, if existing, should not, therefore, contribute more than 10 ergs/sec of luminosity. This has been used extensively in the literature to bring about a phase transition from normal nuclear matter to constituent quark matter at high densities available in neutron stars. It would then become energetically favorable for $u - d$ quark matter to convert itself into three flavour $u - d - s$ matter, the so called "Strange Matter" by undergoing beta decay and the "Strange Matter" with roughly equal number of $u - d$ and $s$ quarks with electrons to guarantee charge neutrality may indeed be the true ground state of matter. Alternatively, at high densities the core may also develop meson condensates and it is now generally believed that there is a large abundance of thermal pions/meson condensates in the core of neutron stars. This would result in modifying cooling rates by giving rise to pion mediated new and faster cooling mechanism and thereby shortening the duration of the observed neutrino burst from SN1987A. Ashok Goyal, S. Dutta and S.R. Choudhury used these considerations earlier to obtain some of the best bounds on neutrino magnetic moment. Strong constraints on right handed vector meson masses in Left-Right symmetric models have now been obtained by Goyal and Dutta. Ashok Goyal, in collaboration with J.D. Anand and Pragya, has studied signals from quark-gluon plasma, in particular photon production from baryon rich plasma and compared the corresponding production from the hadronic matter. The process is important in getting information on the formation of quark-gluon plasma in heavy ion collisions in the ongoing and anticipated experiments at Brookhavens AGS and CERN's existing SPS and at anticipated LHC. Along with V.K. Gupta and S. Singh, they also studied the conversion of two flavour quark matter into strange matter in neutron star cores and in supernovae. The conversion in the supernovae has the effect of raising the core temperature and has bearing on the explosion mechanism itself. The conversion also gives rise to a second detectable neutrino burst.

With S. Pathak, they examined the effect of hadronic and QCD interactions on phase transitions in the early universe and in heavy ion collisions. In the standard model of the hot big-bang universe, the universe must have passed through a succession of phase transitions viz., electro-symmetric phase transition followed by a QCD phase transition from unconfined quark gluon plasma to a confined hadronic phase. These phase transitions may have let their distinctive signature on subsequent evolution of the universe and may have given rise to relics surviving to this date. Ashok Goyal and Deepak Chandra have studied the properties of bulk matter in electro-weak symmetric phase and the possibility of matter getting frozen into "quark nuggets" and if sufficiently big might survive to this date. They studied the formation of these objects in the early universe at the time of QCD phase transition and their possible survival against surface evaporation and boiling (bubble nucleation). The possibility of identifying these objects with the newly observed Jupiter sized objects in the galactic halo with gravitational microlensing (MACHOS) offers an exciting idea.

### P.C. Vinodkumar

*Hadronic properties based on QCD models :* P.C. Vinodkumar has studied confinement properties based on a QCD condensate of a background classical Yang-Mills solution. In light of these confinement schemes, hadronic properties with various flavour combinations are being worked out. Presently, he is engaged with the study of various hadronic decay properties with minimum number of extra parameters. The confined one gluon exchange potential (COGEP) derived in the same framework of colour condensate will be employed for a complete consistent study of hadron physics. By generalising the study of hydrogenic systems of QED for mesons and baryons with a QCD medium coefficient, Vinodkumar has successfully predicted dielectric properties of QCD medium. The nature of the colour dielectric coefficient suggests no ionisation of the quark atoms as well as a non-Coulombic form for the colour interactions. With the medium in hand, various properties related to hadrons and quark gluon plasmas are to be studied.

It has been a distinct possibility that a massive star beyond the neutron – de-generacy pressure undergoes a phase transition to the QCD degrees of freedom. The various stability parameters of such stars are of interest from the point of view of astrophysics as well as high energy physics. Vinodkumar has been able to predict various critical parameters of a pure degenerate phase of quark stars. Attempts are in progress for the complete study of hybrid stars to the degenerate quark stars with QCD motivated equations of state.

## Early universe

### Subenoy Chakraborty

During phase transition at the early universe, several topological defects will arise, of which cosmic string is very important. Recently, monopole and domain walls have been attracting a great deal of interest from the point of view of providing new scenarios of galaxy formation. Subenoy Chakraborty has investigated the gravitational field of a non-static global monopole. He finds that there is a time-dependent solid angle of deficit for the monopole metric. He has also examined the geodesic equations of the test particles in the gravitational field of plane symmetric and planar domain wall and finds that the particles may or may not have bound orbits. In recent past, Ashtekar variables have become important for canonical gravity due to the nice form of the constrained equations that they make possible. Chakraborty has worked on quantum cosmology using Ashtekar variables. The wave function of the universe was evaluated by path integral formulation as well as by solving Wheeler-DeWitt equation. He has obtained inflationary solutions in Scalar-Tensor theory for four and higher dimensions.

### S.S. De

S.S. De has continued the study of early universe regarded as a thermodynamically open system. In fact, in the earlier consideration, the thermodynamic energy conservation law for homogeneous and isotropic universes has been modified following a consideration of Prigogine. The universe was regarded as the perfect fluid in accordance with the conventional model. The important fact about this model of early universe is that, the universe has its nonsingular origin. Also, in the early stage of the evolution, creations of both matter and entropy are possible. Apart from this, the cosmological constant problem can be resolved if one adopts the changing gravity approach. The other aspect of this approach on the early universe is the epoch-dependence of the masses of fundamental particles. This was obtained as a 'byproduct' of earlier consideration by S.S. De in search of Finsler geometrical origin of internal quantum numbers of hadrons as well as from the extended particle formalism for hadrons in Finsler space. This epoch-dependence of particle masses plays a dominant role in the very early period of evolution of the universe.

## Particle Production, Solitons

### V.C.Kuriakose

Particle production is a quantum phenomenon, which results from vacuum fluctuations in strong gravitational field. Several attempts have been made in the past to explain the mechanism of creation of particles in the early universe by introducing a scalar field. Recently, the language of squeezed states has been used to explain the production of particles in the early universe. In this formulation, the background gravitational field plays the role of a parametric medium which squeezes the scalar field vacuum producing squeezed vacuum states and squeezed states. Suresh and V. C. Kuriakose used this method to study the validity of semiclassical theory of gravitation. This was done by calculating the fluctuations in stress-energy tensor of the scalar field using single mode and two mode squeezed vacuum states. The calculations show that the fluctuations are large and hence, the semiclassical theory may break down near the singularity. They have also studied the mechanism of particle production by black hole evaporation and the associated entropy production using the squeezed state representation and obtained an expression for Hawking temperature in terms of the squeezing parameter. This reaches a maximum value and then decreases and become zero. Optical solitions possess the probability of propagating without distortion or spreading and hence, they find many applications in different fields such as communication, medicine, photonic switching, etc. The availability of lasers capable of generating ultrashort pulses and low loss fibers has lead to a revolution in the field of optics. Nonlinear directional couplers and nonlinear birefringent fibers represent good candidates as building blocks of future communication systems. Ganapathy and Kuriakose studied the conditions for observing bound states of two soliton pulses in an elliptically birefringent medium. Propagation of electromagnetic waves through plasma can generate a variety of nonlinear phenomena. Bindu and Kuriakose studied the propagation of such waves through cold collision free plasma using nonlinear reductive perturbation method in (1+1) and (2+1) dimensions. In (1+1) dimensions, the system supports soliton solutions while in (2 + 1) dimensions, the fluctuations take place in the form of solitons and kinks.

### S.N. Paul

Studies on the solitary waves and double layers in plasmas (relativistic and non-relativistic) have been found to be important in the context of different nonlinear phenomena observed both in laboratory and in space. S.N. Paul has theoretically investigated the solitons, double layers and instability of ion-acoustic waves in multi-component plasmas. He has shown that formations of solitons and double layers are significantly influenced by the presence of negative ions, positrons, two-temperature electrons and charged dust particles in the plasma. Moreover, contributions of higher order non-linearity and finite size geometry of bounded plasma on the instability of waves and existence of solitons are found to be significant.

## Molecular Clouds

### Asoke K. Sen

Stars are supposed to be born in the dark interstellar cloud by the method of gravitational collapse. Whereas, the gravitational force favours the collapse, the rotation of the cloud, thermal velocities, ambient magnetic field, etc. disfavour the collapsing process. The grains present in the cloud are generally aligned by the magnetic field and polarize the light coming from the background stars due to forward scattering. By taking the polarization images of the cloud, one can estimate these linear polarization values for background stars which are typically 1-5%. These polarization values help to estimate the magnitude and direction of magnetic field and various dust properties like size, composition, etc., which are important to understand the star formation processes. With these aims, a set of more than ten dark clouds have been observed from Gurushikhar Infra-red Telescope, Mount Abu using the Imaging Polarimeter (IMPOL) of IUCAA. The results are being analysed and it will help us to understand some of the problems related to star formation in dark clouds. The above Imaging Polarimeter (IMPOL) can take polarization images of fields which are as large as 6 arcmin in diameter. However, for off-axis object points, some instrumental polarizations are introduced due to telescope optics. Calculations have been done for a 2 m class telescope, which show that at a F/13 Cassegrain focus, at 90 arcseconds from the axis, the instrumental polarization produced is 0.016% and the amount of depolarization is 99.9983%.

## Solar Corona

### U.Narain

U. Narain, R.K.Sharma and G. Vekstein re-examined quantitatively the linear resistive and viscous damping of Alfven waves propagating in solar coronal holes, using the recently available observational data on the plasma density and temperature as well as taking into account the magnetic field-spreading inside the coronal hole. They found that the latter effect results in a drastic length, thus making linear dissipation a viable mechanism of plasma heating in coronal holes.

Continuing this work, U. Narain and R.K. Sharma have re-examined the nonlinear viscous damping of Alfven waves in coronal holes when magnetic field spreading was strong. Drastic reduction in the wave's dissipation length led them to reconfirm the result that the nonlinear viscous damping is much more effective than the linear one. They further concluded that the nonlinear viscous damping in presence of strong magetic field-spreading should be a viable mechanism for heating the coronal hole plasma.

In solar convection zone, motion is turbulent and eddies of different sizes exist. Magnetic fields are also present there. In such a situation, magnetohydrodynamic waves are generated. These MHD waves consist of slow, fast and Alfven modes. U.Narain, Pankaj Agarwal and R.K.Sharma have studied the generation of MHD waves in solar convection zone using Stein's approach (which was suitably modified) and the best available electron density, temperature, turbulent velocity and $C_p$ / $C_v$ data. They have obtained MHD fluxes which compare reasonably well with the total solar flux (photospheric). There is some uncertainty due to non-availability of turbulent magnetic field data.

## Quantum Cosmology

### S. Mukherjee

S. Mukherjee, in collaboration with B.C. Paul and A. Beesham, has studied the probability of pair creation of primordial blackholes in quantum cosmology in the minisuperspace approximation in $R^2$ model, making use of Hartle-Hawking boundary conditions. The results have been found to be consistent with recent results of Bousso and Hawking. It has been noted that the probability of such pair creation is very much suppressed in a realistic scenario.

## Other topics

### K.N.Joshipura

K.N. Joshipura is engaged in theoretical modelling and calculations on electron-atom-molecule collisions of astrophysicsal and other importance. He has calculated total cross-sections for electron scattering with a number of molecules like $O_2$ ,$O_3$, NO, $NO_2$, $H_2O$, $CH_3$ X (X = $CH_3$, OH, F, $NH_2$). He has developed electron scattering models for water molecules in the liquid and the ice phase.

### G.P. Malik

For some years now, along with his collaborators, G.P. Malik has been following an approach that combines the concepts and methods of quantum field theory with those of many body physics in an attempt to investigate the effects of temperature on the dynamics of systems. For a system of electrons and protons interacting via the temperature modified Coulomb potential, these authors were thus led to a finite temperature Schrodinger equation (FTSE), which turned to be of relevance for the explanation of a large number of emission lines (and their intensities) in the soft X-ray region from the solar corona. These findings, it was pointed out, suggested a possible resolution of the long standing Rowland puzzle that concerns about 30% of all the solar lines that have been observed to date, but which have not been identified. These investigations were based on the solutions of the FTSE in momentum space, which requires somewhat specialized mathematical apparatus such as the

Funk-Hecke theorem for hyper-spherical harmonics and so on. During the year under review, G.P. Malik, along with V.S. Varma and R.K. Jha of Delhi University, have made an attempt to give a simple and transparent derivation of the solutions of the FTSE by following the more familiar co-ordinate space methods, and thus establish the correctness of the earlier derivation. This was duly achieved and reported. In order to lend greater credence to the above body of work, these authors then made it their major concern to use the FTSE-approach for the description of a system other than the astrophysical plasma. This decision naturally led them to extend the scope of their investigations from QED to QCD. Specifically, they have been able to show that the temperature dependent dynamics of confinement of quarks based on several standard QCD potentials/Kernels leads to the masses of the Upsilonium and the Charmonium families which are in reasonably good agreement with the observed masses. The first of a series of such investigations has already appeared in print.

### R.P.Saxena

R.P. Saxena, in collaboration with Patrick Das Gupta and Niraj M. Upadhyaya, has investigated a mechanism for the generation of baryon asymmetry in the early universe (BAU) via the Hawking evaporation of primordial blackholes (PBH) produced at the end of an inflationary era. This evaporation is slowed down by the accretion of relativistic matter present at the time of the formation of PBH's. Thus a sufficiently small PBH can last upto a time which is well past the electroweak phase transition time. At such epochs, the PBH's with a temperature as high as Grand Unified Theory temperatures, can generate BAU through the decay of X-bosons. Since the ambient temperature of the universe at such times is less than 100 Gev, this process occurs well out of equilibrium. Their estimates for the BAU are quite good provided the CP violating parameter is $\sim 0.001$. R.P. Saxena, in collaboration with A. Mukherjee and H.K. Jassal has investigated cosmological compactification of $D = 10, N = 1$ supergravity super Yang-Mills theory obtained from superstring theory. $N = 1$ supersymmetry constraints are imposed on the vacuum state of the theory. A duality transformation was performed on the consistency conditions. The original as well as the transformed consistency conditions are solved numerically for a nontrivial FRW scale factor and a dynamical dilation. It was shown that various classes of solutions are possible, which include cosmological solutions with no initial singularity. In collaboration with N. Panchapakesan, A. Mukherjee and Hatem Widyan, R. P. Saxena has studied a scalar field theory with asymmetric potential at zero and infinite temperatures. The equations of motion were solved numerically to obtain O(4) symmetric and cylindrically symmetric (O(3) symmetric) bounce solutions. These solutions control the tunnelling rates from the false to the true vacuum states of the theory. With these solutions one can investigate the validity of the thin wall approximation. An approximate analytical solution which reproduces the results of the thin wall approximation was also obtained. Efforts are on to extend these results to thick walled bubbles.

### L.P.Singh

L.P. Singh has worked on higher dimensional supersymmetric quantum mechanics (SUSYQM) in collaboration with B.Ram of New Mexico State University, USA, during his visit to IUCAA for two weeks in the month of October 1997. One dimensional

SUSYQM has been extensively studied whereas, the higher dimensional SUSYQM has not received as much attention. In a recent work by Das, Okubo and Pernice, it has been shown that higher dimensional SUSYQM necessarily brings in spin structure into the theory. Vahle and Ram had shown that 1 dimensional SUSYQM can be obtained through 1 - 1 dimensional Dirac equation. Taking cue from both the works mentioned above, Singh and Ram have been able to show that 3-dimensional SUSYQM can also be obtained through 3+1 dimensional Dirac equation. They find that linear superposition of similar helicity states play the role of superpartners. As a practical usefulness of this result, they show that if solution of Schrodinger equation for a class of SUSY partner potentials $V_{\pm}(X) = m^2(X) \pm 3m'(X)$, implies solution of Dirac equation for the corresponding Lorentz scalar potential m(X).

