Annual Report

(April 1, 1996 - March 31, 1997)

of the

INTER-UNIVERSITY CENTRE FOR ASTRONOMY AND ASTROPHYSICS

(An Autonomous Institution of the University Grants Commission)

IUCAA

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Acting Secretary
University Grants Commission

G.D. Sharma (from 8.7.96)
Secretary
University Grants Commission

V.R. Gowariker
Vice-Chancellor
University of Pune

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National Centre for
Radio Astrophysics, Pune

Yoginder K. Alagh (till 31.12.96)
Vice-Chancellor
Jawaharlal Nehru University
New Delhi

Chandrakant Mehta (till 31.12.96)
Vice-Chancellor
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Vice-Chancellor
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Vice-Chancellor
University of Kerala

N. Panchapakesan (till 31.12.96)
Department of Physics
and Astrophysics
University of Delhi

M.I. Savadatti (till 31.12.96)
Veerabhadra Kreepa
Navodaya Nagar
Dharwad, Mangalore

P.V. Subrahmanyam (till 31.12.96)
Director
Centre of Advanced Study
in Astronomy, Hyderabad

R.K. Thakur (till 31.12.96)
21, College Park
Choube Colony, Raipur

Bimla Buti (from 1.1.97)
Emeritus Professor
National Physical Laboratory
New Delhi

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C-536, Saraswati Vihar
New Delhi

Arun Kumar Sen (from 1.1.97)
Director
Institute of Radio Physics
and Electronics, Calcutta

K. Shankara Sastry (from 1.1.97)
Department of Astronomy
Osmania University, Hyderabad

V.N. Rajasekharan Pillai
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Mahatma Gandhi University
Kottayam

Hari Gautam
Vice-Chancellor
Banaras Hindu University
Varanasi

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Gauhati University
Guwahati

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C.V. Vishveshwara
Indian Institute of Astrophysics
Bangalore

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Tata Institute of
Fundamental Research, Mumbai

Nirupama Raghavan
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Nehru Planetarium, New Delhi

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Director, IUCAA

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Members
S.P. Gupta (till June 1996)
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V.R. Gowariker
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V.N. Rajasekharan Pillai
Hari Gautam
H.L. Duorah
M.S.V. Valiathan
C.V. Vishveshwara
S.S. Jha
Nirupama Raghavan
S.N. Tandon

Member Secretary J.V. Narlikar

Honorary Fellows

1. E. Margaret Burbidge (from 20.6.96)
   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. A. Salam *
   Oxford, UK

8. P. C. Vaidya
   Gujarat University
   Ahmedabad

**deceased (21.11.96)*

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Indian Institute of Astrophysics, Bangalore

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Mount Stromlo Observatory, Australia

S. Mukherjee
North Bengal University, West Bengal

K. Sato
University of Tokyo, Japan

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Raman Research Institute, Bangalore

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IUCAA, Pune

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from 1.1.95 to 31.12.97

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S.N. Tandon
IUCAA

N.K. Dadhich
IUCAA (Convener)

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T. Sahay (Member Secretary)

The Finance Committee

Armaity Desai (Chairperson)
J. V. Narlikar
S. P. Gupta
P. Bhatia
T. Sahay (Non - Member Secretary)

* deceased (22.8.96)

Members of IUCAA

Academic

J.V. Narlikar (Director)
S.N. Tandon (Dean, Core Academic Programmes)
N.K. Dadhich (Dean, Visitor Academic Programmes)
S.V. Dhurandhar
R. Gupta
A.K. Kembhavi
T. Padmanabhan
N.C. Rana (till 22.8.96)
Somak Raychaudhury
V. Sahni
R. Srianand (from 10.10.96)
S. Sridhar

Scientific and Technical

N.U. Bawdekar
R.M. Bokde (till 31.7.96)
V. Chellathurai
P.A. Chordia
H.K. Das
M.S. Deshpande
D.V. Gadre
G.B. Gaikwad
S.U. Ingale
A.M. Kane
P.A. Malegaonkar
V.B. Mistry
A. Paranjpye
S.M. Pardeshi (till 8.3.97)
R. Radhakrishnan (till 17.6.96)
S. Sankara Narayanan

Administrative and Support

T. Sahay (Senior Administrative Officer)
K.M. Abhyankar
N.V. Abhyankar
R. Barke (till 30.1.97)
V.P. Barve (from 30.12.96)
S.L. Gaikwad
B.R. Gorkha
B.S. Goswami
R.S. Jadhav
B.B. Jagade
S.M. Jogalekar (from 24.2.97)
A.N. Kamnapure (from 26.6.96)
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
S.N. Parkhe (from 3.3.97)
R. Parmar (from 19.9.96)
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

Post-Doctoral Fellows

S. Bose (from 21.8.96)
R.K. Gulati
S. Kar (from 3.9.96)
R. Misra (from 6.9.96)
B. Nath
S.K. Sethi
S. Sinha
R. Srianand (till 9.10.96)

Research Scholars

J.S. Bagla (till 1.11.96)
R. Balasubramanian
V. Chickarmane
S. Engineer
K. Harikrishna
A.A. Mahabal
S.D. Mohanty
D. Munshi (till 1.11.96)
A. Nayeri

A. Pai (from 1.8.96)
A.N. Ramaprakash
T.K. Ramkumar (from 12.8.96 to 3.2.97)
T.D. Saini
N.B. Sambhus (from 3.8.96)
K. Srinivasan
L. Sriramkumar
Y.G. Wadadekar

Project Appointments

M.V. Anantwal
(2 Meter Telescope Project) (from 7.4.96 to 8.3.97)
S.K. Banerjee
(Project) (from 1.8.96)
D.K. Dhumal
(2 Meter Telescope Project) (from 8.4.96 to 7.3.97)
R. Jayanti
(2 Meter Telescope Project) (from 9.9.96)
A. Kohok
(2 Meter Telescope Project) (from 7.4.96 to 8.3.97)
V. Mahabal
(Project work) (from 31.7.96 to 31.3.97)
S. S. Menon
(2 Meter Telescope Project) (from 1.4.96 to 21.1.97)
S.S. Nair
(2 Meter Telescope Project) (till 18.3.97)
S. Ponrathnam
(DOE-ERNET Project) (from 31.7.96)
S.K. Pradhan
(Indo-US Project) (till 31.8.96)
A.W. Ubale
(DOE-ERNET Project) (from 8.5.96 to 10.12.96)

Visiting Members of IUCAA

Visiting Professors

Abhay Ashtekar
Centre for Gravitational Physics
and Geometry
Department of Physics
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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
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University of Burdwan

Pradip K. Bhuyan
Department of Physics
Dibrugarh University

B. Chakraborty
Department of Mathematics
Jadavpur University, Calcutta

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Suresh Chandra
School of Sciences
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Tripura University, Agartala

D.P. Datta
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NERIST, Arunachal Pradesh

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Kumaun University, Nainital

A.D. Gangal
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Ashok K. Goyal
Department of Physics
Hans Raj College, Delhi

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Department of Physics
Meerut College

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Swami Ramanand Teerth Marathwada University
Nanded

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...till June 30, 1996

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from July 1, 1996...

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International School of Photonics
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University of Gorakhpur

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

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

G. Yellaiah
Department of Physics
Kakatiya University, Warangal

...till June 30, 1996

Kalyanee Boruah
Department of Physics
Gauhati University, Guwahati

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School of Physics
Vikram University, Ujjain

C. Mukku
School of Mathematics
Hyderabad University

A.C. Balachandra Swamy
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from July 1, 1996...

Indira Bardoloi
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Handique Girls' College, Guwahati

S.P. Bhatnagar
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Bhavnagar University

P. Das Gupta
Department of Physics and Astrophysics
Delhi University

M.K. Gokhroo
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Government College, Ajmer

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

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

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

The Seventh batch of Senior Associates and Associates of IUCAA, who were selected for a tenure of three years, beginning July 1, 1996

Z. Ahsan

S. Chatterjee

V. B. Johri

V. C. Kuriakose

I. Bardoloi

S. P. Bhatnagar

M. K. Gokhroo

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

K.N. Joshipura
S.P. Khare
D. Lohiya
L.K. Pande
L.P. Singh
T. Subba Rao
S.V. Vaishampayan
C. Venugopal

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

M.N. Anandaram
A. Banerjee
S. Banerji
D.K. Chakraborty
S. Chandra
M.K. Das
A.D. Gangal
B.A. Kagali
P. Khare
S. Mukherjee
S.K. Pandey
L.K. Patel
S.S. Prasad
L.M. Saha
R.S. Tikekar
S.Chakrabarty
P.Das Gupta

Organizational Structure of IUCAA's Academic Programmes

The Director
J.V. Narlikar

Dean, Core Academic Programmes
(S.N. Tandon)

Head, Instrumentation Laboratory
(S.N. Tandon)

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

Head, Computer Centre
(A.K. Kembhavi)

Head, Library & Documentation
(T. Padmanabhan)

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

Head, Publications
(T. Padmanabhan)

Dean, Visitor Academic Programmes
(N.K. Dadhich)

Head, Associates & Visitors
(N.K. Dadhich)

Head, Workshops & Schools
(V. Sahni)

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

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

Head, Recreation Centre
(S.V. Dhurandhar)

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* The Science Popularization and Amateur Astronomy activities were handled by *N.C. Rana* till his death on August 22, 1996.

Director's Report

The Annual Report, of which this is a part, gives details of the manyfold activities of IUCAA, and so, I will highlight only a few here.

In the early days of IUCAA, a committee consisting of Professor Rais Ahmed and Professor N. Mukunda and myself had a brainstorming session to outline the ways and means of making IUCAA a success. The first criterion for this to happen, according to this committee was that the centre should work towards attaining an international reputation for research so that it has credibility to guide the universities in nucleating and promoting A & A. The second criterion was, of course, the centre's impact on the university sector. How far has the centre progressed towards these goals?

An objective assessment of these issues is carried out by the Scientific Advisory Committee of IUCAA (SAC-IUCAA) twice in a three-year period and these inputs have been extremely useful. There is also a Users' Committee which periodically meets to review the facilities created at IUCAA for users from the universities.

In addition, during this year the Governing Body appointed a Review Committee to review IUCAA's overall progress since inception in December 1988. Chaired by Professor Govind Swarup (Emeritus Professor, NCRA-TIFR), the RC had as members Professor S.M. Alladin (Osmania University, Hyderabad), Professor S.M. Chitre (TIFR, Mumbai), Professor J.N. Desai (PRL, Ahmedabad) and Dr. Nirupama Raghavan (Nehru Planetarium, New Delhi).

The RC had extensive discussions with the IUCAA faculty, students and staff and submitted a detailed report to the Governing Body. While expressing satisfaction with the way IUCAA was progressing, the RC made some practical suggestions which will be extremely useful for the future programmes of the centre. We are grateful to all the members for devoting so much time and energy for the review process.

A measure of the growing reputation of IUCAA in its field of research is to be found in the participation of its faculty members in important international meetings as plenary speakers and coordinators of workshops. In December 1997, IUCAA will host the 15th meeting of the International Society on General Relativity and Gravitation (GR15). This important meeting is held once in three years and the GR15 will be the first such meeting to be hosted in India.

An important recommendation of SAC-IUCAA came to fruition this year when the UGC approved the 2-metre IUCAA-Telescope project and order for the instrument was placed with the Royal Greenwich Observatory, U.K. If all goes as per schedule, the telescope should be in operation during 1999. After conducting site testing studies (which are still going on), a site near the Giravali village about 75 km from Pune has been chosen. Details of this project have been given elsewhere in this report.

The usage of the IUCAA facilities by the academics in the university sector continues to grow. It is encouraging to find that some faculty members also bring their students for work at IUCAA. Nevertheless, the perception of the inter-university centres as essential facilities for the universities has still to reach high officials in some universities and colleges. IUCAA and other IUCs are continuously lobbying the university vice-chancellors to urge them to look upon the IUCs as field stations for their academic programmes. Despite help from the Chaiperson, UGC, we still have some way to go to bring about the change in perception.