**S.K. Srivastava**

S.K. Srivastava has carried out investigations based on the dual role of Ricci scalar at high energy level i.e., at or above $10^9$ GeV. Ricci scalar is a geometrical field, but from the theory of higher-derivative gravity it is found that it also behaves like a spinless physical field at or above $10^9$ GeV. Recently, in collaboration with K.P. Sinha, he has published a paper in which he has obtained the same behaviour of Ricci scalar from higher-dimensional higher-derivative gravity. In field theory, fields are mathematical concepts representing particles. The physical aspect of Ricci scalar is manifested by scalar fields of mass dimension in natural units ($\hbar = c = 1$) which is denoted as $\tilde{R}$. Here $\tilde{R} = \eta R$, where $R$ is the Ricci scalar and $\eta$ is a quantity of unit magnitude and length dimension in natural units. Particle represented by $\tilde{R}$ is called riccion. In this work, Srivastava and Sinha have shown that riccion can disintegrate into fermion and anti-fermion pair provided parity is violated. Mass of these fermions is exactly equal to mass of riccion showing a possible existence of supersymmetry. Moreover, using dual role of Ricci scalar, Srivastava has also obtained inhomogeneous and anisotropic cosmological models of the early universe using physical techniques of phase transition and spontaneous symmetry breaking. S.K. Srivastava has authored a review article on Kaluza-Klein cosmology.

## (III) IUCAA-NCRA GRADUATE SCHOOL

The IUCAA graduate school is run jointly with the National Center for Radio Astrophysics (NCRA, TIFR). Since its inception almost ten years ago, nine IUCAA students have been awarded Ph.D. degrees and another three will be defending their Ph.D's very soon. Presently, the IUCAA graduate school has nine 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. Additionally, 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.

Four IUCAA research scholars, J.S. Bagla, Vijay Chickarmane, Dipak Munshi and L. Sriramkumar 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:

### Gravitational clustering in an expanding universe

*by J.S. Bagla*

The theme of this doctoral thesis is to explore some aspects of formation of large scale structures in our universe. Structures like galaxies and clusters of galaxies are believed to have formed out of small density perturbations via gravitational instability. In this picture, over dense regions accrete mass and grow at the expense of under dense regions. Observation suggest that a large fraction of the mass in the universe is invisible, the so called dark matter. In most of the popular models, the process of gravitational instability is driven by the gravitational force of the collisionless dark matter which is the dominant constituent of the universe. Visible structures like galaxies arise when baryonic matter condenses and forms stars, etc., in the potential wells produced by dark matter.

The full problem of structure formation at very large scales is to explain appearance and physical properties of galaxies, and clustering of galaxies, starting from constituents of the universe and some initial spectrum of density perturbations. This involves studying gravitational instability and other astrophysical phenomena in an expanding universe. Further, this analysis has to be carried out for a large variety of initial conditions and background cosmologies in order to explore the parameter space. This problem is simplified, and made tractable by breaking it up into smaller pieces. It is assumed that galaxies are fair tracers of the total mass distribution. In this formulation, the key problem lies in understanding the evolution of clustering of dark matter. In this thesis we make an attempt to isolate and understand some generic aspects of gravitational clustering of dark matter. An understanding of such model independent features can serve as a base for understanding the full problem of structure formation outlined above.

A chapter wise summary of the thesis is given below:

Cosmology is studied in the framework of general relativity, and our universe is described as an isotropic and homogeneous universe at large scales. The spacetime metric used here is known as the Robertson-Walker metric. However, on small scales the universe is very inhomogeneous and galaxies show significant clustering. Perturbations in non-relativistic matter at these scales can be studied in the Newtonian limit of Robertson-Walker metric. This also requires the dominant constituent of the universe to be non-relativistic. As all models that compare well with observations have non-relativistic dark matter as the dominant component, we will work exclusively in the Newtonian limit.

In chapter 1, we briefly review cosmological models and discuss the Newtonian limit of Robertson-Walker metric. We introduce basic terminology and mathematical framework that is used in the study of evolution of gravitational clustering. We discuss some earlier work that has been done in this field and is relevant to issues discussed in the later chapters.

Evolution of clustering for small over densities can be computed analytically using linear perturbation theory. There is no equivalent method available for handling large perturbations in density and one has to resort to numerical simulations. Numerous approximation schemes have been developed in the past few years to understand the evolution of gravitational clustering in the intermediate regime which is characterised by over densities of order unity. These offer interesting insights about the contribution of different processes in evolution of density perturbations. One very useful scheme was suggested by Zel'dovich, and is generally known as the Zel'dovich approximation. This approximation scheme predicts that the first structures to form as a result of gravitational collapse are surfaces of high density, popularly known as pancakes, irrespective of the detailed model of structure formation. This prediction has been verified in numerous N-Body simulations. These simulations have also shown that the pancakes remain thin and persist for a long time.

In chapter 2, we discuss an approximate method for evolving density perturbations which brings out essential physical reasons for stability of pancakes. This scheme, called the frozen potential approximation [Bagla and Padmanabhan, 1994], shows that expansion of universe is the primary reason for thin and stable pancakes and evolution of gravitational potential does not play a very significant role. Expansion of universe dampens all velocities and the particles are trapped within the pancake. This approximation gives good position and velocity information, even after shell crossing. In this chapter, we also compare this approximation scheme with N-Body simulations and other approximation schemes to access its validity.

The success of frozen potential approximation for a wide class of models implies that the evolution of potential is relatively unimportant for these models even in the nonlinear regime. We show that this can be understood on the basis of scaling relations between the true correlation function and the linearly evolved correlation function. The correlation function of gravitational potential at a given scale does not evolve if the density correlation function at the same scale is evolving at the linear rate. Scaling relations show that this is true for power law spectra with index $n = -1$ in the quasi linear regime, and $n = -2$ in the nonlinear regime. We show that it is possible to have conspiracy spectra with "correct" index of power spectrum in the nonlinear and quasi linear regimes, so that the gravitational potential undergoes very little evolution. The popular class of models known as the Cold Dark Matter models satisfy this criterion and the gravitational potential for such models varies by less than 10% at scales larger than 1 $h^{-1}$ Mpc. [Bagla and Padmanabhan, 1995a]

Chapter 3 is devoted to a detailed discussion of cosmological N-Body simulations. The main focus here is on Particle Mesh codes. We discuss the algorithm and various components of a Particle Mesh N-Body code and choose a set of components, on the basis of error analysis of individual components, to construct an optimum code. We describe many tests for N-Body codes and use these tests to quantify limitations of the code.

A density field in the growing mode can be described completely by specifying density contrast in its linear phase. This is no longer true in the nonlinear regime and we must supplement information contained in density contrast with some other indicator. In chapter 4, we discuss an indicator called velocity contrast that determines the level of nonlinearity in the velocity field. Velocity contrast relies exclusively on dynamical information, namely velocity and force [Bagla, 1996a ; Bagla and Padmanabhan, 1996a]. This indicator makes use of the fact that velocity and gravitational force are well aligned before formation of pancakes, but after shell crossing the mismatch continues to increase till the particle/mass element becomes part of a virialised system. We have shown that it discriminates between different levels of nonlinearity where density contrast can not provide such information. Velocity contrast can be used to define a bias in clustering of nonlinear and the underlying mass distributions. The bias parameter defined in this way is scale dependent and approaches unity at large scales. It is larger for regions at higher level of nonlinearity in dynamics. It is however, a softer function of scale as compared to bias defined using density contrast. Velocity contrast also attempts to bypass the simplifying assumption that galaxies are fair tracers of the total mass distribution.

Evolution of density perturbation in quasi linear regime generates density perturbations at small scales if there were no perturbations to begin with, for example in evolution of HDM model. In chapter 5, we try to understand this power generation on the basis of toy power spectra. Here we consider voids to be the fundamental objects in the process of structure formation, and formation and instability of shells around voids is used to understand the transfer of power. Evolution of these models suggests that there exists a critical index for the power spectrum in the quasi linear regime, and the slope of any arbitrary power spectrum tends towards this critical index. Such a behaviour is also seen in scaling solutions for correlation function. [Bagla and Padmanabhan, 1996b].

In most popular models of structure formation, first structures are expected to form around $z \approx 5$. It may be possible to detect neutral hydrogen in proto-clusters of young galaxies by observing red shifted 21 cm line. Chapter 6 explores the possibility using simple models for evolution of neutral fraction in galaxies along with N-Body simulations of CDM like dark matter models to compute the expected flux. Here we compute the expected signal for different models of structure formation and compare it with expected noise levels in the Giant Metrewave Radio Telescope. We generate artificial maps from simulation data and discuss methods by which we can optimally detect these proto-clusters.

Appendix 1 contains an analysis of observational constraints for cosmological parameters for the CDM class of models. We show that only a narrow range of parameter space is allowed with the present observations. We use one of these models in chapter 6 for computing the flux due to proto-condensates at high redshifts.

The thesis is mainly based on the following publications:

Bagla J.S. and Padmanabhan T. : *Nonlinear Evolution of Density Perturbations using Approximate Constancy of Gravitational Potential*, Monthly Notices of Royal Astronomical Society, 266, 227-237, 1994.

Bagla J.S. and Padmanabhan T. : *Nonlinear Evolution of Density Perturbations*,

Proceedings of the sixth Asia Pacific Regional Meeting of the IAU, ed. V.K.Kapahi et al, Special supplement to the Journal of Astronomy and Astrophysics, 16, 77, 1995a.

Bagla J.S. and Padmanabhan T. : *Evolution Of Gravitational Potential In The Quasilinear And Nonlinear Regimes*, IUCAA 8/95, 1995b.

Bagla J.S. : *A New Indicator of Nonlinear Gravitational Clustering*, IUCAA 26/95. *Clusters, Lensing, and the Future of the Universe*, ed. V.Trimble and A.Reisenegger, ASP series, vol.88, 201, 1996a.

Bagla, J.S., Padmanabhan, T. and Narlikar, J.V.: *Crisis in Cosmology - Observational Constraints on $\Omega_0$ and $H_0$*, Comments on Astrophysics, 18, 275-278.

Bagla J.S. and Padmanabhan T. : *A New Statistical Indicator To Study Nonlinear Gravitational Clustering And Structure Formation*, IUCAA 9/95, Astrophysical Journal, 469, 470, 1996a.

Bagla, J.S. : *Observational Constraints on $\Omega_0$ and $H_0$*, IUCAA 21/96, To appear in proceedings of Moriond Workshop on Dark Matter in Cosmology, Quantum Measurements, Experimental Gravitation, 1996b.

Bagla J.S. and Padmanabhan T. : *Critical Index and Fixed Point in the Transfer of Power in Nonlinear Gravitational Clustering*, IUCAA 20/96, To appear in the Monthly Notices of Royal Astronomical Society, 1996b.

Bagla J.S. and Padmanabhan T. : *Cosmological N-Body Simulations*, IUCAA 39/96, To appear in Pramana, 1996c.

Bagla J.S., Nath B. and Padmanabhan T. : *Neutral Hydrogen at High Redshifts as a Probe of Structure Formation - III. Radio Maps from N-Body Simulations*, IUCAA 40/96, To appear in the Monthly Notices of Royal Astronomical Society, 1996.

## Theoretical Aspects of Laser Interferometric Gravitational Wave Detectors

*by Vijay Chickarmane*

The direct detection of gravitational waves (GW) is perhaps the most challenging problem in experimental physics today. Success in this field will benefit both astronomy, where new information is expected to emerge and fundamental physics, where various theories of gravitation could be tested. Cosmic GW are emitted by the coherent bulk motion of matter from regions of strong gravity. Also, matter is almost transparent to GW due to the weak coupling of gravity. Hence, GW pass easily through matter, unlike electromagnetic radiation, and their observation will provide us with a new window to the universe. The observation of gravitational waves will lead to a better understanding of several astrophysical objects such as: supernovae, black holes and compact coalescing binaries. This has resulted in a world wide effort to detect GW with plans to build large scale laser interferometric gravitational wave detectors, namely, the LIGO (a US project), VIRGO (a French-Italian project), GEO (A German-British project), AIGO (an Australian project) and TAMA (a Japanese project).

These detectors in their simplest form consist of a simple Michelson interferometer, with their end mirrors freely suspended as pendulii. They operate by sensing the difference in phase shifts imposed on the laser light in the two orthogonal arms of the interferometer by a passing GW. This phase shift manifests itself in the observed intensity change of the interference pattern. Since the amplitude of these GW is expected to be extremely weak, the change in the output intensity is very small. It is easily swamped out by various sources of noise. This has lead to a considerable effort to understand the various noise sources and find techniques to reduce them. The sensitivities of the detectors being currently developed are limited in the relevant frequency range by the thermal noise of the mirror holders, seismic isolators, suspension wires, substrates, etc. In the next generation of detectors, when sufficiently high quality factor materials are used, the quantum noise will be a significant factor in determining the sensitivity. There are two fundamental sources of quantum noise: the photon counting error, which arises due to the discreteness of the electromagnetic field and the fluctuation of the radiation pressure of the light on the end mirrors. In the presently planned configurations, radiation pressure fluctuations are negligible. It was first realised by Caves that the photon counting noise could be understood as arising due to the interference of the vacuum modes which enter the interferometer through the unused input port of the beam splitter and the input laser light. He suggested instead, that a squeezed photon state could be injected through this port to reduce the photon counting noise. So, squeezing may be a significant improvement in the next generation of detectors. Significant improvement in sensitivity can be obtained by using light recycling techniques such as power recycling and signal recycling. When both recycling techniques are employed, the detector is said to be dual recycled. It is, therefore, important to study the sensitivity of an interferometer which employs dual recycling and squeezing.

The goals of the thesis are described below:

- The first goal is to study the optical system of a dual recycled interferometer into which squeezed light is injected. The study includes an interferometer with Fabry-Perot cavities in the arms. Specifically, the aim is to determine the improvement in sensitivity due to the squeezed light.

- The detection of small phase shifts suffers from low frequency laser noise which is orders of magnitude larger than the signal. Thus, the frequency bandwidth in which GW are expected to be detected has to be shifted to higher frequencies. This is achieved by using phase modulation techniques. It is, therefore, important to study a signal recycled frontal phase modulated interferometer with an input field of squeezed light. The goal is to study the sensitivity, bandwidth and the spectrum of the squeezed light necessary to bring about an enhancement in the signal to noise ratio.

- Power recycling in the interferometer will lead to very large powers which will be incident on the mirrors. The radiation pressure due to this stored power will tend to push the mirrors and change the tuning of these cavities. The objective of the thesis is to study the stability of these cavities and derive the conditions for stability /instability. The effects of input laser noise will also be examined.

In chapter 1, after a general introduction to the subject of gravitational waves, we discuss the present status of gravitational wave experiments. We then discuss the goals of the thesis and finally present the outline for the rest of the thesis.

In chapter 2, we discuss the basic issues involving gravitational waves and detection, and a few astrophysical sources and the generation of these waves. The gravitational waves produce tidal distortions on test masses. These tidal forces cause very tiny displacements, which are measured by interferometry. The effect of a gravitational wave on an electromagnetic wave propagating along a fixed direction is then computed. A simple treatment of a Michelson interferometer which illustrates the basic detection scheme is then discussed. A general description of advanced detectors is given. The understanding of noise in interferometers is the most important aspect of detection. The various noise sources such as seismic, thermal and photon shot noise are discussed. Simple estimates are given for the power spectral density of the noise. We then review the optical properties of simple Fabry-Perot cavities. The frequency response of these cavities is derived and the standard theory of paraxial propagation of light is discussed.

We discuss light recycling techniques in chapter 3. The power recycling technique which effectively enhances the power incident on the beam splitter of the interferometer is first discussed. The effect of a gravitational wave on the light which propagates in a Fabry-Perot cavity is computed. The gravitational wave creates sidebands on either side of the carrier (which is the monochromatic laser light) which differ in frequency from the laser by the gravitational wave frequency. We then construct the electromagnetic field equations in the cavity by matching the fields at the mirrors. The treatment is formulated in terms of scattering matrices which give us the output field in terms of the input field. Having discussed the signal that has to be detected, we move on to describe the signal recycling technique. In signal recycling the gravitational wave induced sidebands are recycled by appropriate optics and this is illustrated by using the results obtained earlier. We finally discuss dual recycling.

In chapter 4, the squeezed state technique is introduced. We begin by setting up the formalism to understand quantum noise in the interferometer. Coherent states are discussed in detail and using these results, we derive the expression for the photon shot noise. Squeezed states are then discussed, first by understanding, how they are produced in a parametric amplifier and then through formal definitions of the squeeze operator. The reduction of the photon shot noise is then demonstrated. Radiation pressure fluctuations are then discussed and by considering the total noise, we derive the standard quantum limit. Losses are detrimental to the squeezed state technique. We describe a simple model using beam splitters, to understand losses, within the frame work of quantum optics. The simple model is compared to the more formal one which uses the Langevin treatment.