IUCAA's science popularization programmes continue to expand and diversify. The second-saturday lectures are over-subscribed by the Pune schools and we now have to hold lectures on some other saturdays also. The open house on the National Science Day (February 28) attracted more than 2000 from the general public. The same morning we had a very busy programme of activities for school students including competitions, quiz and a demonstration of pseudo-miracles by the Andhashraddha Nirmulan Samiti. The booklet on comets brought out to coincide with the visit of Comet Hale Bopp has been very well received.

With the advent of desk-top publishing, IUCAA has started bringing out a few technical publications also, which are listed elsewhere in this report.

It was a pleasure to welcome Professor Suma Chitnis for the Foundation Day Lecture on December 29. Her talk on "The Crisis in Higher Education" was indeed very thought provoking.

This year we lost an Honorary Fellow in Professor Abdus Salam, who passed away on November 21, 1996 after a long illness. He had been greatly sympathetic to the IUCAA programmes and his creation, the International Centre for Theoretical Physics had been a model for IUCAA to emulate. We also lost our very enthusiastic faculty member Professor N.C. Rana, whose untimely death on August 22, 1996 came as a great shock to all of us. An obituary note on him appears in this volume.

I end this report with my grateful thanks to Professor (Miss) Armaity Desai, Chairperson, UGC and Professor Naresh Mathur, Vice-Chairperson, UGC for their encouragement and guidance in IUCAA's activities and help on crucial occasions whenever needed. We also acknowledge the cooperation we receive from the senior officials in the UGC secretariat and the IUC-Bureau without which many of our activities would not have proceeded so smoothly. Finally, I am indebted to my colleagues on the IUCAA faculty and staff for sharing the burden of "running IUCAA" which makes my own job almost redundant.

J.V. Narlikar

Awards and Distinctions

J.V. Narlikar

- Star of India Award from the U.S.-Asia Foundation, USA, April 7
- Rabindranath Tagore Birth Centenary Plaque for creative contribution to Human Culture, May 6.
- Gajanan Madhav Muktibodh Award of Maharashtra Rajya Hindi Sahitya Akademi on December 21 for Hindi writing
- UNESCO's Kalinga Award 1996 for science popularization

T. Padmanabhan

- Shanti Swarup Bhatnagar Award in Physical Sciences for the year 1996
- A.C. Banerjee Memorial Lecture Award by The National Academy of Sciences, India for the year 1997

R. Srianand

- Elected Young Associate of the Indian Academy of Sciences

Calendar of Events

April 15 - May 24	School Students' Summer Programme, at IUCAA
May 20 - June 8	Introductory Summer School on Astronomy and Astrophysics, at IUCAA and National Centre for Radio Astrophysics (NCRA), Pune
May 17	IUCAA-NCRA Graduate School: Second Semester (1995-96) ends
June 3 - July 12	Vacation Students' Programme, at IUCAA
June 17-21	DST Contact Programme for Students in Astronomy and Astrophysics, at IUCAA
August 19	IUCAA-NCRA Graduate School: First Semester (1996-97) begins
August 31	Seminar on Astronomy and Astrophysics, at University of Bombay, Mumbai
September 17-27	Les Houches School on Starbursts: Triggers, Nature and Evolution, at Centre de Physique, Les Houches, France
November 14-18	Workshop on Inhomogeneous Cosmological Models, at North Bengal University, Siliguri, West Bengal
November 14-18	TIFR-IUCAA Winter School on Gamma-ray Astronomy at Pachmarhi
December 16-21	Second Zel'dovich meeting on Large Scale Structure and Cosmology, at IUCAA
December 20-24	Workshop on Astronomical Image Processing and the Internet, at University of Kerala, Thiruvananthapuram
December 28	IUCAA-NCRA Graduate School: First Semester (1996-97) ends
December 29	Eighth IUCAA Foundation Day
January 6-8	Discussion Meeting on Big Bang and Alternative Cosmologies: A Critical Appraisal, at JNCASR, Bangalore
January 13	IUCAA-NCRA Graduate School: Second Semester (1996-97) begins
January 27-29	Workshop on Introductory General Relativity and Applications, at Tezpur University, Assam
February 3-12	Mini-School on Cosmology, at Lucknow University, Lucknow
February 12-14	Workshop on Astrophysical Spectroscopy at Sri Krishnadevaraya University, Anantapur
February 28	National Science Day

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

Zero-point length of spacetime

It has been conjectured for a long time that the spacetime structure at very small scales - close to the Planck length, $L_P \equiv (G/c^3)^{1/2}\ 10^{-33}$ cm, will be drastically affected by quantum gravitational effects. Since any quantum field will harbour virtual particles of arbitrary high energy - which probe arbitrary small scales - it follows that the conventional quantum field theory can only be an approximate description, valid at energies far smaller than Planck energies. The 'correct' description of nature has to take into account the quantum nature of spacetime geometry and should reduce to the conventional description at low energies. Can we say anything about the kind of modifications quantum gravitational effects will introduce into the description of other quantum fields?

The strongest hint is the *existence* of the length, $L_P \equiv (G/c^3)^{1/2}$, which is expected to play a vital role in the 'ultimate' theory of quantum gravity. Simple thought experiments indicate (*Padmanabhan*, 1987) that it is not possible to devise experimental procedures which will measure lengths with an accuracy greater than about $\mathcal{O}(L_P)$. This result suggests that one could think of Planck length as some kind of "zero-point length" of spacetime. In some simple models of quantum gravity, L_P^2 does arise as a mean square fluctuation to spacetime intervals, due to quantum fluctuations of the metric. In more sophisticated approaches, like models based on string theory or Ashtekar variables, similar results arise in one guise or the other. The existence of a fundamental length implies that processes involving energies higher than Planck energies will be suppressed and the ultra-violet behaviour of the theory will be improved. All sensible models for quantum gravity provide some mechanism for good ultra-violet behaviour, essentially through the existence of a fundamental length scale.