We present our results of the application of the squeezed state technique to a dual recycled interferometer in chapter 5. We first analyse the minimum detectable phase difference in an interferometer which uses the dual recycling technique and squeezed light. We then discuss the linearised method of treating quantum fluctuations which is then applied to a simple Michelson interferometer to obtain the signal to noise ratio. We consider the consequences of imperfect fringe visibility in the interferometer. The equations for the electromagnetic field in the dual recycled interferometer are then constructed. Losses are incorporated in the arms of the interferometer by making the end mirrors partially transmitting. Losses not only take away some of the incident power but also introduce noise in the form of vacuum fluctuations. We present arguments which, when the interferometer is made to operate at a dark fringe for the laser light, show that the entire interferometer can be thought of as two coupled cavities. One is the power recycling cavity and the other is the signal recycling cavity, which are coupled by the phase offset in the arms of the interferometer. Two cases are considered, namely, the broad band and the narrow band dual recycling. In each of these cases, it is demonstrated that the sensitivity is *enhanced* by the use of squeezed light, and the results are illustrated by graphs. The enhancement in sensitivity is approximately equal to the squeeze factor for very low losses. For the narrow band, we consider the impedance matched case, that is, when the signal recycling mirror reflectivity is set equal to the reflectivity of the effective mirror formed by the two arms of the interferometer. The gain in sensitivity as well as the bandwidth for different amounts of squeezing is compared. Comments are made on the spectrum of the squeezed light that must be used to bring about an enhancement of the sensitivity.

In chapter 6, we then extend the squeezed state technique to an interferometer which uses a specific phase modulation technique.

Phase modulation techniques in interferometers are required to shift the detection frequencies to a very high region (MHz), where the laser noise is quantum noise limited. This is explained using a simple model for an internal phase modulated Michelson interferometer. We then consider a frontal phase modulated interferometer into which squeezed light is injected. The signal to noise ratio is calculated for frequencies around the modulation frequency, by using the linearised method. Several inferences are drawn about the required spectrum of squeezing. The output noise spectrum is found to be coloured in general due to the squeezed input field. This treatment is then extended to a frontal modulated signal recycled interferometer. It is once again found that squeezed light can enhance the sensitivity of the instrument for both, the broad band and narrow band cases, if its spectrum is suitably chosen. The bandwidth of the instrument for the narrow band case is found to depend on the choice of the squeezed light spectrum. Particular attention is paid to the impedance matched case for the narrow band, where the sensitivity for the interferometer with squeezed light is compared for different amounts of squeezing. An important result of this chapter is that, by manipulating the input squeezed spectrum, it is possible to shift the resonant frequency of the detector for the narrow band case. This is illustrated through various curves for the signal to noise ratio as well as through physical arguments. We finally consider the physical effects of imperfect fringe visibility in the interferometer and find that the total noise spectrum now gets additional contributions from the laser and squeezed noise. This allows us to set limits on the modulation index.

We then consider in chapter 7 the effects of high powers in Fabry-Perot cavities, which have the end mirror suspended as a pendulum in chapter 7. Here the main interest is in the stability of the cavity. The forces acting on the mirror are due to the radiation pressure which pushes the mirror, gravity which tends to get the mirror back in place and a servo which has high gain at low frequencies (where the noise is high). The radiation pressure due to the stored power tends to displace the mirror, thus, detuning the cavity.

Thus, the problem is nonlinear. By computing the forward and reverse transfer functions, a characteristic equation is obtained for the stability problem of the cavity. It is then found that for a given finesse and a negative phase offset, below a critical value of the input power, the system is stable. For positive phase offsets the system is inherently stable. Instability occurs in the limit of relatively large negative phase offsets, high finesse and large input powers. Conditions on the system parameters are obtained for stable configurations. We finally do a preliminary analysis of the effects of the laser input noise which is incident on such a cavity. We then discuss the implications for large scale detectors such as VIRGO.

We finally present our conclusions and point out future directions in chapter 8.

This thesis is mainly based on the following publications :

Vijay Chickarmane and Biplab Bhawal, *Squeezing and Dual Recycling In laser Interferometric Gravitational Wave Detectors, Physics Letters* **A 190**, 22-28, 1994.

Vijay Chickarmane and S.V. Dhurandhar, *Performance Of A Dual Recycled Interferometer With Squeezed Light*, Physical Review **A54**, 786, 1996.

V. Chickarmane, S.V. Dhurandhar, T.C. Ralph, M. Gray, D.E. McClelland and H-A. Bachor, *Squeezed Light In A Frontal Modulated Signal Recycled Interferometer*, In preparation.

V. Chickarmane, S.V. Dhurandhar, R. Barillet, P. Hello and J-Y. Vinet, *Radiation Pressure and Stability of Interferometric Gravitational Wave Detectors,* Submitted to Physical Review D.

## Certain aspects of the formation and evolution of large scale structure in the universe

*by Dipak Munshi*

Observationally, we notice that galaxies are not distributed at random in space, rather they are arranged in thin sheets or filaments surrounding large empty regions called voids. Explaining these large scale structures (their origin and evolution) is one of the major problems in modern cosmology. Recent observations made by the COBE (Cosmic Microwave Background Explorer) satellite suggest that very small ripples in energy density were already present during the cosmological recombination epoch. It is commonly believed that these small fluctuations were later amplified via gravitational instability to give the present-day large scale structures in the universe such as galaxies, clusters and super-clusters of galaxies. Even though the gravitational instability picture is widely accepted, we still do not have a clear analytical picture of gravitational instability due to its highly complicated nonlinear nature. A complete understanding of gravitational clustering will provide us with a means to analyze the diverse observational data in a meaningful way. The objective of this thesis is to study different dynamical and statistical characteristics of gravitational clustering through the different stages of its evolution and through the imprint it has left behind on the Cosmic Microwave Background.

There are several different stages marking the evolution of gravitational clustering. At the very early stage one can use linear theory to follow evolution, but with time, higher order corrections to linear theory begin to grow and one has to take into account higher order terms in the perturbative series, describing physical quantities such as density, velocity and gravitational potential. Finally, inhomogeneities become very large and the whole perturbative analysis breaks down. Since, no analytical methods are available to explain the fully developed nonlinear stage of gravitational instability, one has to rely upon N-body simulations. However, there are several approximation methods which one can use in order to follow the evolution of self-gravitating matter to an intermediate stage of nonlinearity. Examples of successful approximation methods include the Zel'dovich approximation and the Adhesion model. Although, these approximations break down eventually, they do highlight one or the other aspect of gravitational instability. Using analytical calculations, we were able to show that all these approximations (Zel'dovich, Frozen Flow and Linear Potential) agree with perturbation theory at linear order but begin to deviate from exact dynamics once nonlinear corrections start dominating. It was possible to give a closed form expression for the second order correction to linear order for all these approximations. As a result of this analysis, it became clear that the Zel'dovich approximation, which is the simplest and most widely used, still remains the best possible approximation to apply in the nonlinear regime, until shell crossing. In the linear regime the evolution of perturbations is self-similar and the Gaussian nature of initial perturbation remains unchanged. Second order corrections to linear theory introduce signatures of non-Gaussianity, which can be characterized by skewness parameters $S_3$ and $T_3$ of the density and divergence of the velocity field respectively. Using second order calculations, we have calculated these parameters explicitly for all approximations. Higher order corrections to linear theory are difficult to handle due to the complicated nonlinear nature of the problem. However, an ansatz developed by us based on the generating function approach for moments of density and velocity fields, allows us to calculate all order correlation functions at tree-level. This information has been used to construct other useful quantities, such as the void probability function, probability distribution function, etc., in closed form for all nonlinear approximations. One of the most valuable outcomes of this analysis has been the conclusion that perturbation theory, based on a Lagrangian description is invariably better than Eulerian approximations in approaching exact quasi-linear dynamics. It was found that $n^{th}$ order Lagrangian theory always reproduces the first $n+1$ moments of the density and velocity fields.

The intermediate stage of nonlinear gravitational clustering exhibits very interesting features of gravitational instability. Formation of cellular structure which starts to develop during the late quasi-linear stage by trajectory crossing of particles is completed in this epoch, and matter starts collecting in the form of two dimensional sheets (also known as pancakes), which are connected with each other in the form of filaments and clumps. At still later stages, matter begins to move in a complicated fashion within pancakes and filaments and finally ends up in virialised clumps. None of the perturbative techniques (Lagrangian or Eulerian) discussed so far is able to handle such a complicated process, although they remain valid on scales larger than typical sizes of these nonlinear elements (pancakes, filaments or clumps). Statistical descriptors like correlation functions remain important tools for understanding clustering, however, more advanced indicators are needed to describe geometrical shapes or topological connectivity of overdense or underdense regions. Much of the effort towards understanding gravitational clustering in the intermediate and highly nonlinear regime, has been devoted to developing different approximations which contain the flavour of such nonlinear physics. We have checked the performance of different approximation methods against N-body simulations, using a number of statistical indicators such as filamentary statistics, spectrum of overdense or underdense regions, and the void probability function, each of which probes a particular aspect of gravitational clustering. We use these statistical indicators, to discriminate between different approximations to gravitational instability. The approximations which we test are, the truncated Zel'dovich approximation (TZ), the adhesion model (AM), and the frozen flow (FF) and linear potential (LP) approximations. Of these we find that FF and LP break down relatively early, soon after the non-linear length scale exceeds the mean distance between peaks of the initial gravitational potential. The reason for this break-down is easy to understand; particles in FF are constrained to follow the streamlines of the initial velocity field. Shell crossing is absent in this case and structure gradually freezes as particles begin to collect near minima of the gravitational potential. In LP, particles follow the lines of force of the primordial potential, oscillating about its minima at late times. Unlike FF and LP, the AM (and to some extent TZ) continues to give accurate results even at late times. This is because, both AM and TZ utilize the presence of long range power in the gravitational potential to move particles. Thus, as long as the initial potential has sufficient long range power to initiate large scale coherent motions, TZ and AM will remain approximately valid. In relation to AM, TZ suffers from a single major drawback - it underestimates the presence of small clumps. Similarly, it predicts the right mean density in large voids but misses subcondensations within them. On the other hand, TZ is very fast to implement and more accurately predicts the location of large objects at late times.

The fully developed non linear regime is characterized by the gradual disappearance of cellular structure, most matter having now collected in clumps of different sizes. The knots connecting filaments in the intermediate regime are progenitors of these virialised clumps. It is natural to assume that these virialised clumps no longer participate in the background expansion of the universe and maintain a constant size in proper coordinates. Such an ansatz is also known as the stable clustering ansatz. One can also argue that, since gravitational dynamics itself does not introduce any scales in the system except for the scale of nonlinearity, gravitational clustering for scale-free initial conditions will always be self-similar. Combined with the stable clustering ansatz, self-similarity can be used to calculate the slope of correlation functions in the highly nonlinear regime. While, self-similarity can give their slope, an analytical derivation of the amplitude of correlations in the strongly nonlinear regime, remained unknown until very recently. In this thesis we derive the amplitude and slope of correlation functions of all orders both in the intermediate and the highly nonlinear regime. According to the analysis, which is based on spherical collapse of peaks of different heights in the initial density field, the intermediate regime is characterized by the collapse of only very high peaks, whereas the highly nonlinear regime is based on collapse of peaks of intermediate height in the initial density field. This analysis extends the scaling relations proposed earlier to relate the nonlinear correlation function to the linear correlation function to arbitrary order, which can be used to calculate $S_N$ both in the intermediate and the highly nonlinear regime. Comparison with existing simulation results shows very good agreement.

As mentioned earlier, complete knowledge of $S_N$ parameters in any regime gives us the possibility of determining other statistical quantities such as the probability density function (PDF), void probability distribution function (VPF), etc. Scaling relations generally suggest that the $S_N$ parameters will reach constant values in the highly nonlinear regime. Based on this ansatz one can make generic predictions about several properties of VPF and PDF. We have successfully checked such predictions against N-body simulation for a class of initial spectra both in two and three dimensions. We also propose a completely new technique based on factorial moments to calculate $S_N$ parameters from N-body catalogues. Several spurious effects, which makes determination of $S_N$ parameters difficult, were shown to be easily avoidable using such techniques. This method was also found to be superior to other methods based on central moments, generally used in the highly nonlinear regime especially for small length scales where shot noise begins dominating the signal for correlations.

Comparison of observations of large scale structure with theoretical predictions are done mainly along three directions. While observed galaxy catalogues provide information regarding present day density inhomogeneity, measurements of peculiar velocities for a large number of galaxies, currently in progress, will give us a detailed picture of the velocity field of galaxies. While all such information is extremely important for sketching a complete picture of the inhomogeneous universe at relatively recent epochs, the other major ingredient in such a picture has to do with the nature of initial fluctuations in the density field. In the context of inflationary scenarios, the observed anisotropy in the Cosmic Microwave Background (CMB) is believed to probe the primordial metric perturbations (fluctuation in gravitational potential in the Newtonian picture) arising from inflation. Although, perturbations generated by inflation are Gaussian in nature, there remains the possibility that nonlinear gravitational clustering at later epochs induce "secondary" non-Gaussian features in the CMB anisotropy maps. If detected, such a feature will definitely provide a strong support in favor of gravitational instability scenarios. Although, there are claims in the literature that such a signature will always be possible to detect with better resolution, a careful analysis carried out in this thesis clearly shows that even though such signals will exist in principle, they will be almost impossible to detect for most of the currently popular cosmological models (CDM, etc.) because of the fact that the level of non-Gaussianity lies below the limit imposed by cosmic variance.

In addition to predicting scalar perturbations, which act as seeds for large scale structure formation, inflation also predicts a background of relic gravitational waves. CMB photons travelling in such a background get scattered of such gravitons. Such multiple scattering can change the Gaussian nature of perturbations. We have calculated the non-Gaussianity introduced by such a process.

This theory is mainly based on the following publications:

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### Quantum fields in non-trivial backgrounds

*by L. Sriramkumar*

Quantum field theory has been enormously successful as a theory describing the behaviour of fields up to energy scales of the order of 100 GeV. Quantum electrodynamics, the earliest of the gauge theories, describes the interaction of the electromagnetic field with matter. Though, during the early stages of its formulation, the divergences that arise in the theory had seemed too big a hurdle to overcome, regularization and renormalization procedures have been developed to handle these divergences and the theory has come up with a large number of predictions. Several of these predictions, like, Lamb shift, anomalous magnetic movement of the electron, have been experimentally verified, thereby firmly establishing the validity of quantum electrodynamics. The theory due to Salam and Weinberg has been able to successfully unify the electromagnetic and weak interactions into a single gauge theory. Also, the *W* and the *Z* bosons predicted by the theory have been observed experimentally, thereby establishing the Salam-Weinberg theory as the correct theory of weak interactions. Though, we are yet to have a theory that describes the strong interactions adequately, we have in hand a workable model in quantum chromodynamics. Efforts to describe all these three interactions by a unified gauge theory have also been successful.

The gravitational interaction has been the odd one out. All attempts to provide a quantum framework for the gravitational field have so far proved to be unsuccessful. In the absence of a viable quantum theory of gravity, can one say anything at all about the influence of the gravitational field on quantum phenomena? 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 semiclassical description yields some results that are 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 the conventional quantum field theory. Though, we are yet to have a quantum theory of gravity, there exist compelling reasons to believe that quantum gravitational effects will be important only at energy scales of the order of Planck energy ($\sim 10^{19}$ GeV). There exists a domain of 17 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 the matter fields can be assumed to have a quantum nature. Though, there exist other contesting theories to describe the classical gravitational field, experiments have pointed towards Einstein's general theory of relativity as the correct classical theory of gravity. Thus, adopting general relativity as a theory describing classical gravity, one is led to the subject of quantum field theory in curved spacetimes which has been an area of active research during the past couple of decades.

The conventional formulation of quantum field theory in Minkowski spacetime is invariant under the Poincaré group, i.e., the theory is invariant only under linear coordinate transformations. Under non-linear coordinate transformations, even in flat spacetime, quantum field theoretic concepts such as vacua, particles, etc., do not, in general, seem to possess a covariant meaning. Similar problems are encountered when the evolution of quantum fields are studied in curved spacetimes. Further, in a curved spacetime, the presence of the gravitational background can lead to production of particles corresponding to the quantum field. These particles that have been produced can also react back on the classical background. The metric, which is assumed here to be described by Einstein's equations, is a covariant concept. Therefore, if the backreaction of the quantum field on the gravitational background has to be studied meaningfully, a covariant description of the phenomenon of particle production is called for. This in turn, requires an understanding of the concept of a particle in an arbitrary curved spacetime.

The phenomenon of particle production takes place in classical electromagnetic backgrounds too. We can possibly learn lessons for the gravitational case by studying the evolution of quantum fields in electromagnetic backgrounds. In fact, some of the conceptual problems that arise while studying quantum fields in curved spacetimes are encountered in electromagnetic backgrounds too. Just as a covariant formulation of the phenomenon of particle production is required for gravitational backgrounds, a gauge invariant description of the same phenomenon is called for, in the case of electromagnetic backgrounds.

This thesis work is focussed towards improving our understanding of the phenomenon of particle production and also the backreaction of these particles that have been produced on the classical backgrounds.

A chapter wise summary of the thesis is given below:

In chapter 1, we introduce the basic terminology and the mathematical framework that is used to study the evolution of quantum fields in classical gravitational and electromagnetic backgrounds. This chapter reviews some of the essential results that serve as a background for the chapters that follow. We begin this chapter by illustrating the coordinate dependence of the particle concept with the aid of a simple example in flat spacetime. We then present an example of a time dependent gravitational background in which the phenomenon of particle production takes place. Motivating the usefulness of the detector concept, we introduce the Unruh-DeWitt detector. We discuss the response of inertial and uniformly accelerated Unruh-DeWitt detectors in flat spacetime and also analyze the response of these detectors in Schwarzschild and de-Sitter spacetimes. Carrying out the canonical quantization of a complex scalar field in a constant electric field background, we illustrate how the tunneling interpretation is invoked to explain the phenomenon of particle production in time independent gauges. Introducing the effective Lagrangian approach, we show that invariant results can be obtained by this approach with the help of an electromagnetic example. Finally, we discuss as to how the backreaction of the quantum field on the classical background can be taken into account and introduce the semiclassical Einstein's equations.

Chapter 2 is devoted to the study of finite time response of Unruh-DeWitt detectors. We begin this chapter by motivating the need for a finite time detector. We then study the response inertial and uniformly accelerated Unruh-DeWitt detectors in flat spacetime when they are switched on smoothly as well as abruptly for a finite proper time interval. We identify the divergences that appear in the response functions of the detectors when they are switched on abruptly and point out the origin of these divergences. We conclude this chapter by pointing out the limitations of the detector concept.

In chapter 3, we study the evolution of a quantized complex scalar field in classical electromagnetic backgrounds. We begin this chapter by introducing Schwinger's proper time formalism to evaluate effective Lagrangians. We then examine the validity of the tunneling interpretation, that is usually invoked in literature to explain the phenomenon of particle production in time independent gauges. With the aid of an example, we show that the tunneling interpretation can be inconsistent with the effective Lagrangian approach. The effective Lagrangian being a more reliable approach, we conclude that, this lack of consistency between these two approaches calls into question the validity of the tunneling interpretation. We then discuss the limitations of the Klein approach, that is used to study particle production in time independent gauges.

Though the effective Lagrangian approach is more reliable, the evaluation of the effective Lagrangian, even for a given classical background proves to be a rather difficult task. In chapter 3, we also propose a conjecture that can possibly help us guess the form of the effective Lagrangian for an arbitrary background. We put forward the conjecture that the effective Lagrangian for a classical background will be zero if all the invariant scalars (involving the field and its derivatives) describing the background vanish identically. We verify this conjecture by explicitly evaluating the effective Lagrangian for some non-trivial electromagnetic and gravitational backgrounds. We conclude this chapter with a few remarks on the boundary condition, that is implicitly assumed in the evaluation of effective Lagrangians using Schwinger's formalism.

In chapters 2 and 3, we had neglected the backreaction of the quantum field on the classical background and had concentrated our efforts on obtaining an invariant description of the phenomenon of particle production. Once such description is at hand, the backreaction of the quantum field on the classical background can be taken into account. It is generally assumed that the backreaction of the quantum field on a gravitational background is given by the expectation value of the energy-momentum tensor of the quantum field. Since, such a semiclassical theory is incapable of providing a preferred state for the quantum field by itself, the expectation value of the energy-momentum tensor has to be evaluated in a state specified by hand. This semiclassical theory can then be relied upon only if the fluctuations in the energy-momentum densities of the quantum field are small when compared to their expectation values. Using this as the criterion, in chapter 4, we analyze the validity of the semiclassical theory for a minisuperspace model of a massless scalar field in a Friedmann universe. We evaluate the magnitude of the fluctuations in the backreaction term for the states of the scalar field mode that correspond to the vacuum, *n*-particle and coherent states of the quantized scalar field. We find that the fluctuations in the backreaction term are small, even when a large amount of particles are being produced, only for coherent states with a large value for the parameter describing them. We, therefore, conclude that the semiclassical theory we have considered will be valid during all stages of evolution, only if the quantum fields are assumed to be in 'coherent' like states.

In quantum field theory, it is the coefficients of the positive frequency components of the normal modes of the quantum field that are identified to be annihilation operators. Therefore, the evolution of a quantum field is governed by the behaviour of the normal modes of the equation of motion satisfied by it. But, even a classical field satisfies the same equations of motion as does a quantum field. If so, can some of the non-trivial effects that arise in quantum field theory arise in classical field theory too? In chapter 5, we show that, this indeed can be the case. Fourier analyzing real plane waves modes of scalar and electromagnetic fields in flat spacetime with respect to the proper time of a uniformly accelerated observer, we find that the resulting power spectrum has a Planckian nature. We then outline as to how such a Planckian spectrum can also prove to be a feature of observers stationed at a constant radius in Schwarzschild and deSitter spacetimes. We conclude this chapter by presenting a model of a detector which responds to the Fourier spectrum of the field with respect to its proper time thereby illustrating that it should, in principle, be possible to physically measure the power spectrum we have obtained.

Finally, in chapter 6, we present our conclusions and outlook.

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## (IV) PUBLICATIONS

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*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.*

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**Padmanabhan, T.** (1996) Understanding nonlinear gravitational clustering in the expanding universe, *in* The Early Universe, Series on new frontiers in advanced physics), Ed. V.B. Johri, 195 (Hardonic Press of America).

- Nonlinear gravitational clustering in expanding universe (1997) *in* Proceedings of the ICGC-95 Conference held at IUCAA, Pune, India on December 13-19, 1995, Eds. Sanjeev Dhurandhar and T. Padmanabhan, 37 (Kluwer Academic Publishers, Netherlands).

- Inflation and other theoretical models (1997) *in* Reports on Astronomy, Vol. XXIIIA, 477, Ed. I. Appenzeller, 489 (Kluwer Academic Publishers, Netherlands).

**Ramaprakash, A.N., S.N. Tandon** and **Ranjan Gupta** (1998) Imaging polarimetry of nearby molecular clouds, *in* Proceedings of the IAU Colloquium No. 166: The Local Bubble and Beyond, D. Breitschwerdt, M. J. Freyberg and J. Trumper, Eds., Lecture notes in Physics, **506**

**Raychaudhury, Somak** (1998) The evolution of large-scale structure and the first quasars, invited review *in* AGN, Dense Stellar Systems, and Galactic Environments, Eds. S. Lamb & J. Perry (ASP Conf. Series).

**Srianand, R.** (1998) Origin of B-K colours of quasars, *in* ESO workshop on Quasar hosts, Ed. P. Crane, 150.

**Srinand, R.** and P. Petitjean (1998) Molecules in the $z_{abs} = 2.8112$ damped system toward PKS 0528-250, *in* IAP workshop on intergalactic medium, Ed. P. Petitjean.

**c) Books (Edited/Authored)**

**Dhurandhar, S.V.** and **T. Padmanabhan** (1997) [edited] Gravitation and Cosmology, Proceedings of the ICGC-95 conference held at IUCAA, Pune, India, December 13-19, 1995 (Kluwer Academic Publishers).

**Dhananjay V. Gadre** (1998) Programming the Parallel Port: Interfacing the PC for data acquisition and control (Published by R&D Books).

**Padmanabhan, T.** (1997) After the first three minutes - The story of our universe (Cambridge University Press, Cambridge).

**Narlikar, J.V.** (1997) [edited] Solar and Interplanetary Disturbances, by S.K. Alurkar [World Scientific Publishing Company Limited, Singapore].

**Padmanabhan, T.** (1997) [edited] New challenges in astrophysics, Lectures delivered at the IUCAA Dedication Seminar, December 28, 1992 (New Age International (P) Ltd., Publishers).

**d) Popular Articles**

**Narlikar, J.V.** (1997) Search for new planets, (Studies in History of Sciences, Calcutta, 90).

- (1997) The Importance of Experiments, (Physics Education, January-March, **13**, 4, 339).

- (1997) Cranks' Constant, (The Times of India, Mumbai, March 29).

- (1997) Popularizing Science : A Weapon Against Superstition, (The Times of India, Mumbai, June 28).

- (1997) Attacking Achievements, (The Times of India, Mumbai, July 17).

- (1997) The Balance Sheet, (Deccan Herald, August 19).

- (1997) Alphabetical March, (The Times of India, Mumbai, August 30).

- (1997) Bureaucratic Gravity, (The Times of India, Mumbai, October 4).

- (1997) Stars in our skies looking beyond our Galaxy, (Times of India, Mumbai, November 24).

- (1997) In Relative Terms : The Heavier Side of Gravity, (The Times of India, Mumbai, December 26).

- (1997) The Progressive Decline in Higher Education Over the Last Fifty Years, (Special Issue of Biblio, December 1997, 27).

- (1998) The Cosmological Debate : Big Bang vs QSSC, (Universe and Beyond, **1**, 2, 8 January 1998).

- (1998) A Burning Question, (Resonance, **3**, 3, March 1998).

- (1997) Yadon Ki Durbin Se (in Hindi), (Pradnya, Kashi Hindu Vishwavidyalaya Patrika, Mahamana Smruti Ank, **Part I and II**, 7).

- (1997) Mazi Kalpak Aai (in Marathi) [My Imaginative Mother], (Ravivar Sakal, April 20 and Suvarta, July, 17).

- (1997) Acharya Atre : Kahi Athavani (in Marathi) [Acharya Atre: Some reminences], (Acharya Atre, Pratibha and Pratima, Prestige Publications, Pune, 646).

- (1997) Sampale Mangalache Amagaltwa (in Marathi) [The inauspiciousness of Mars is over], (Andhashradha Nirmulan Vartapatra, 56).

- (1997) Mangalvar Abhiyan (in Marathi) [The Martian Campaign], (Pudhari - Bharari, August 28).

- (1997) Mazi Shala (in Marathi) [My School], (Kesri, October 22).

- (1997) Pradhushan Aani Khagol Nirikshan (in Marathi), [Pollution in Observational Astronomy], (Vanrai, Diwali issue, 98).

- (1997) Vaidyanaymik Chaukatitun Phaljyotishashe Mulyankan (in Marathi) [Astrology Evaluated within the Scientific Framework], (Lokmat, November 2).

- (1997) Vedh Gurutwakarshancha (in Marathi) [Probing Gravity], (Sakal, December 28).

- (1998) IUCAA Pahave Bandhun (in Marathi) [Setting up IUCAA], (Ruperi Kinar, Sakal, February 1998).

**Somak Raychaudhury** (1998) Where are the Waves? (Ripples in Spacetime), (The Telegraph, Calcutta, January 5).

- (1998) Wrestler Physicist (Obituary of David N. Schramm), (The Telegraph, Calcutta, January 26).

### e) Resource Summaries in the IUCAA quarterly Bulletin "Khagol"

**S. Sridhar** (1997) Galaxies: their structure and dynamics, (Issue No. 30, April 1997)

**J.V. Narlikar** (1997) Cosmology, (Issue No. 31, July 1997).

**S.N. Tandon** (1997) Site evaluation, (Issue No. 32, October 1997).

## (V) PEDAGOGICAL ACTIVITIES

### a) IUCAA-NCRA Graduate School

**S. Bose:** Quantum and Statistical Mechanics

**N.K. Dadhich:** Cosmology

**S.V. Dhurandhar:** Gravitational Waves, Electrodynamics and Radiation Processes

**S. Kar:** Mathematical Methods

**Ranjeev Misra**: Radiative Processes

**T. Padmanabhan:** Aspects of Quantum Field Theory

**Somak Raychaudhury:** Astronomical Techniques

**S. Sridhar:** Statistical Mechanics

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

**S.V. Dhurandhar:** Astrophysics II

**Ranjan Gupta:** Laboratory Course and Astrophysics I

**J.V. Narlikar:** Astrophysics II

### c) Supervision of Projects

**S.K. Banerjee**

Amit Dhurandhar
Prasad Bakre
Gaurang Sardesai
Neeraj Iyer
Zaki Mulla
Shrikant Pathak
Ravi Sastry
Supriya Alyalmath
(School Students' Summer Programme, 1997)
*Measurements of Stellar Distances Using the Method of Parallax (Triangulation)*

**S. Bose**

Neeta G. Alwani
Arvind R. Iyer
Pooja H. Notwani
Shripad B. Tiwari
Darshan A. Jawalebhoi
Vaibhav K. Vilashrao
Vaibhav Khandale
Sangram S. Pandit
Sadika S. Mallick
Sandeep C.
Sargam Tatwawadi
Shrinivas B. Kulkarni
Suriya A.K.A. Razzak
Suhas Vairat
(School Students' Summer Programme, 1997)
*Trigonometry and measuring the radius of Earth*

**Ranjan Gupta**

Amitesh Raj and Priya Pharate (M.Tech., University of Pune)
*Automated Telescope Control Software - Software testing and running of the telescope*

**J.V. Narlikar**

Jayashree Sadu Bambale
Kavita Anandilal Agarwal
Ashish D. Dixit
Prasanna Venkatesh Shivputra
Rekha Sampat Chormala
Anil Ratilal Patil
Arun Laxman Rasal
Suvarna Kaluram Taware
Nishikant H. Bhalerao
Ramesh Balasaheb Galgale
Sourabh Sudhir Patwardhan
Vipul Mahendrakumar Shah
(School Students' Summer Programme, 1997)

P.A. Kale
Shilpa Mulay
(under support from INSA)
*Search for historical references to the sighting of the Crab supernovae of 1054 A.D.*

S. Shukla
*Observational Tests of Cosmological Models*
(Vacation Students' Programme, 1997)

**T. Padmanabhan**

A.S. Oberoi and Y.Kulkarni (IBM Authorised Educational Centre)
*Educational software and visualisation packages in astronomy and astrophysics*

**Somak Raychaudhury**

Tarun Deep Saini (Graduate student)
*Gravitational Lensing by clusters of galaxies*

Mridula Chandola (Ph.D. student)
*X-ray and optical studies of very rich clusters of galaxies*

Rajesh P. Deo (M.Sc., Wadia College, Pune)
*Estimating the mass of dwarf elliptical galaxies*

Debojyoti Dutta (IIT, Kharagpur)
*Designing a Parallel Virtual Machine for fast n-body simulations*

Ashish P Garg & Buby D Bhandari
Bhurat B Ramesh
Suhasini Rao
Somsekhar Pal
Aparna Rajaraman
Sangamesh Kapust
Snehal Sharma
Ashwin Tidke
Kshitij Kulkarni
(School Students' Summer Programme, 1997)

**Somak Raychaudhury and Ranjan Gupta**

Sunayana Uberoi, Nilambari Ashar and Annapurna Mushriff (BE, Cummins College, Pune)
*A portable photometer and data acquisition system for amateur use*

**R.Srianand**

S. Shankara Narayanan (Graduate student)
*Chemical enrichment of high z galaxies*

**S.Sridhar**

Kishore Darak (M.Sc. Physics, Pune University)
*Gravitational dynamics in one dimension*

Dheeraj Patankar (IIT Kanpur)
*Plasma Physics*

**d) Supervision of Thesis**

**S.V. Dhurandhar**

V. Chickarmane (1997) qualified for the Ph.D. degree of University of Pune for his thesis on *Theoretical aspects of laser interferometric gravitational wave detectors.*

**T. Padmanabhan**

J.S. Bagla (1997) qualified for the Ph.D. degree of University of Pune for his thesis on *Gravitational clustering in an expanding universe*

L. Sriramkumar (1998) qualified for the Ph.D. degree of University of Pune for his thesis on *Quantum fields in non-trivial backgrounds.*

**V. Sahni**

Dipak Munshi (1998) qualified for the Ph.D. degree of University of Pune for his thesis on *Certain aspects of the formation and evolution of large scale structure in the universe.*

**e) Tutorial Assistantship**

**S.K. Banerjee**

General Relativity and Cosmology, M.Sc. (Physics), University of Pune, (for J.V. Narlikar)

## (VI) IUCAA COLLOQUIA, SEMINARS, ETC.

**a) Colloquia**

R. Amritkar: *Control of chaotic systems*, August 4.

Sriram Ramaswamy: *Are moving lattices unstable?*, August 12.