If the ultimate theory of quantum gravity has a fundamental length scale built into it, then it seems worthwhile to use this principle as the starting point to obtain a glimpse of the modifications introduced by quantum gravity effects at lower energies, provided we can introduce the quantum gravitational effects through some powerful, general principle.

In a recent work, *T. Padmanabhan* has attempted to do this using a principle of "path integral duality". The idea behind this approach is as follows: One can obtain quantum theory from classical theory by adding up the probability amplitudes for different possible alternatives with a weightage for each alternative determined by a quantity called "action". For a free relativistic particle, the weightage depends on the length of trajectory taken by the particle to go from one event to another. *Padmanabhan* conjectures that the key modification of quantum gravity will be to change this weightage in such a way that paths which are smaller than L_P and paths which are longer than L_P will be related in a specific manner. This principle is called the 'path integral duality'.

Using this action in a path integral, *Padmanabhan* succeeded in calculating the Feynman propagator for a spinless particle of mass m in any background spacetime. It turns out that the key feature of this modification is the following: The proper distance $(\Delta x)^2$ between two events, which are infinitesimally separated, is replaced by $\Delta x^2 + L_p^2$; that is the spacetime behaves as though it has a 'zero-point length' of L_p !. This equivalence suggests a deep relationship between introducing a 'zero-point-length' to the spacetime and postulating invariance of path integral amplitudes under duality transformations. As to be expected, the ultraviolet behavior of the theory is improved significantly and divergences will disappear if this modification is taken into account.

Following up on this suggestion, *K. Srinivasan, L. Sriramkumar* and *T. Padmanabhan* have worked out various consequences for quantum field theory. The need for regularisation disappears because of improved convergence of the theory. The technique allows them to explicitly compute the quantum gravitational corrections in a well-defined manner.

End-state of black hole evaporation

In conventional quantum mechanics, one distinguishes between two kinds of descriptions of a quantum mechanical system - those based on "pure" states (like the energy eigenstate of a system) or those based on "mixed" states (like the state describing the thermal equilibrium of a gas). There are powerful theorems in quantum mechanics, which prevent a pure state to evolve into mixed state under most circumstances.

This issue assumes significance when one studies black holes which emit thermal radiation and evaporate. Such a situation can potentially lead to a mixed end state, starting from a pure state. More generally, one would like to know whether such a possibility arises as a consequence of combining quantum theory and general relativity. Does evolution from an initial pure state take place in accordance with the expectations of quantum mechanics ("unitarily") to a final pure state or non-unitarily to a final mixed state? The knowledge of the final spacetime geometry, resulting from black hole evaporation, is crucial in answering this question. Since Hawking's semiclassical analysis breaks down when the evaporating black hole reaches Planck-size, an attempt to study the final fate of such an evolution necessarily entails quantizing gravity, which is still an unsolved problem in four dimensions.

One can, however, attempt to answer this question in a two-dimensional (2D) model of dilaton gravity which has been inspired by superstring theories. In an earlier work, *S. Bose*, L. Parker, and Y. Peleg made such an attempt. They discovered a natural end-state geometry which may be regarded as a "remnant" of the evaporation process. Subsequently, Mikovic found that in a manifestly unitary formulation of 2D dilaton gravity, when the spacetime metric is expanded in a power series of the quantum matter stress-tensor, one retrieves this remnant geometry in the one-loop approximation. This suggests that their solution is consistent with a unitary theory of black hole formation and evaporation. However, a complete picture of black hole evolution requires full quantization of the model. Recently, Kuchar, Romano, and Varadarajan have 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 throw light on the ultimate fate of black hole evaporation.

Origin of black hole thermodynamics

Both classical and quantum thermodynamics can be studied in a well defined way using a mathematical construct called "partition function". Since black holes behave very much like thermodynamic systems, it is interesting to see whether similar techniques can be used to study their quantum behaviour.

In the past, people have calculated and studied the thermodynamical partition function of four-dimensional (4D) spherically symmetric, vacuum, Einstein gravity using both Hamiltonian and path-integral techniques. The next logical step will be to extend this study to the case where matter-fields are coupled to gravity which is an enormously complex task in four dimensions. But - as a close alternative - one can address this problem in the context of 2D dilaton gravity.

As a first step, *S. Bose*, L. Parker, and Y. Peleg have obtained the partition function of a canonical ensemble for a 2D vacuum dilatonic black hole in a box using the Hamiltonian approach, and studied its equilibrium thermodynamics. Currently *S. Bose* is working on extending the above approach to the case where matter-fields are coupled to gravity. The results may help to clarify (a) the relationship between thermodynamic entropy and statistical-mechanical (or fine-grained) entropy, (b) the origin of black hole entropy and its relation to Bekenstein's interpretation of this quantity as the information that is lost when the black hole forms from collapsing matter, and (c) the mass spectrum of quantum black holes.

Classical solutions with vanishing quantum corrections

Classical theories are approximations to the true quantum world. Because of this fact, any particular solution to a set of classical field equations - say, Maxwell's equations, which describe the electromagnetic field - will get modified when the quantum effects are taken into account. For example, consider a region of space with a constant electric field. If the field is strong enough, it will produce electron-positron pairs from the vacuum which will tend to modify the field. One may conclude that a constant electric field is a valid solution to classical Maxwell's equations but not to the equations which include quantum effects.

Usually, the quantum corrections to classical equations can be studied using a method called "effective Lagrangian". In this approach, one can study both the vacuum polarization due to the presence of "virtual particles" and real particle production effects, which arise in classical electromagnetic and gravitational backgrounds. Background field configurations for which the effective Lagrangian vanishes identically are special in the sense that the lowest order quantum corrections vanishes for such configurations. These will represent classical solutions which are unaffected by quantum fluctuations to the lowest order. It would be interesting to see what are the general features of such configurations.

L. Sriramkumar, T. Padmanabhan and R. Mukund proposed the conjecture that there will be neither particle production nor vacuum polarization in classical field configurations for which all the scalar invariants are zero. They verified this conjecture, by explicitly evaluating the effective Lagrangian, for non-trivial electromagnetic and gravitational backgrounds with vanishing scalar invariants. These are classical solutions to the field equations which do not lead to vacuum polarisation or particle production. The existence of such solutions is somewhat surprising and significant and a general proof of their conjecture will throw light on quantum field theory in curved spacetime.

Semiclassicality and decoherence of cosmological perturbations

The models for inflationary universe, which came into vogue in the eighties, have a mechanism for generating seed perturbations which could grow into structures like galaxies through gravitational instability. To do this successfully, one needs to model the transition from quantum physics to classical limit, so that the fluctuations of the quantum field can be eventually related to classical density perturbations.

In the stochastic inflationary scenario, originally proposed by Starobinsky, it was suggested that the modes of vibration of the quantum field with wavelengths greater than the characteristic scale of the universe will behave classically. The evolution of these waves were described by a particular equation - called Langevin equation - and is essentially driven by a classical white noise source provided by the short wavelength modes. However, in this picture the understanding of the transition from a quantum field theoretic description to a classical, stochastic, field theory description of the field and its fluctuations is - at best - incomplete. A more natural and plausible mechanism for the quantum field to become effectively classical is through a process called "decoherence", in which quantum interference effects are suppressed as a consequence of the field interacting with an "environment".

For the past year, *S. Sinha* has been investigating this issue using a model of a self-interacting scalar field theory where the short wavelength sector field acts as an environment coupled to the long wavelength sector. The results lend a clearer picture of the transmutation of quantum fluctuations into classical stochastic fluctuations or noise. Specifically, it is also seen that (i) generically, the noise is coloured, as opposed to white and (ii) while this approach yields the usual scale-free spectrum, it leads to a significant relaxation of the fine-tuning constraints for the amplitude of the density perturbations.

Graceful exit in superstring cosmology with back reaction

The Standard Cosmological Model (SCM) successfully explains many features of 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 - which attempts to study the universe at Planck scales using the superstring theory as the theory of gravity - appears to be more promising in this regard. Firstly, it is known to be better behaved at high energy scales. Secondly, apart from the gravitational field, 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 field equations of this theory - in an approximation called "the tree level effective action" does lead to a FRW phase. But, 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.

It was shown by S.-J. Rey that this problem is avoided in a string-inspired two-dimensional cosmological model provided back reaction effects to first order in the Planck constant were incorporated. However, Rey's solution to graceful exit requires a somewhat ad hoc condition that the number of massless scalar fields in the universe should be less than twenty four! Recently *S. Bose* has found a new two-dimensional cosmological model which solves the graceful exit problem for any finite positive value of N.

Planetoid strings : solutions and perturbations

Exact solutions of the string equations of motion and constraints in generic curved background spacetimes has been a topic of active interest over the last few years, both in the context of fundamental, as well as, cosmic strings. A novel ansatz for arriving at such solutions representing string configurations, namely the *planetoid ansatz*, was proposed recently by Larsen and Sanchez, de Vega and Egusquiza. The ansatz constitutes a generalisation of the usual planetary orbits to world—sheets representing strings; hence the name *planetoid*.

Sayan Kar and Swapna Mahapatra have constructed several specific examples of planetoid strings in curved backgrounds which include Lorentzian wormholes, spherical Rindler spacetime and the 2+1 dimensional black hole. A semiclassical quantisation is performed and the Regge relations for the planetoids are obtained. The general equations for the study of small perturbations about these solutions are written down using the standard, manifestly covariant formalism, recently proposed by Guven, Larsen and Frolov and Carter. Applications to special cases such as those of planetoid strings in Minkowski and spherical Rindler spacetimes are also discussed.

Work involving attempts towards newer ansatz under which the string equations of motion and constraints are solvable is in progress. Furthermore, an understanding of the perturbative (through the Jacobi equations) and non—perturbative (through the generalised

Raychaudhuri equations) deformations of extremal string world - sheets described by Nambu - Goto or other actions is also being carried out in greater detail.

Classical Gravity

Non-singular cosmological solutions

In the past, *N.K. Dadhich* and his collaborators have been working on cosmological solutions to Einstein's equations which are non-singular. One of the main criticisms of such solutions, which were obtained earlier, was that they are cylindrically symmetric. Since our universe is known to be spherically symmetric for a good degree of accuracy, these solutions cannot be of much practical use to cosmology.

Dadhich, Tikekar and Patel have now addressed the question: What does it take for a spherical universe to be non-singular? First of all, it is clear from their earlier work that two specific geometrical quantities - called "shear" and "acceleration" - must be non-zero. This would require the spacetime to be both inhomogeneous (i.e., different at different spatial locations) and anisotropic (i.e., different in different directions). It turns out that, in Einstein's theory, any spherically symmetric spacetime can always be modelled as arising due to a source which is an imperfect fluid with radial heat flow. There is no need to solve any differential equations to make this identification since there are only four independent components of energy-momentum tensor, which can be identified with energy density, radial and transverse pressures and heat flux. The important thing is to be able to give a non-singular prescription for all physical and geometrical parameters. They do this by modifying a well-known static solution to Einstein's theory into an expanding one. It turns out that the pressure anisotropy as well as heat flux decrease as the universe expands. This universe has no singularity; the curvature, density and pressure remain finite all through the evolution. Further, the solution satisfies the weak and strong energy conditions. It begins contracting from low density at large negative t, attains maximum density and then expands to low density again for large positive t without encountering any singularity anywhere. It would be interesting to examine physical viability of this model with a view to application in practical cosmology. The point to note is that if one is prepared to have imperfect fluid as viable matter source, then there exist several new set of possibilities. It is conceivable that there may be some that are acceptable as viable cosmological models.