Abhay Ashtekar: *Quantum mechanics of geometry and black hole entropy*, August 19.

Sumit R. Das: *Microscopic understanding of black hole radiation*, September 1.

Peter Warlow: *Catastrophes of the solar system*, September 8.

Rohini Godbole: *Theoretical significance of the 'top' quark discovery*, October 6.

K.P.Singh: *Our universe in X-Rays*, October 13.

R. Nityananda: *Resonance : When atoms and light meet*, October 27.

Krishan Lal: *Real structure of real crystals*, November 11.

A.D. Gangal: *Local fractional calculus*, November 17.

G. Baskaran: *Novel quantum phases in condensed matter physics*, November 24.

V.P. Frolov: *Plenty of nothing: Black hole entropy in induced gravity*, December 26.

T.V. Ramakrishnan: *Why are high temperature superconductors interesting?*, January 19.

G. Meynet: *Wolf-Rayet stars: A link between gamma ray lines, meteorites and cosmic rays?*, February 12.

B.P. Das: *Atomic probes of the unification of fundamental forces*, March 2.

N.D. Hari Dass: *Duality in its many avatars*, March 9.

J.K. Bhattacharjee: *What is turbulence and why should we be mindful of it?*, March 17.

S. Chakravarti: *Life in anharmonic wells*, March 30.

**b) Seminars**

R.G. Vishwakarma: *Some Robertson-Walker models with constant active gravitational mass*, April 3.

Bruno Guiderdoni: *The cosmic infrared background and ISO deep counts*, April 4.

Prasenjit Saha: *Can lensed QSOs really tell us Ho?*, April 22.

Debojyoti Dutta: *Think parallel, think now*, June 18.

Niranjan Sambhus: *Optical morphology of radio galaxies*, June 20.

R.P. Saxena: *Duality and cosmological compactification of superstring*, June 25

Yuri Shtanov: *Preheating after inflation*, June 26.

Archana Pai: *Mode analysis of the bar detector*, July 17.

Y. Sobouti: *Oscillations in spherical stellar systems?*, August 7.

Urjit Yagnik: *Baryogenesis in the early universe*, August 8.

R. Balasubramanian: *Interferometric detection of gravitational waves from coalescing binaries*, August 21.

J.N. Islam: *Confinement, Schrodinger equation for Yang-Mills theory, Wheeler-De Witt equation and all that*, August 26.

Avinash Khare: *Non-Archimedean algebra, the law of gravitation and red shift in a finite universe*, September 10.

S.D. Mohanty: *Efficient data analysis techniques for the detection of gravitational waves from some important astrophysical sources*, September 12.

Rachel Somerville: *Galaxy formation at high redshift: Some recent results from semi-analytic models*, October 3.

Ved Ratna: *Project ideas for astronomy exhibitions for students of schools and colleges*, October 3.

Rohini Godbole: *Structure of photon*, October 7.

Noella D'Cruz: *The origin of extreme horizontal branch stars*, October 24.

Alain Omont: *Millimetre detection of molecular gas and dust in quasars at redshift larger than 4*, November 3.

G. Baskaran: *Quantum Hall systems*, November 26.

V. Faraoni: *Light meets gravity waves*, December 11.

J. Mikolajewska: *Symbiotic systems: Interacting binaries with the longest orbital periods*, January 5.

A. Chakraborty: *What's new at the heart of the lagoon nebula?*, January 6.

B. Jain: *Gravitational lensing and cosmology*, January 12.

R. Di Stefano: *Discovering planets and other* *topics in gravitational microlensing*, January 27.

A.N. Petrov: *On the energy distribution in general relativity*, January 28.

J. Bagchi: *The detection of Compton scattering of cosmic microwave background photons (CMBR) from the relativistic gas in a galaxy cluster*, March 11.

J. Vijapurkar: *Post-asymptotic giant branch stars*, March 16.

Fu-Xing Hu: *The orientation of spin vector of bright disk galaxies in the local super cluster and its implication and Introduction to Chinese astronomy*, March 24.

**c) PEP Talks**

K. Bhaskar: *Discovering strange attractors using experimental data*, April 17.

P. Saha: *Frobnication, universal grammars, and the "Pela Bilong Missus Kwin": A review of "The Language Instinct" by Pinkar*, April 23.

S. Sridhar: *Flow through pipe*, May 2.

Patrick Das Gupta: *For a few monopoles more (or Less)*, June 26.

Jihad Touma: *Oh! When the planets go marching in*, July 1.

Naveen Gaur: *Beyond the standard model*, July 8.

Ashish Mahabal: *The incompleteness theorem*, October 17.

Amitabh Bhattacharyya: *Liquid crystal domains at the water surface*, December 12.

**d) IDG (Informal Discussion Group) Meetings**

Vijay Kapahi (NCRA): *The Hubble deep field*, April 10.

Biman Nath: *The Hubble deep field*, April 10.

Ranjeev Misra: *Detection of gravitationally redshifted iron lines in AGNs*, April 24

D.J. Saikia (NCRA): *Probing the AGN environment using radio polarization observations*, April 24.

Rajaram Nityananda (RRI): *Merging of galaxies with central black-holes*, May 8.

R. Srianand: *Metal abundance and ionization in QSO intrinsic absorbers* , May 8.

Anish Roshi (NCRA): *Variance imaging in astronomy*, May 23.

V. Sahni: Does the Supercluster - *Void network show excess power on 120 $h^{-1}$ Mpc. scales?*, May 23.

S. Jeyakumar (NCRA): *Detection of a cosmic microwave background decrement towards high redshift quasar pair*, June 5.

Tarun Deep Saini: *Gravitational telescope in 0024+1654: Reconstruction of the source image*, June 5.

J.V. Narlikar: *Deceleration without dark matter*, June 19.

C.R. Subrahmanya (NCRA): A Radio Continuum Survey of Shapley-Ames galaxies at 2.8 cm: The radio-far infrared correlation, June 19.

S. Bose: *Explaining the periodic self-similarity of the zero-mass black hole space-time*, July 17.

Alain Lecavelier (NCRA): *New objects in outer solar system,* July 17.

Vijay Chickarmane: *Sagnac Interferometer for Gravitational Wave Detection*, July 31.

Gopal Krishna (NCRA): *HST and ground based observations of a sample of z ~ 1 radio galaxies,* July 31.

S. Ananthakrishnan (NCRA): *Parsec-scale radio cores in spiral galaxies*, August 14.

S.N. Tandon: *Discoveries of Planets (outside the solar system)*, August 14.

V.K. Kulkarni (NCRA): *Subparsec radio counter jet in Centaurus A*, August 28.

Sunu Engineer: *Non-linear Correlation functions*, August 28.

## (VII) TALKS AT WORKSHOPS OR AT OTHER INSTITUTIONS

### a) Seminars, Colloquia and Lectures

**S. Bose**

*Effect of quantum corrections on critical gravitational collapse, black hole evaporation, and in string cosmology*, (Golden Jubilee Workshop on Quantum Gravity, Physical Research Laboratory, Ahmedabad, August 8-9).

*Evaporating black holes and quantum corrections; Gravitational collapse, critical phenomena, and quantum effects*, (Workshop on Modern trends in gravitation and cosmology, Cochin University of Science and Technology, September 29 - October 3).

*On the detection of gravitational waves from coalescing compact binaries using a network of detectors; Exact solutions in string cosmology with back reaction; On different approaches to quantizing two-dimensional dilaton gravity models*, (The Fifteenth International Conference on General Relativity and Gravitation, IUCAA, December 16-21, 1997).

**N.K. Dadhich**

*Gravitation*, (Workshop on Astrophysics and Gravitation, Mount Charal, Kerala), September 11-13), 2 lectures.

*On electromagnetics of gravitation*, (Department of Physics, Punjab University, February 5).

**S.V. Dhurandhar**

*Radiation pressure induced instabilities in high power laser cavities with suspended mirrors*, (LAL, Orsay, France, June 2).

*Hierachical search strategies for detecting coalescing binary signals and parameter estimation*, (Observatory du Meudon, France, June 6).

*Hierarchical strategies for inspiralling compact binaries*, (Gravitational wave data analysis workshop 2, Orsay, France on November 13).

*The search for gravitational waves*, (Basic Sciences Research Institute, Istanbul, Turkey, November 21).

*Gravitational wave astronomy*, (XVIIIth meeting of the Astronomical Society of India, Ahmedabad, November 29).

*Data analysis of inspiralling compact binaries*, (Golden Jubilee meeting, Raman Research Institute, Bangalore, December 12).

*Data analysis of gravitational wave signals from inspiralling compact coalescing binaries*, (Physics Department, Australian National University, Canberra, Australia, February 20; and University of Western Australia, Perth

Australia, February 24).

**Valerio Faraoni**

*Can we detect gravitational waves using their effects as lenses?,* (College de France, Paris, November 12).

*Nonminimal coupling of the scalar field and inflation,* (GR15, IUCAA, December 20).

*Lensing by gravitational waves,* (WHEPP-5, IUCAA, January 19).

*Nonminimal coupling of the scalar field: good or bad for inflation?,* (WHEPP-5, IUCAA, January 20).

**Ranjan Gupta**

*Artificial neural networks as a pattern recognition tool in astronomy*, (Institute of Physics and Mathematics, Tehran, Iran, April 23).

*CCD compared with photography*, (Astrophotography in CCD era - a lecture/ demonstration series, IUCAA, September 8-9).

*New applications of artificial neural networks in stellar spectroscopy*, (Astronomical Data Analysis Software and Systems (ADASS'97) Conference, September 14-17, Sonthofen, Germany).

*Interstellar extinction by porous dust and related studies*, (Astrophysics Colloquium at Astrophysical Institute and Observatory, University of Jena, Jena, Germany, September 25).

*Seminar on astronomy and astrophysics*, (2 lectures, Introductory astronomy and observational aspects, Department of Physics, Pondicherry University, Pondicherry, October 13-14

*Pattern recognition by artificial neural networks: An application to classification of spectra*, (Colloquium at Institute of Plasma Research, Gandhinagar, December 16).

*Artificial neural networks applied to stellar spectroscopy*, (Workshop on Stellar structure and evolution, IUCAA, February 9-13).

**S. Kar**

*Black holes in string theory,* (Workshop on Modern trends in gravitation and cosmology, CUSAT, Cochin, October).

*Gravitational collapse,* (Workshop on Modern trends in gravitation and cosmology, CUSAT, Cochin, October).

*String cosmology without and with back reaction,* (WHEPP-5, IUCAA, January).

*String cosmology without and with back reaction,* (IOP, Bhubaneswar and Visva Bharati, Santiniketan, February).

*Ripples and kinks on strings and branes,* (IOP, Bhubaneswar, February).

**A.K. Kembhavi**

*Observation of 3CR radio galaxies with the UPSO telescope*, (UPSO, Nanital, April 7)

*Elements of image processing*, (Pune University, April 16).

*Cosmic images*, (NCPA, Bombay, September 26).

*Radio and normal ellipticals*, (University of California, Los Angles, October 24).

*Optical morphology of radio galaxies*, (Caltech, October 28).

*Surface brightness profiles of radio galaxies*, (Lawrence Livermore National Laboratory, November 2).

*The central blue colours of radio galaxies*, (University of Pittsburg, November 5).

*Colour of radio galaxies*, (Space Telescope Science Institute, November 12).

*Cosmic images*, (NCL, Pune, November 26).

*Stellar astronomy,* (Pune University, 2 lectures, February 24).

*Information technology*, [English] (KTHM, Nasik, March 7).

*Pargrahavarchi jeev srusti,* [ Marathi] (KTHM, Nasik, March 7).

**Arun Mangalam**

*MHD Generation and Acceleration Mechanisms in Quasars* (PLASMA 97, organised by Institute of Plasma Research, Gandhinagar, PRL, Ahmedabad December 3-5).

**Ranjeev Misra**

*Radiative processes in astrophysics* (Refersher course, IUCAA, May 97, 2 lectures)

*Transition disk fit to Cygnus X-1* (TIFR, Mumbai, September).

*Evidence for advective flow in black hole systems* (Physics of black holes, IISc, Bangalore, December).

*Transition disk fit to Cygnus X-1* (Observational evidence for black holes, SNBNC, Calcutta, January).

**J.V. Narlikar**

*New ideas in astronomy*, (Pre-dinner talk at the workshop on "Astronomy with modest sized telescopes", UPSO, Nainital, April 8).

*The quasi-steady state cosmology*, (Institute for Advanced Studies, Zan Zan, April 21 and at the Sharif University, April 27).

*Challenging problems in astronomy*, (Isfahan University of Technology, Iran, April 28 and Shiraz University, April 30).

*The big bang cosmology and an alternative*, (Department of Mathematics, Banaras Hindu University, June 12).

*Cosmology*, (VSRP-VSP Students, IUCAA, June 16)

*Alternative cosmologies*, (IAU General Assembly-183 at Kyoto, Japan, August 22).

*Big bang cosmology : Strengths, weaknesses and alternatives*, (TUBITAK, Istanbul, September 22).

*Nature of the universe*, (Department of Physics, Middle East Technical University, Ankara, September 24).

*Inter-university centres - A new experiment in the university sector in India*, (TUBITAK, Ankara, September 25).

*New challenges in astronomy*, (Physics Department, Roorkee University, November 26).

*Structure formation in the quasi-steady state cosmology*, (Tata Institute of Fundamental Research, December 10).

*Problems of astroparticle physics in the quasi-steady state cosmology*, (6th Symposium on Workshop on High Energy Physics Phenomenology, (WHEPP-5), January 23).

**T. Padmanabhan**

*Nonlinear gravitational clustering*, (Caltech, USA, April 16).

*Inflation and the generation of density* *perturbations*, (Caltech, USA, May 28).

*Understanding the structures in the universe*, (Department of Physics, St. Berchman's College, Changanacherry, Kerala, September 30).

*Structure formation in the universe*, (2 lectures in the workshop on Modern trends in gravitation and cosmology, Cochin, October 1-2).

*Understanding the gravitational clustering in expanding universe*, (A.C. Banerji Memorial lecture delivered at the 67th Annual session of the National Academy of Sciences), Bhubaneswar, October 24).

*Gravitational clustering and transfer of power*, (Symposium on Progress in Science, 63rd AGM of Indian Academy of Sciences, Hyderabad, November 1).

*Nonlinear gravitational clustering in expanding universe*, (18th ASI meeting, Ahmedabad, November 30).

*Conceptual issues in blackhole entropy*, (Matscience, Chennai, February 13).

**Somak Raychaudhury**

*Highlights of extragalactic observations using the Hubble Space Telescope*, (Invited review at the Joint Session of the Astronomical Society of India (18th meeting) and the National Space Sciences Symposium, Ahmedabad, November 28).

**Varun Sahni**

*The inflationary universe - from theory to observations*, (Workshop on High Energy Physics Phenomenology (WHEPP-5), IUCAA, January).