Scale factor duality and the energy condition inequalities

Given any model for quantum gravity, one can try to work out its consequences for early universe. In cosmological models based on string theories, there arises an interesting symmetry. This feature, called scale factor duality was first discovered by Veneziano in 1991. In its simplest incarnation, it involves a transformation of the scale factor $a(t)$ appearing in a cosmological line—element, to its *dual* scale factor $1 / a(t)$, along with other transformation rules for the matter fields appearing in the theory. Shortly after its discovery, it was extended to a more general symmetry of the low energy effective action of string theory. *Sayan Kar* has shown, by a simple analysis, that cosmological line elements related by scale factor duality also exhibit a duality with respect to the conservation/violation of the Weak Energy Condition (WEC) by the source of effective Einstein equations. This is proved for both isotropic, as well as, anisotropic cosmological models. Furthermore, a study of specific pairs of line elements, related to each other via a more general but related transformation, hints at a possible generalisation of the above duality with respect to WEC for a wider set of spacetimes. Work is in progress towards establishing a general result which would clarify the exact correspondence between these spacetimes and the nature of the matter that threads such geometries.

Interpreting the Schwarzschild solution

In 1988, *J.V. Narlikar* and *T. Padmanabhan* discussed a conceptual problem in general relativity, related to the simplest solution of spacetime produced by a spherical mass, namely the Schwarzschild solution. This solution has an arbitrary constant relating to the strength of the source mass. This constant is, however, determined with respect to the Newtonian approximation rather than intrinsically within the general theory of relativity. Whereas, in the Newtonian theory, the problem is completely solved even in the case of a point mass, the general relativistic problem leads to inconsistencies and incompleteness.

The recent work of A.N. Petrov and *Narlikar* throws light on this issue and goes on to discuss the more general problem of energy distribution for a spherically symmetric isolated system in general relativity. For this purpose, they take the field formulation of relativity by L.P. Grishchuk, A.N. Petrov and A.D. Popova. In this formulation there is a background spacetime against which all dynamical fields, including the gravitational field are described. Petrov and *Narlikar* consider the Schwarzschild and the Reissner Nordstrom solutions in detail and use the Minkowski spacetime as the background spacetime. These explicit examples clearly set out how the gravitational energy is distributed non-locally in space and shed light on the earlier conundrums relating to Schwarzschild type solutions.

Global monopoles and minimally curved spacetimes

It is well-known that the Schwarzschild solution is the unique solution of the Einstein vacuum equation for spherically symmetric spacetime. This solution is also "asymptotically flat" - that is, all gravitational effects die down at large distances from the source. It follows that there cannot exist any asymptotically non-flat vacuum solution which is also spherically symmetric.

The question arises as to whether one can break asymptotic flatness of spacetime yet retain the essential physical features of the field of a static massive object. It turns out that it is indeed possible. In fact this amounts to adding a global monopole charge on the massive object. Global monopole charge is supposed to be created when global O(3) symmetry is spontaneously broken into U(1) in a phase transition in the early universe. In this case, the spacetime is not asymptotically flat but corresponds to a global monopole charge (in the limit of vanishing central mass). It can be viewed as "minimally" curved for it is free of active relativistic mass (the "gravitational charge"); as a result, not only acceleration but also the tidal forces vanish for radially moving particles. It is possible to give a geometrical ansatz for generating spherically symmetric spacetimes with vanishing gravitational charge from a 5-dimensional flat spacetime. The ansatz covers several previously known topological objects called cosmic string, global monopole, global texture and their generalizations.

Dadhich, Narayan and Yajnik have studied the particle orbits and the Hawking radiation for the Schwarzschild black hole endowed with a global charge. In this analysis, all the quantities will be referred not to asymptotically flat spacetime but to the minimally curved spacetime. Thresholds for existence, boundedness and stability, and the perihelion shift and the light bending scale up by different amounts while the Hawking temperature scales down from the value for Schwarzschild metric. The radius of the event horizon scales up which causes surface gravity (and temperature) to scale down.

Spacetimes which are conformal to flat spacetime form an important class of physically interesting spacetimes. It includes the well-known Friedman - Robertson - Walker models as well as the Schwarzschild solution for stellar interior. It is, therefore, interesting to examine what happens if we consider spacetime conformal to minimally curved spacetime [MCS] discussed above. It turns out that it characterises the isothermal fluid sphere without boundary. That is, a necessary and sufficient condition for an isothermal fluid sphere without boundary is that the spacetime describing it be conformal to MCS. This is rather remarkable that conformal property of spacetime metric has one to one correspondence with the physical property of isothermality.

Black hole dynamics

There exists a distinct analogy between black hole dynamics and conventional thermodynamics. This parallel was strengthened by Hawking's demonstration that a black hole has a thermal radiation spectrum of a black body, with the surface gravity of black hole playing the role of temperature. In thermodynamics, the third law prohibits the temperature of any system to reach zero by a finite sequence of operations. By analogy, one expects the same result to hold in black hole dynamics as well. For a black hole, the temperature tends to zero when (i) either mass tends to infinity or (ii) electric charge [or rotation parameter] equals mass. So the limit of zero temperature for a black hole could mean either of the two conditions above. The impossibility of the first condition simply points to impossibility of infinite mass for a hole while the latter case (which corresponds to what is known as "extremal" black hole) deserves further consideration.

Dadhich and Narayan have explicitly demonstrated that as "extremality" is approached, the window for allowed values of parameters for infall of matter into the black hole closes. Thus a non-extremal black hole cannot - by finite sequence of operations - be converted into an extremal hole; and its temperature cannot be reduced to zero. An analogy can be drawn between extremal/non-extremal black holes and massless/massive particle. Just as a massive particle cannot be accelerated into travelling with speed of light, a non-extremal black hole can never be turned into an extremal one. Conversely, we also know that a massless particle like photon can never attain a non-zero mass. Is the correspondence valid in this case? There is nothing classically that prohibits an extremal hole from becoming non-extremal. But recent work involving quantum and topological considerations seem to suggest that an extremal hole cannot turn non-extremal thereby strengthening the analogy.

Lorentzian black hole thermodynamics

S. Bose, L. Parker, and Y. Peleg have recently extended the analysis of Brown and York to find the quasilocal energy in a spherical box in the Schwarzschild spacetime. Quasilocal energy is the value of the Hamiltonian that generates unit magnitude proper-time translations on the box orthogonal to the spatial hypersurfaces foliating the Schwarzschild spacetime. They call this Hamiltonian the Brown-York Hamiltonian. They show that although the Brown-York expression for the quasilocal energy is correct, one needs to supplement their derivation with an extra set of boundary conditions on the interior end of the spatial hypersurfaces inside the hole in order to obtain it from an action principle. Replacing this set of boundary conditions with another set yields the Louko-Whiting Hamiltonian, which corresponds to time-evolution of spatial hypersurfaces in a different foliation of the Schwarzschild spacetime. They argue that in the thermodynamical picture, the Brown-York Hamiltonian corresponds to the internal energy whereas the Louko-Whiting Hamiltonian corresponds to the Helmholtz free energy of the system. Unlike what has been the usual route to black hole thermodynamics in the past, this observation immediately allows them to obtain the partition function of such a system without resorting to any kind of Euclideanization of either the Hamiltonian or the action. In the process, they obtain some interesting insights into the geometrical nature of black hole thermodynamics.

Quasilocal mass under conformal transformations

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 is a conformal invariant. The reason being that a conformal transformation is simply a local field reparametrization, which is supposed to leave the mass of a system unchanged. *S. Bose* and D. Lohiya have now shown that the quasilocal mass of a finite-sized region in a classical spacetime solution of a generic scalar-tensor theory of gravity is, in general, not invariant under conformal transformations of the spacetime metric. However, in the particular case of an asymptotically flat static spherically symmetric solution, the ADM mass is shown to be conformally invariant. They apply the generalised quasilocal mass expression to obtain the masses of charged black holes and cosmological solutions in some scalar-tensor theories of gravity. Specifically, for four-dimensional dilaton gravity they show that the (conformally invariant) ADM mass of a charged black hole is different from its Schwarzschild mass.

Gravitational Waves

The design and the construction of new and more sensitive detectors of gravitational waves is currently underway in several places in the world. These include the LIGO being built by the US, VIRGO by the Italian/French collaboration, GEO-600 by the Anglo-German collaboration and the TAMA-300 by the Japanese. Besides these, there are several bar detectors in operation around the globe. The network of detectors would not only detect gravitational waves, but perform as directionally sensitive gravitational wave observatories. The detection of gravitational waves from astrophysical sources is probably one of the most keenly awaited events in the history of astrophysics. In this world wide effort IUCAA has contributed handsomely in the theoretical aspects of the experiment, especially, in gravitational wave data analysis. So far the work at IUCAA is divided among two major areas:

(i) the gravitational data analysis of two important astrophysical sources namely, the coalescing binaries and pulsars;

(ii) modelling the optics of giant laser interferometric cavities in the context of the laser interferometric gravitational wave detector. This work is being carried out in collaboration with the VIRGO group at Orsay under the programme sponsored by the Indo-French Centre for the Promotion of Advanced Research (IFCPAR).

There is a future possibility of an officially funded collaboration, consisting of exchange visits with the Australians - the Australian National University, Canberra and the University of Western Australia - in which both the areas mentioned above will be covered.

(a) Coalescing binaries

Coalescing binary systems are one of the most promising sources of gravitational waves. Since they are comparatively easier to model, one can design detection strategies which are specifically tuned to the signals from coalescing binaries. Lot of attention has been devoted in the literature studying such techniques and most of the work has revolved around the Weiner filtering and the maximum likelihood estimators of the parameters of the binary system.

Earlier work by *R. Balasubramanian*, B.S. Sathyaprakash and *S.V. Dhurandhar* who applied differential geometric methods to these signal extraction problems - showed that the covariance matrix underestimates the actual errors by a large margin. A more detailed study - centered on determining the reason for this behaviour - was taken up by *R. Balasubramanian* and *S.V. Dhurandhar*. They found that the answer lay in examining the fully non-linear equation which provides the maximum likelihood estimates. The covariance matrix errors are merely obtained by linearising this non-linear equation. The non-linear equation yields *multiple solutions* for the estimates of the parameters. The multiple solutions basically correspond to waveforms which are half-integral cycles away from the true one. The main solution produces the covariance matrix results while the others, although they occur less frequently, contribute significantly to the errors because the estimates differ a lot from the true values.

This resolves the question of the understanding of the problem. But how can one live with this large error? Fortunately, this problem is not so severe as it appears. The reason for the large error partly lies in the measure used to define the error - namely, the variance. In this situation when multiple solutions occur with much lower frequency, a better measure could be the percentage of points that lie in the central region for a given signal-to-noise ratio. With this measure it is found that the maximum likelihood estimator still performs reasonably - about 85 percent points lie in the central region at a signal-to-noise ratio of 10. Although this somewhat reduces the severity of the problem, searching for a better estimator than the maximum likelihood is still desirable. Efforts in this direction are also in progress.

Another important problem is that of devising fast detection strategies for coalescing binary signals. *S.D. Mohanty* has further extended the earlier strategies suggested by Sathyaprakash and *Dhurandhar* to include post-Newtonian corrections. Now there is essentially a two-dimensional parameter space (basically corresponding to the two masses of the stars) which needs to be searched. The two-dimensional analogue of the technique employed in the Newtonian case is used and although far more demanding, it finally bears excellent fruits. The saving in the computational cost can go up to a factor of 20. This means that for the advanced LIGO, and a mass range for the stars beginning from 0.2 M_O upwards, the online computational requirement comes down to between 10 and 20 GFlops for a maximum drop of 3 percent in the signal-to-noise ratio. This is a tremendous saving in the computational cost.