*Analysis of large scale structure using percolation, genus and shape statistics*, (IAU Symposium 183: Cosmological Parameters and Evolution of the Universe, Kyoto, Japan, August).

*Dynamical and statistical aspects of nonlinear clustering*, (Research Centre for the Early Universe, Tokyo, September).

*Geometrical methods of analysis of large scale structure*, (Institute of Astronomy Colloquium, Mitaka, Japan, September)

*Cosmology*, (Workshop on Introductory Astronomy and Asrophysics, Raman School of Physics, Pondicherry University, October 13-14, 2 lectures).

**R. Srianand**

*Nature of low z absorbers*, (midterm meeting of Indian Academy of Sciences, Bangalore, June 1997).

*Quasar astronomy*, (Vacation Students' Programme, IUCAA, June 1997).

*Introduction to optical astronomy*, (IUCAA-TIFR school on Cosmic Ray Astrophysics, Ooty, 2 lectures).

*Do central engines of quasars evolve by accretion*, (IAP, Paris, February 12).

*Molecules in the high z damped system*, (IOA, Cambridge, March 4).

**S. Sridhar**

*Dynamics*, (Vacation Students' Programme, IUCAA, June 9).

*Turbulence*, (Vacation Students' Programme, IUCAA, June 10).

*The cores of ellipticals*, (Workshop on Dynamics at the Centres of Galaxies, IUCAA, July 3-5).

*Dynamics at the centres of galaxies*, (18th meeting of the Astronomical Society of India, Ahmedabad, November 28-December 1).

*Sources and sites of interstellar turbulence*, (Conference on Interstellar Turbulence, January 12-16, Puebla, Mexico).

**L. Sriramkumar**

*Classical backgrounds with vanishing effective Lagrangians*, ('Quantum Fields in Curved Space' session of The Eighth Marcel Grossmann Meeting on General Relativity, Hebrew University, Jerusalem, ISRAEL, June 26).

**S. Surya**

*Topological geons*, (Golden Jubilee Celebrations, Raman Research Institute, Bangalore, December).

*Global anomalies in canonical quantum gravity*, (Quantum Gravity session, GR15, Pune, December).

**b) Lecture Courses**

**N.K. Dadhich**

*General Relativity*, (Workshop on Modern Trends in Gravitation and Cosmology, Cochin University, September 29 - October 3), 6 lectures.

**Ranjan Gupta**

*Introductory course in observational astronomy and laboratory experiments*, (Institute for Advanced Studies in Basic Sciences (IASBS), Zanjan, Iran, April-June), 25 lectures.

*Astronomical observations*, (Level I Workshop on Astronomical Photometry, September 29-October 3), 3 lectures.

*Astronomy basics, stellar spectra and neural networks*, (Workshop on Physics of Stars, Department of Mathematical Sciences, Tezpur University, Tezpur, January 16-20), 4 lectures.

*Stellar spectra, telescopes and observational aspects*, (Introductory School in Astronomy and Astrophysics, Department of Physics, Bangalore University, Bangalore, March 2-6), 3 lectures and slide shows.

**A.K. Kembhavi**

*Stellar structure and compact objects*, (VSP, IUCAA, June 9-10), 4 lectures.

*Stellar structure evolution*, (Workshop on Physics of Stars, Department of Mathematical Sciences, Tezpur University, Assam, January 16-20), 4 lectures

**T. Padmanabhan**

*Order of magnitude astrophysics*, (VSP, IUCAA, June 13), 2 lectures.

*Structure formation in the universe*, (St. Stephen's College, Delhi, November 24-27), 4 lectures.

*Astrophysics concepts*, (UGC Refresher Course for college teachers held at Department of Physics, Cochin University, Cochin, February 17 & 18), 4 lectures.

**Somak Raychaudhury**

*Observational cosmology*, (UGC Refresher Course in A&A for College and University Teachers, IUCAA, May 16-21), 4 lectures.

**Varun Sahni**

*Large scale structure of the universe and the cosmic microwave background*, (Refresher Course in Astronomy and Astrophysics for College and University teachers, IUCAA, May 14 - June 3), 4 lectures.

**R. Srianand**

*Radiative processes in Astrophysics*, (Refresher course on Astronomy and Astrophysics for College and University teachers, IUCAA, May-June 1997) 4 lectures.

**S. Sridhar**

*Structure of galaxies*, (Refresher Course in Astronomy and Astrophysics for College and University teachers, IUCAA, May 29-June 2), 3 lectures.

**c) Popular Lectures**

**Ranjan Gupta**

*Our universe - View from Earth and space*, (Introductory Camp for School Children on Astronomy and Astrophysics, Chinmaya Seva Samiti Trust, Hubli, August 10-11).

*Comets as intruders*, (Science Day, IUCAA, February 26).

**A.K. Kembhavi**

*Exploring the universe*, [Marathi] (Range Hill School, Pune, April 11).

*Black holes*, [English] (Exploratory, Pune, April 17).

*Black holes*, [Marathi] (Exploratory, Pune, April 28).

*Is there life outside the earth?*, (Chinmaya School Trust, Hubli, August 10).

*Computers in astronomy*, [English] (IUCAA, August 23).

*Computer in astronomy*, [Marathi] (IUCAA, August 23).

**J.V. Narlikar**

*The search for extra-terrestrial intelligence*, (India International Centre, New Delhi, on the Kalinga Award, April 1).

*Some puzzles on the physics astronomy frontier*, (Utkal University, Bhubaneswar on the Kalinga Award, April 3).

*New challenges in astronomy*, (Nehru Centre, Mumbai, April 18).

*Gurutvakarshan*, (Exploratory Group, Pune, May 8).

*Astronomy and human welfare*, (Uttar Pradesh Academy of Administration, May 29).

*Men, scientists and institutions*, (Tata Management and Training Centre, Pune, June 3).

*Myths, beliefs and facts in astronomy*, (Banaras Hindu University, June 12).

*Krishnavivar*, (Range Hills Secondary School, Pune, June 20).

*To inculcate scientific attitude among the students in day to day teaching*, (Udayachal High School, Vikhroli, June 23).

*The urgency of developing a scientific ethos*, (Third Godrej Memorial lecture, Mumbai, June 23).

*Scientific temper*, (Lecture to the teachers from English Department, Pune University, July 25).

*The expanding universe*, (Physics Department, University of Pune, August 4).

*Career in pure research*, (Panel Discussion in Garware College, August 8).

*Our universe (Part I and II)*, (Mini School on Introductory Astronomy and Use of

Computers, St. Thomas College, Kozhencheri, September 12-13).

*Some recent developments in astronomy*, (Marathi Vidnyan Parishad, Vadodara, Octrober 25).

*Myths and facts in astronomy*, (Physics, Department, MS University of Baroda, October 25).

*A review of Ruchi Ram Sahni's contributions to the scientific temper*, (Institute of Engineers, October 28).

*Tryst with destiny : The renewed challenges of the 21st century*, (Panel Discussion in YASHADA, Pune, November 14).

*Astronomy and human welfare*, (Keynote address at Gargi College, New Delhi, November 21).

*Current ideas on the origin of the universe*, (Physical Research Laboratory, Ahmedabad, November 27).

*Human endeavours to understand the universe*, (Tagore Memorial Lecture in Gujarat University, November 28).

*Current puzzles in cosmology*, (85th session of the Indian Science Congress Association, Hyderabad, January 4).

*Intellectual challenges at the frontiers of astronomy*, (Khailshankar Durlabhji Memorial Oration (Annual Series), Jaipur, January 17).

*Some unsolved problems in astronomy*, (TECHFEST '98, Indian Institute of Technology, Powai, January 24).

*Science popularization and science fiction*, (Veda Thakurdas Golden Jubilee Lecture, Miranda House, New Delhi, February 9).

*Recent exciting developments on the physics-astronomy frontier*, (Centre for Advanced Technology, Indore, February 13).

*Prithvipalikade jeeva srishticha shodh*, (Jagatik Marathi Academy, Indore, February 12).

**T. Padmanabhan**

*Astronomy research in India*, (University College, Trivandrum, September 26).

*Journey through the universe*, (Women's College, Trivandrum, September 27).

*Reality of mathematical modelling*, (Department of Mathematics, Cochin University of Science and Technology, Cochin, October 2).

*Cosmogenesis a scientific perspective*, (Department of Physics, Cochin University of Science and Technology, Cochin, October 3).

*Large scale structures in the universe*, (Department of Physics, Maharaja's College, Cochin, October 3).

*Cosmic structure*, (IUCAA, Science Day, February 26).

*Length scales: From Planck to Hubble*, (Pauling Club meeting, IUCAA, March 14).

**S. Raychaudhury**

*The universe on different scales*, (Andhashradha Nirmoolan Samiti, Pune, March).

*Is it necessary to popularize science?*, (Jyotirvidya Parisanstha, Pune, March 22).

**R. Srianand**

*Evolution of the universe*, (Jyotirvidya Parisanstha, Pune, June).

**S. Sridhar**

*The centre of M31*, (Jyotirvidya Parisanstha, Pune, July 20).

*Why do stars twinkle?*, (National Science Day, IUCAA, February 26).

**d) Radio / TV Programmes**

**Pravin Chordia**

*Comet Hale-Bopp*, All India Radio, April 8.

**J.V. Narlikar**

*The National Programme of Talks*, All India Radio, February.

*Memoirs/views on scientific and rational approach for development of scientific temper among today's young*, Doordarshan, March 1.

Interview for the Special Weekly bulletin of "Star News", May.

Interview to SPOT FILMS, New Delhi on "Time and Acceleration", Doordarshan, July 28.

*The role of science and the scientific outlook in shaping the future of our country*, Sardar Patel Memorial Lectures at Pune, All India Radio, October 18 and 19.

*Dr. Homi Bhabha*, All India Radio, January 24.

*Mazya velche vyavasthapan*, All India Radio, February 9.

Monthly appearances in the scientific question-answer session in Doordarshan Programme: *Surabhi*.

**T. Padmanabhan**

*Origin of universe: Scientist's view (Interview)*, All India Radio, Cochin, October 10.

**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].*

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## (VIII) EXTERNAL PROJECTS

### INSA Project on Crab Nebula Sighting

The Crab Supernova was sighted by the Chinese astronomers whose records show that the explosion was first observed from the Earth on July 4, 1054. Was the spectacular event, which was visible for several days, reported by any other observers? The Japanese have also recorded it. Evidence in the form of pictures carved or drawn on rocks has come from the Red Indians of the Navajo Canyon and White Mesa, while writings of the Middle Eastern physician Ibn Buttan show that it was observed also in that part of the world.

Do any records of this event exist in India? A project sponsored by the Indian National Science Academy under the direction of *J.V. Narlikar* of IUCAA has begun searches of old manuscripts for a possible reference. Under guidance of Saroja Bhate, Head of the Sanskrit Department of Pune University, two scholars Pushpa Kale and Shilpa Mulay are going through various libraries and archives. If not a direct description of the event, at least some allusion to it as a catastrophic phenomenon might exist.

Searches at leading libraries in the country are being carried out but so far without success. The search will continue during 1998-99.

## (IX) FOREIGN COLLABORATIONS

### S.V. Dhurandhar

**(i) France:** The Indo-French project on the *Stability of giant high power laser cavities* under the IFCPAR programme was successfully completed on August 31, 1997. The total duration of the project was 3 years and 3 months. The investigators on the Indian side were S.V. Dhurandhar and B.S. Sathyaprakash and on the French side were J.Y. Vinet and P. Hello. As a part of the collaboration, students are being encouraged to work on this project and Vijay Chickarmane has contributed handsomely. Although the project is formally over, the collaboration still continues and Archana Pai is continuing the work on radiation pressure instabilities in the nonlinear regime of the operation of the Fabre-Perot cavity.

Instabilities in the cavities may be caused in several ways. Two of the most important ones were investigated: (i) Thermoelastic deformation and (ii) radiation pressure. Numerical and analytical techniques were applied to model the interferometric cavities. Such investigations are important because at the moment no experiments exist which have cavities with powers from tens of kW to MW. It is expected that these results can be used by the experimentalists in their future design of high powered laser cavities.

In the first year of the project, thermal distortion of the mirrors and its effect on the detuning of the cavity was investigated and a fully time dependent solution was given. The second part consisted of radiation pressure effects. Radiation pressure effects are important when the mirrors are not fixed but freely hanging which is the case for gravitational wave detectors. The effect of the radiation pressure on the motion of the mirrors including time delays was obtained by Vijay Chickarmane. Finally, a realistic servo system was considered, (servo system akin to the one employed in the VIRGO detector), and the stability of the cavity studied when the relevant parameters such as the input power, phase offsets, finesse of the cavity are varied. At present, Archana Pai is investigating the pumping of the cavity due to the delay effect, which now has been modelled accurately, and the further goal is to examine the stability when the servo is activated.

Since this project has been allotted a high grade, the teams are eligible to apply once again for another project. The next project is envisaged to be on the data analysis of gravitational waves.

**(ii) Australia:** Since the AIGO500 has been funded recently to build a 12 metre interferometer as a part of the central station, IUCAA will be collaborating with Australia on data analysis. As a beginning to the venture, a proposal was submitted to the Australian Research Council in which S. V. Dhurandhar is one of the *International Partners*. The proposal is on analysing data from interferometers by characterising the noise, testing the available algorithms of signal extraction and generally develop expertise on the data analysis of gravitational waves with real data.

The proposal was written and submitted when S.V. Dhurandhar visited the Australian National University, Canberra and University of Western Australia under the exploratory visit programme between India and Australia funded and sponsored by the DST (India) and the DIST (Australia). Further, in this visit collaborative programmes were identified, which will form the core of the proposal for a longer term future collaboration.

As a part of our ongoing collaboration with the University of Western Australia, S. D. Mohanty visited D. Blair on the bilateral exchange programme for three months and has developed a code for detecting millisecond pulsars with bar detectors. The aim is to use the code on the data of the bar detector at UWA for a real search of the nearest pulsar PSR 437 - 4715. There is also an offer for a student working in gravitational waves at IUCAA to visit UWA, intent to carry out further work.

**(iii) Cardiff / Potsdam:** The strong interaction with B.F. Schutz continues on various problems in gravitational wave data analysis. So far, the main concern has been coalescing binaries. However, another promising source of gravitational waves namely, pulsars, needs more attention than has been given to date. S.V. Dhurandhar visited the Albert Einstein Institute, Potsdam, for a week in June 1997 and again will be visiting the same institute from the fall of 1998 for an extended period on a sabbatical.

## (X) SCIENTIFIC MEETINGS

### Refresher Course in Astronomy and Astrophysics for College/University Teachers

A refresher course in Astronomy and Astrophysics for college/university teachers was held at IUCAA during May14 - June 3, 1997. This course was meant for the teachers from colleges and universities. There were about 30 participants from all over India. An attempt was made to cover basic astrophysical processes, stellar structure and evolution, interstellar medium, properties of galaxies, intergalactic medium, general relativity, cosmology and structure formation in the universe. In addition to the regular course work, observational sessions and informal discussions were also arranged as a part of the course. The lectures and seminars were given by members of IUCAA and NCRA. R. Srianand was the local coordinator.

### Lecture / Demonstration on Astrophotography in CCD Era

A two day Lecture / Demonstration on Astrophotography in CCD Era was held at IUCAA during September 8-9,1997.

The speakers included Ranjan Gupta and Arvind Paranjpye (IUCAA), B.D. Limaye and Ram Abhyankar (Jyotirvidya Parisanstha, Pune), Anand Khopkar (Nashik) and Peter Warlow (UK). The topics covered were: CCD compared with photography; Structure, sensitivity and processing of films for astrophotography; Applications of astronomical photography for meteor shower observations, photographic image enhancements etc.; Experiences of an amateur astronomer as a photographer; A simple drive for astrophotography and a special lecture on Catastrophies in Solar System. A special session was organised where a representative from the Kodak office, Mumbai, presented details on Kodak films for astronomical applications.

The audience was mostly amateur astronomers and few students.

### Mini school on Introductory Astronomy and Use of Computers

A mini school on Introductory Astronomy and Use of Computers was organized by IUCAA and St. Thomas College, Kozhencheri, Kerala, at Charal Mount, which is a retreat close to Kozhencheri, during September 12-13, 1997. About 150 undergraduate and postgraduate students as well as college and university teachers participated in the school. Lectures were given by Jayant Narlikar, Naresh Dadhich, Ajit Kembhavi of IUCAA; Babu Joseph of the Cochin University of Science and Technology and Prabhakaran Nayar of the University of Kerala. In addition to the lectures, there were computer demonstrations and a discussion session, on the overlap between science and philosophy. Plans for further activities in the region were formulated at the school. A.K. Kembhavi was the coordinator from IUCAA.

### Workshop on Introductory Astronomy and Astrophysics

A workshop on Introductory Astronomy and Astrophysics was organised by IUCAA at the Raman School of Physics, Pondicherry University, during October 13-14, 1997. There were 65 students (graduates and postgraduates) and 20 college / university teachers attending this workshop. Lectures were given by Varun Sahni, Ranjan Gupta of IUCAA; Biman Nath of Raman Research Institute, Bangalore; and K.S.V.S. Narasimhan from Chennai. The lectures were given on introductory astronomy, cosmology, observational astronomy, stars and galaxies. In addition to these, there was a brief

Participants of the Seminar on Astronomy and Astrophysics, held at Pondicherry University

demonstration and discussion on photometer by A. Balasubramanian from the Raman School of Physics, Pondicherry University, who was the local convener of the workshop, explaining the method of calculating the magnitude of a star by measuring the intensities of the sky and the star with a photometer, which was constructed by the speaker at IUCAA. Also, slide shows and video shows were arranged in which interesting aspects of the solar system and galaxies were illustrated. An exhibition of books on A & A, published by the Cambridge University Press was arranged during this workshop.

**15th Meeting of the International Society on General Relativity and Gravitation (GR15)**

GR15, the Fifteenth Meeting of The International Society on General Relativity and Gravitation (ISGRG), was hosted, for the first time in the Asia-Pacific region, during December 16-21, 1997 by IUCAA. The triennial meeting united about five hundred active minds (from more than thirty countries) in celebration and pursuit of Einstein's theory and its ramifications in a broad spectrum of related avenues of research.

The Conference began on the 16th morning with brief introductory remarks by Jayant Narlikar, Naresh Dadhich, Ted Newman and P.C. Vaidya. Jurgen Ehlers presented the Basilis Xanthopoulous Award to Matt Choptuik for his pioneering work on novel phenomena in scalar field collapse, which has opened up a new area of research in GR over the last five years.

The morning sessions had seventeen plenary lectures by renowned experts on topics which could be broadly classified as - (i) Classical Gravity, (ii) Quantum Gravity, (iii) Black holes, (iv) Cosmology, (v) Gravitational waves, (vi) Experimental aspects of GR, (vii) Related topics. The afternoons had six workshops running in parallel on four days, which dealt with more specialised presentations on each of the above fields.

Classical gravity was covered from the analytic and numerical viewpoints by Helmut Friedrich and Ed Seidel. While Friedrich presented recent developments in geometric asymptotics and the Einstein equations, Seidel showed us how numerical explorations can reveal the as yet unknown secrets of general relativity through an appropriate definition and analysis of the initial value problem. In another lecture, Carlos Kozameh focussed on a new formulation of GR in terms of null surfaces, a topic which has attracted some attention over the last few years.

On the other front, lectures on quantum gravity by Gary Gibbons and Carlo Rovelli set out to explore the various approaches to the subject. One of the major contenders of QG-string theory - was represented in an overview lecture by Gibbons. Rovelli dealt with the several different approaches to QG, briefly summarizing their successes and failures and made an attempt towards emphasizing what the future line of research should be. The curious, opposite facts that loop quantum gravity has been successful entirely in the non-perturbative regime, whereas string theory has largely been so in the perturbative domain (modulo recent progress in non-perturbative string theory) was emphasized in his presentation.

Black hole physics had three speakers - Ramesh Narayan, Jorge Pullin and Matt Choptuik. These three talks presented a fairly unique combination of new results. Narayan dealt with the possible astrophysical evidence of such objects through the analysis of observational data - a fact which is of great current interest in recent times. Pullin focussed on black hole collisions from the analytic (perturbation theory) point of view (with an eye on improving upon numerical techniques) and Choptuik presented exciting evidence of new phenomena (such as universality, discrete self similarity, which have parallels in condensed matter systems) first observed in numerical work on massless scalar field collapse and later found in other collapse scenarios as well.

In cosmology, we had Kumar Chitre and Vladimir Lukash summarizing gravitational lensing, CMBR and structure formation. Malcolm Longair, on the other hand, gave a stimulating overview of both theoretical and observational cosmology, including results from the Hubble Space Telescope observations.

A large international community on gravity wave (re)search has indeed developed over the last few years. Progress on this topic was reported by Eanna Flanagan, Norna Robertson and Massimo Cerdonio. While Flannagan covered astrophysical sources, Cerdonio dealt with resonant bar detectors. Robertson summarized the future of the upcoming interferometric detectors in various parts of the globe and emphasized the importance of building a collective effort as a concluding remark.

The last talk of the conference, by Neil Ashby, focussed on the Global Positioning System and its importance and applications in the context of testing special and general relativity.

Apart from lectures devoted exclusively to GRG, there were a couple of talks, which incidentally had no direct connection to the main theme of the Conference. These were - Michael Berry's plenary talk on caustics and singularities in the context of optics and Anton Zeilinger's interesting discussion on quantum teleportation from the experimentalist's point of view. Both the speakers, however, demonstrated quite seriously, how the topics they dealt with could actually be of deep relevance in future in the context of gravity as well.

The afternoon sessions had a fair number of extended presentations by renowned experts - Roger Penrose and George Sparling (on twistors), Hermann Nicolai (on D = 11 supergravity), Gautam Mandal (on strings and semiclassical properties of black holes), Alexei Starobinsky (on cosmological models with a decaying cosmological constant), A.K. Raychaudhuri (on singularity free models) - to name a few.

The 17th December morning session commemorated the fiftieth anniversary of the Gravity Research Foundation. Louis Witten, who chaired this session, briefly summarized the history of GRF with amusing remarks, as well as a few slides. The General Body meeting of the ISGRG was also held during the Conference.

The galaxy of distinguished personalities who attended the meeting included, among others, Brandon Carter, A. Starobinsky, David Finkelstein, P.C. Vaidya, Robert Wald, Hans Stephani, Piotr Chrusceil, Richard Isaacson, Bernard Carr, Malcolm MacCallum, Donald Lynden-Bell, Cliff Will, Bruno Bertotti. Roger Penrose delivered a public lecture - `Science and the mind' - in a city auditorium, which was attended by thousands from near and afar.

The Conference participants, of course, had an afternoon's worth of local sight-seeing, a sumptuous banquet and a Odissi dance recital by the reputed danseuse, Yogini Gandhi. Our very own Vishu (C.V. Vishveshwara) well-known for his brilliant sense of humour , gave an enthralling after-dinner speech at the banquet.

On the whole, the meeting was a great success. The fact that IUCAA had the privilege of having many a great physicist on campus for an extended period of six days or so, actively participating in discussions on diverse topics, would certainly be worth reminiscing in the years to come.

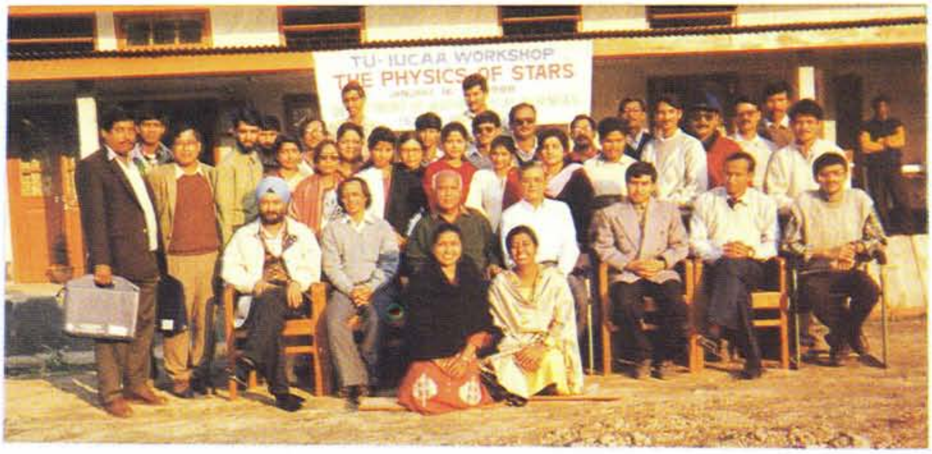
**XIX Meeting of the IAGRG**

The XIX Meeting of the Indian Association for General Relativity and Gravitation (IAGRG) was held at IUCAA on December 21, 1997. On this occasion, the fifth Vaidya-Raychaudhuri Endowment Fund Lecture, titled Accretion powered astronomical sources was given by Ramnath Cowsik of the Indian Institute of Astrophysics, Bangalore.

**WHEPP-5 at IUCAA**

The 5th Workshop on High Energy Physics Phenomenology was held at IUCAA during January 12-26, 1998. This was mainly funded by the S.N. Bose National Centre for Basic Sciences. There were 80 participants, including 19 from abroad and 19 from Indian universities. The rest were from various Indian institutes, such as IISc, IMSc, IUCAA, PRL, MRI, NPL, SINP and TIFR.

There were 25 invited talks on various topics and 4 working groups on i) Astroparticle Physics, ii) Collider Physics and B-Factories, iii) Quantum Chromodynamics and iv) Physics Beyond Standard Model. There were seminars in these working groups as well as discussion meetings. The topics covered in plenary talks included: Higgs and SUSY Searches at LHC (D. P. Roy), The Inflationary Universe (V. Sahni), Gravitational Lensing as a Cosmological Probe (A. Stebbins), Quark Gluon Plasma (S. Gupta), Neutrino Masses and Mixing (E. Ma, W. Grimus), Gauge Mediated SUSY Breaking Models (G. Bhattacharyya, B. Mukhopadhyay), Recent Results from Tevatron (N.K. Mondal), LEP-II (S. Banerjee) and HERA (J. Gayler), Particle Dark Matter (M. Drees), Astrophysical Constraints on New Particles (J.A. Grifols, S.Mohanty), R-parity Non-conserving SUSY (H. Dreiner, D. Choudhuri), Quarkonium Production (M. Kraemer), Direct Photon Production (M. Fontannaz) CP-violation (R. Aleksan), Particle Mass Limits in SUSY (P.N. Pandita), Topological Defects and Cosmology (R. Brandenberger), Low-x Physics (R. Basu), Resolved Photons (R.M. Godbole), Photon Colliders (F. Boudjema) and Quantum Loop Effects in SUSY (J. Sola). A special feature of this workshop was its emphasis on the exciting growing area of Astroparticle Physics.




Participants of the Workshop on The Physics of Stars, held at University of Tezpur

**Workshop on The Physics of Stars**

A workshop on the Physics of Stars was held at the Department of Mathematical Sciences, University of Tezpur, during January 16-20, 1998. This was a follow-up of an introductory workshop on astronomy & astrophysics held in the same department in early 1997. About 40 participants from Assam and some from other North-Eastern states participated in the workshop. Lectures on various aspects of stellar structure, evolution, compact objects including white dwarfs and neutron stars, etc. were given by B. Datta (IIA), R. Gupta (IUCAA), A. Kembhavi (IUCAA) and H. Singh (Venkateswara College, Delhi). Tutorial sessions were conducted by Yogesh Wadadekar (IUCAA). The workshop was coordinated by A. Borkakati of Tezpur University and his colleagues. There was excellent response to the lectures and there were lively discussions between participants as well as participants and lecturers. A trip to the Kaziranga Sanctuary was arranged during the workshop. A.K. Kembhavi was the coordinator from IUCAA.

**Workshop on Stellar Structure and Evolution**

A research level workshop on Stellar Structure and Evolution was held at IUCAA during February 9-13, 1998. About 40 participants attended the workshop. The academic programme consisted of short lecture courses as well as seminars, which covered different aspects of stellar processes. The main lecturers were H. Antia


Participants of the Introductory School in Astronomy and Astrophysics, held at Bangalore University

(TIFR), B. Datta (IIA), G. Meynet (Geneva Obs.), H. Singh (Venkateswara College, Delhi) and C. Tout (IOA). The topics covered included helioseismology and asteroseismology, equations of state, compact binaries, physical processes, stellar populations, nucleosynthesis, equation of state, rapid binary evolution, etc. C. Tout also conducted a series of tutorials on Eggleton's stellar evolution code. A.K. Kembhavi was the coordinator from IUCAA.

### Introductory School on Astronomy and Astrophysics

An Introductory School on Astronomy and Astrophysics for college teachers was held during March 2-6, 1998, at the Department of Physics, Bangalore University. It was inaugurated by the Vice-Chancellor, N.R. Shetty. Forty college teachers participated in the school.

The resource persons and the topics were: K.S.V.S. Narasimhan (Positional Astronomy, Systems of time, etc.); M.N. Anandaram (Basic stellar properties); Ranjan Gupta (Telescopes, Stellar spectra and Observational aspects); C. Sivaram (White dwarfs, Neutron stars and Black holes); S.P. Bagare (Solar physics) and Biman Nath (Stellar structure and evolution). Tutorial sessions were held in the afternoons to clarify doubts and solve problems.

Several interesting video shows and night sky watching sessions were also conducted. At the end of the school, the participants expressed their satisfaction on the content of the lectures and the other arrangements. Some of them felt that they would like to make telescopes with the help of IUCAA and attend more detailed workshop on Astronomy and Astrophysics.

Ranjan Gupta was the coordinator from IUCAA and B.A. Kagali was the coordinator from Bangalore University.

## (XI) VACATION STUDENTS' PROGRAMME 1997

The VSP-97 was conducted during June 2 - July 11, 1997. Seven students, selected from various universities, participated in this programme. There were 24 lectures covering most aspects of Astronomy and Astrophysics. Each student worked on a project with the guidance of a faculty member. They also presented a seminar describing their research. This year one student was pre-selected for the Research Scholarship starting from August 1998. Ranjeev Misra was the coordinator for this programme.

## Facilities

### (I) Computer Centre

The IUCAA Computer Centre extends state-of-the-art facilities to users from IUCAA as well as visitors from the universities. The hardware and software are constantly being upgraded in line with facilities in other leading centres in the world.

During 1997-1998, the emphasis has been on upgradation of the existing outdated hardware. In June 1997, old personal computers (PCs) in the Administrative building were upgraded to faster pentium processor based PCs with windows 95 operating environment. The old SUN Sparc 1 and 1+ machines were replaced with SUN Ultra Sparc 1 machines having high computing power.

So far IUCAA had a 64 kbps dedicated link to NCST and then to other internet nodes. IUCAA also had a VSAT connection. While these provided reliable E-mail connection, the available bandwidth was completely inadequate to other internet services. IUCAA has recently commissioned a 2 mbps dedicated link to a VSNL node in Pune. This link has been funded by ERNET, and is one of the few high speed links operating in the country, and the only one directly available to members of an academic institution. The link is used by IUCAA members as well as the many visitors for accessing databases and software all over the world.

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

### (II) Astronomical Data Centre

The Astronomical Data Centre (ADC) at IUCAA has a large and rich collection of astronomical catalogues and data, which can be accessed in a variety of ways including the internet. During the period of this report, there has been conspicuous increase in number of types of astronomical catalogues available with the ADC. The centre has obtained several latest CDs, to faciliate the use of recent catalogues.

The centre gets weekly mail from other data centres, which gives the list of catalogues published during the week. These catalogues are made available to users immediately.

Efforts have been made to develop software using network browsers which can be easily installed on a variety of machines. As a result of this development, software which makes it possible to easily access catalogues is available in highly portable form. The software also allows the user to efficiently browse catalogues at remote sites when the required communication facilities are available.

The astronomical catalogues in IUCAA, as well as those situated worldwide data centres, can easily be accessed and browsed through using the homepage of ADC on the World Wide Web. The facilities offered by the ADC have been used extensively by astronomers from the university sector as well as research institutions.

### (III) Library

The library is equipped with Pentium MMX PCs and two multimedia machines for the user community. During the period under review the "barcode" technology was applied for the first time for annual physical verification of reading material with minimum use of human power and maximum reliability. The library collection now amounts to 14522 which includes audio visual astronomical material and conventional print media.

The library is subscribing to almost all the important astronomy and astrophysics periodicals including online titles. Internet based user services along with traditional services like inter-library loan, reprographic aids, etc. are also provided and utilised. The library functions from 8 am to 12 midnight everyday without any holidays.

### (IV) Instrumentation Laboratory

The laboratory has facilities for the design, construction, and testing of the instruments for optical observations. During the year, the Gorakhpur University and the Mahatma Gandhi University received their portable telescopes and the accessories. These instruments were tested by the respective groups in our laboratory. A workshop 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 his laboratory.

A new liquid Nitrogen cooled CCD camera, with a optical-fibre link to the host computer and a capacity to change the CCD read out format in real time, has been developed and tested with an electrical grade CCD; it would soon be fitted with a science grade CCD and tested on a telescope. A new (third in our series) version of the CCD controller, with a capacity to handle multiple readouts from one or several CCDs, is under development; this controller could be used for a near infrared array detector too. An imager-spectrograph is being developed for the IUCAA telescope in collaboration with some other laboratories. For more details, please see under the head Instrumentation in the section Research at IUCAA.

### (V) The IUCAA Telescope

As reported last year, IUCAA is setting up a 2 m telescope for observations in the optical and near infrared bands. The telescope has been ordered with the Royal Greenwich Observatory of UK, and it would be set up on a hill at a height of ~ 1000 metres and located at Lat. : 19 deg. 4.4 arcmin North, and Long. : 73 deg. 50.8 arcmin East. 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..

The design of a wide-field (~ 11 arcmin. square) imager-spectrograph is in progress, and the fabrication of the instrument would start soon; for more details please see the item Imager Spectrograph for IUCAA Telescope in the section Research at IUCAA. In addition to this instrument for the optical band, a similar instrument is being planned for the near infrared band.

The design of the buildings is nearing completion, and the process of acquiring the forest-land at the chosen site is in its final stage of processing. However, there has been some delay in completion of the design of the telescope. This delay has been caused by the uncertainty, prevailing during the year 1997, about the future of the Royal Greenwich Observatory. Now the Particle Physics and Astronomy Research Council of UK (the parent agency of the Royal Greenwich Observatory) is taking steps to make arrangements so that the delivery of the IUCAA telescope is not affected by any changes at the Royal Greenwich Observatory.

### (VI) Publications

IUCAA has a full-fledged Publications department that uses the latest technology and DTP software for preparing the artwork of its publications like the Annual Report, Quarterly bulletin "Khagol", Posters, Academic Calendar, Conference Proceedings, etc. Following are the major IUCAA DTP Publications till date :

**Astronomy in India**
Edited by Rajesh Kochhar (IIA, Bangalore) & J.V. Narlikar (IUCAA)

ISBN : 81-900378-2-X
Price : US $ 10.00 International, including Air-Mail Postage & Rs.120.00 India

**Some Aspects of Gravitation and Cosmology**
Edited by J.V. Narlikar (IUCAA)

ISBN : 81-900378-1-1
Price : US $ 12.00 International, including Air-Mail Postage & Rs. 120.00 India

**Singularities, Black Holes and Cosmic Censorship**
Edited by Pankaj S. Joshi (TIFR, Mumbai)

ISBN : 81-900378-2-X
Price : (Soft back) US $ 9.00 International, including Air-Mail Postage & Rs. 90.00 India
(Hard back) US $ 150.00 International, including Air-Mail Postage & Rs.150.00 India

**Ordering Information:**

*Contact Address:*
Library, IUCAA, Post Bag 4,
Ganeshkhind, Pune 411 007, INDIA
*International Orders:*
Only by Demand Draft in favour of IUCAA
*Inland Orders:*
Within Pune : Banker's Cheque in favour of IUCAA
Outstation Orders : Only by Demand Draft payable at Pune in favour of IUCAA

## Science Popularization Programmes

One of the major goals of IUCAA is to help bring current scientific research into the public domain in the country, particularly in the areas of widespread superstition and misconceptions about the physical world around us. We are also committed to support and assist in the growth of the amateur astronomy community in India, and to get school students interested in research in astronomy and physics.

Many of our current programmes involve high school students in the Greater Pune area. In our summer programme, more than a hundred high school students spend a week each during their vacation at IUCAA supervised by an IUCAA member. We organize lecture demonstrations in Physics, Astronomy, Mathematics or Biology every other Saturday (excluding school vacations) for high school students. In addition, in our annual Science Festival, we hold a number of inter-school competitions, which bring a large number of students and science teachers together.

For the general public, we have our annual Open House, where we present the research areas pursued at IUCAA to members of the public and organize demonstrations of our facilities. Once a month, visitors may view the sky using our telescopes assisted by IUCAA members. We have a host of activities for amateur astronomers in Pune and all over India.

Our telescope making workshop is now in full swing, where amateurs from anywhere in India can visit us for a couple of weeks and make a six-inch reflector for their club or institution, guided by members of our Laboratory. We also maintain several relevant pages on the world-wide web, organize popular lectures in other institutions (schools, colleges, clubs) and assist popularizers of science elsewhere in India by supplying them with audio-visual aids and copies of published material on astronomy.

### (I) The National Science Day

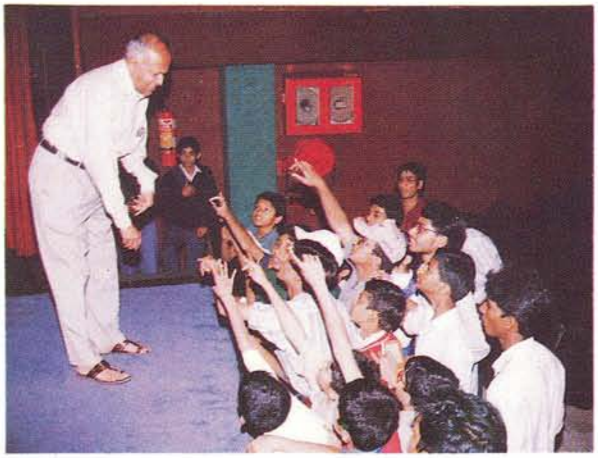
The National Science Day was celebrated at the Inter-University Centre for Astronomy and Astrophysics (IUCAA) on February 26, 1998, with a Science Festival for high school students in the morning and an Open House for the general public in the afternoon and evening. The festival featured a number of inter-school competitions. During the afternoon events, visitors could view special displays on the research facilities and activities at IUCAA, and meet many of the academic staff and students.

#### Inter-school Science Festival

As in previous years, IUCAA organized inter-school science competitions for students up to Class X in the morning. About 550 students from over 90 (English, Marathi and Hindi media) schools in the Greater Pune area participated in four competitions: a Science Quiz contest, two

One student from each participating school took part in the drawing competition on themes of space travel

One of the four-member teams of high school students who competed in the final round of the inter-school science quiz.



A scrum of eager questions after a talk on "Illusions in Space" in Marathi. This talk was later repeated in English to a full auditorium.

People of all ages used the various telescopes set up by IUCAA & Jyotirvidya Parisanstha, Pune, to view the night sky

Essay (English and Marathi) competitions and a Drawing competition on scientific themes.

Each school was represented by up to six students and a teacher. From each school, one student competed for the Drawing competition, where they were asked either to *Design a spaceship*, or to imagine a sample of *Deep sea life*, or what would happen if *the Pathfinder finds life on Mars*. First and second prizes were awarded to Gaurav S. Sawant (St Patrick's High School, for his imaginative drawing of the discovery of life on Mars) and Kranti Girme (Jnana Prabodhini Prashala, for her spaceship design) respectively.

Another student from each school participated in either of the two Essay competitions, where they were asked to write, in English or in Marathi, on any one of diverse topics like *If I were an alien left on Earth by a spaceship*, *If I became a science teacher* or *What would I like to clone*. The first and second Marathi Essay prizes were awarded to Kalyani Kokate (HHCP High School for her essay on *Cloning*) and to Dambar Thapa (Samata Vidyalaya for his essay on *Dreams of being a science teacher*) respectively. Ratnakar Ranade (DES English High School) won the first prize in the English category, for his fantasy about *Being a Martian abandoned on Earth*, while Darshan Vaidya (Don Bosco High School) won the corresponding second prize for his essay *If I were a Science teacher*.

Each school was represented by a team of four students in the first round of the Science Quiz,

Many IUCAA scientists displayed samples of the ongoing research at IUCAA and were present at the Open House to answer questions

More than 4000 visitors attended the IUCAA Open House, according to the register at the Reception where they had to answer 25 multiple-choice questions in physics, astronomy, mathematics, chemistry and biology in 45 minutes. Of these, six schools were chosen to compete for the Quiz Trophy in the final round, which was conducted in the presence of a full Chandrasekhar Auditorium. The six teams faced five rounds of questions, many involving slides and pictures. The team from Kendriya Vidyalaya (Southern Command) were the clear winners of the Quiz trophy. The tie for the second place went into a protracted tie-breaker round, culminating in the second place for Jnana Prabodhini Prashala, and the third place for Loyola High School.

The trophy for the best overall performance (the N.C. Rana Memorial Trophy) was won by the Jnana Prabodhini Prashala. Individual prizes (book tokens) were given to each winner. J.V. Narlikar gave away the prizes.

A major attraction of the morning's events was the lecture demonstration by Kiran Purandare and members of his group **Nisargavedh** on *Bird life in Maharashtra,* where the audience was made familiar with the appearance and calls of many of the exceptional birds of the region.

### Open House

The Open House in the afternoon and evening was held jointly with our neighbouring institution, the National Centre for Radio Astrophysics (NCRA). Both the institutions were open to the general public, and had set up exhibits especially prepared for this purpose.

Most of the academic members (including students and visitors) of IUCAA were present in the Bhaskara lobby to discuss their research with the visitors; many of them had put up posters providing glimpses of their work. In the Instrumentation Laboratory, one could witness the current status of their automated telescope and low-cost photometer projects, plus various demonstrations involving lasers and CCD cameras. The staff of the Computer Centre and

The Open House included demonstrations on how to crawl on the world-wide web.

a few students provided demonstrations of the working of the internet, of samples of the Astronomical Data Centre at IUCAA, and of the image processing research that is carried out at IUCAA.

Two parallel series of half-hour public lectures (in English, Hindi and Marathi) given by IUCAA and NCRA scientists were arranged to capacity audiences all through the afternoon. The lecturers found themselves surrounded by members of the audience with questions for long times outside the lecture halls. Video films on astronomy and space programmes were also shown at yet another location. The library's display included an account of C.V. Raman's work, which is commemorated by the National Science Day each year.

From 7 p.m. till midnight on February 26 and 27, hundreds of visitors viewed the night sky through telescopes set up by IUCAA members with the help of members of the amateur astronomers' organisation, Jyotirvidya Parisanstha, Pune. The same telescopes had been used during the Open House on the 26th to view the Sunspots and Venus during daytime.

IUCAA recorded over 4000 visitors during this period, in addition to the students who had taken part in the morning's events.

### (II) Astronomy Camp

A camp on Astronomy for high school and junior college students was organized at Hubli, Karnataka during August 10-11, 1997 by IUCAA and Chinmaya Seva Samiti Trust, Hubli. Ajit Kembhavi, Ranjan Gupta and Arvind Paranjpye of IUCAA lectured at the camp. There were also demonstrations of an 8" telescope and of astronomical images on computers. About 2,000 students and teachers attended the camp.

### (III) Programmes for School Students

#### a) Summer Programme

Like previous years, the School Students' Summer Programme was very successful with an unprecedented response from local schools. About 140 students completed their week-long project at IUCAA under the guidance of the academic members. The students were from about 70 local schools in Pune. Each school had nominated two students of eight/ninth standard. The programme was spread over six consecutive weeks starting from April 14, 1997. Students performed experiments/observations, made astronomical models, attended informal lectures and discussions and were given reading assignments in the library. Some of the projects undertaken by these students were on the Foucault's pendulum, the Sun dial, Sun spots and the determination of the rotation period of the Sun, the solar system, construction of the periscope and kaleidoscope, etc. Instructions were given in Marathi and Hindi as well as in English.

#### b) Lecture Demonstrations

This programme was instituted for conveying the excitement of doing science to secondary school students. The following lecture demonstrations were conducted during the period under review:

**S. Ananthakrishnan (NCRA)**

*The exotic nature of the Sun,* November 22.

**Deepti Deobagkar (University of Pune)**

*Cloning in mammals: The birth of Dolly,* (in Marathi and English), January 31.

**S.V. Dhurandhar**

*Gravity: From falling apples to time machines and beyond,* August 9.

**Pradeep Gothoskar (NCRA)**

*Lives of stars,* (in Marathi and English), February 14.

**A.K. Kembhavi**

*Adventures of pathfinder : Is there life on Mars?,* (in Marathi and English), August 23.

**J.V. Narlikar**

*A journey through the universe,* (in Marathi and English), July 12.

**T. Padmanabhan**

*Story of a star,* July 26.

**Arvind Paranjpye**

*Meteor showers,* (in Marathi and English), December 13.

**S.N. Tandon**

*How does heat escape the Sun?,* (in Hindi and English), September 27.

**U.S. Tumne (NCSTC, New Delhi)**

*National children's science congress, 1997,* (in English and Marathi), September 13.

**Y.R. Waghmare**

*Atomic nucleus: A world of wonders,* January 17.

## (IV) Other Programmes

### a) Sky-viewing for the public

During the year, apart from the regular fourth Friday public night sky viewing, Arvind Paranjpye, along with members of the local amateur organization, the Jyotirvidya Parisanstha, has been organizing sky-viewing exercises for various local schools and other organisations using the IUCAA 16" and 8" reflectors plus various smaller refractors.

### b) Observing meteor showers

IUCAA has taken the initiative in organizing trips to darker suburbs of Pune to observe meteor showers. Many enthusiasts from the Greater Pune area have participated in meteor shower observations several times since December 1997. Before a major shower, the group meets for a lecture in IUCAA about the event. They have already observed the Quadrantide (peaking on January 3) and Delta Leonides (peaking on February 24) and have reported their observations to the International Meteor Organization.

### c) Making small telescopes for schools and amateur organizations

The workshop for training enthusiastic amateurs in the grinding and polishing of 6" mirrors and building telescopes for the use of their respective institutions is now a year-round activity. Arvind Paranjpye and Vinaya Kulkarni have been assisting visiting amateurs in making such telescopes at an average rate of five per month. We have had an overwhelming response from the community of local amateur astronomers and telescope makers for this activity.

# Abstract of the 9th IUCAA Foundation Day Lecture

## GEOMETRIC PHASES AND THE SEPARATION OF THE WORLD

by
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Geometric phases[1,2] arise in wave physics as a reflection of the more fundamental geometrical phenomenon of anholonomy, exemplified by the self-righting of a falling cat and easing a car into a small parking space. The phases can be generated in rapidly oscillating systems whose environment is slowly cycled. New examples involve polarization changes in twisted stacks of crystal plates[3], half-turns of certain special spin states[4], the Pauli exclusion principle[5], and Hannay's angle for the world (a small contribution to the length of the year)[6].

The geometric phase reacts on the environment that causes it, inducing on its parameters a force of 'geometric magnetism'[7,8]. This force is analogous to the pseudo-forces in physics, such as the Coriolis force, or gravity, that are associated with chosen reference frames; geometric magnetism is an artefact of the decision to separate the world into fast and slow components. But geometric magnetism, like the other pseudo-forces, produces real effects. These appear in many guises throughout physics and chemistry[9-11]. The fast and slow systems can be classical or quantal, and, if classical, regular or chaotic[12,13]. Geometric magnetism can be illustrated by several lecture demonstrations[14].

Geometric magnetism is just the first of a hierarchy of reaction forces describing how the average motion of a fast (light) system influences the motion of a slow (heavy) system coupled to it. Some progress has been made in understanding this hierarchy[15-17], but its full structure is mysterious. The problem is important because it addresses the question of how accurately the parts of the world can be separated and studied independently, as is always assumed in science. If the separation is inherently imperfect, this reflects a kind of holism, even in classical physics.

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Apples on Newton's tree behind Einstein!

Chittaranjan Swimming Pool