(b) Pulsars

Another important source of gravitational waves is the pulsar or a rotating neutron star. If the star possesses slight asymmetry, it can be a source of continuous gravitational waves. However, even for a galactic pulsar the signal is expected to be weak. For the known pulsars, the maximum gravitational wave amplitude can be estimated from the spindown luminosity. These amplitudes turn out to be very small from the point of view of the initial detectors whose sensitivities would not have reached the ultimate goal. In order to obtain an acceptable number of events, it is thus necessary to expand the field of vision to include other rotating neutron stars which do not appear to us as pulsars, which have either become extinct in their electromagnetic emission or are beamed away from us. Therefore, it is necessary at this stage to launch an 'all sky all frequency' search for such unknown 'pulsars'.

However, the all sky all frequency search for pulsars/rotating neutron stars has been shown to be computationally a formidable problem. Since the pulsar signal is expected to be weak, a long integration time typically of the order of a few months is needed to extract the signal from the noise. The Earth's motion around itself, sun and moon modulates the signal from a pulsar and introduces incommensurate Doppler shifts corresponding to each direction in the sky. The number of such directions for a sensible choice of parameters turns out to be $\sim 10^{13}$. Even after applying the stepping method of Schutz described briefly below, the number of operations still escalate to $\sim 10^{23}$ for analyzing just four months of data! This is a formidable requirement even for today's high speed computers.

Schutz suggested a method called 'stepping around the sky' which allows one to calculate the demodulated Fourier transform for one direction from the demodulated Fourier transform in some other direction *directly* via a kernel. The general structure of the problem looks amenable to wavelet-like methods and techniques like fast wavelet transforms. The literally million dollar question is 'Can wavelet methods be employed to significantly speed up the signal extraction?' *Bose, Mohanty* and

Dhurandhar are working on this problem.

(c) Network of Detectors

The network of interferometric detectors consists of the following:

(i) LIGO: Two 4 km armlength detectors one at Hanford, Washington, and the other at Livingstone, Louisiana. In addition, there is a half length (2 km) detector within the same housing at Hanford.

(ii) VIRGO: A 3 km armlength detector at Pisa, Italy.

(iii) GEO: A 600 metre detector near Hannover, Germany.

(iv) TAMA: A 300 metre detector at Mitaka (near Tokyo), Japan.

These detectors will be in operation by the turn of the century. The medium scale detectors, namely, the GEO and TAMA are likely to be completed sooner. Already, the first ideas for processing the data are seriously being discussed. There will be a general agreement between various projects for the exchange and transfer of data so that the detectors operate as a network and enhance their sensitivity and their ability to extract useful astrophysical information.

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 maximizes the detection probability for a given false alarm probability (Neyman-Pearson Lemma). It is desirable that the problem be investigated within this optimal framework and *Mohanty, Bose* and *Dhurandhar* have so far carried out the initial analysis. This work will be pursued most vigorously since this is a major problem of current interest to all the experimental groups around the world.

(d) Modelling the interferometer

Dhurandhar and Sathyaprakash, in collaboration with J.Y. Vinet and P. Hello of Linear Accelerator Laboratory, University of Orsay, France, have been funded by the IFCPAR to model interferometric gravitational wave detectors that employ very high laser power in their giant cavities. The programme has reached maturity now and several different aspects of this problem have been analyzed so far. When high power lasers are employed in interferometric cavities that contain freely suspended mirrors one can envisage several physical effects to be important: In particular, radiation pressure on the freely hanging mirrors can effectively change the length of the cavity detuning it in the process. The radiation pressure pushes on the mirrors detuning the cavity which in turn changes the power and thus the radiation pressure. This is clearly a coupled problem. The previous investigations have either considered naive models of servo-controls or have completely ignored servo-controls. *V. Chickarmane, Dhurandhar*, R. Brillet, P. Hello and J-Y. Vinet have investigated the realistic problem by taking into account time delay effects and a realistic servo-control system, the type of servo-control system that will be employed in the VIRGO. They have found that instabilities occur at high input powers of the order of a few kW and in the limit of high finesse for negative phase offsets. Although the ideal operating point for the cavity may be at its resonance, noise from various sources may cause the operating point to shift into the regime of instability. It is expected that the analysis will allow the experimentalists to be wary of these pitfalls.

(e) Squeezing the noise

Squeezed states of light can be used to advantage in reducing the photon shot noise in the laser interferometric gravitational wave detector. However, in the practical implementation of laser interferometers to measure low frequency displacements, the sensitivity is hampered by relatively large laser intensity noise. The laser amplitude fluctuations which are quite large at low frequencies (especially in the frequency range 1-10kHz) plague the efficiency with which gravitational waves (around these frequencies) can be detected. Phase modulation techniques effectively shift the signal to very high frequencies in the MHz range, where the laser source is quantum noise limited. All large scale interferometers under construction plan to use in-line modulation and hence it is important to understand how this practical method of controlling an interferometer interacts with squeezed light.

Chickarmane, Dhurandhar, T. C. Ralph, M. Gray, H.A. Bachor and McClelland have analysed how squeezed light can be used in a frontal phase modulated signal recycled interferometer to increase the signal to noise ratio (SNR). An analysis of the model shows how various sources of noise such as the laser, the squeezed field and the noise associated with the losses in the interferometer, contribute to the total noise in the intensity. Finally, they have computed the spectrum of squeezed light that must be used in order to obtain optimal sensitivity. Moreover, the bandwidth of the detector changes during the process which is especially important when the detector is operating in a narrow band mode. Therefore, the experimenter can use squeezed light to alter the bandwidth of the interferometer which is clearly a very useful option to have.

Cosmology and Structure Formation

Quasi-steady state cosmology

The work on the quasi-steady state cosmology (QSSC)continues in a non-local collaborative mode between its three original authors, Fred Hoyle, Geoffrey Burbidge and *J.V. Narlikar*. Recently, they have compared the role of the cosmological constant in the standard hot big bang cosmology (HBBC) and in the QSSC. They have shown that, in the HBBC, the lambda term is forced into a relatively narrow window which is hard to relate to its supposed origin in phase transition in the early universe. In the QSSC, on the other hand, the lambda term has an origin in a Machian theory of inertia which relates its magnitude to the number of particles in the present observable universe. The magnitude turns out to be of the right order and suggests that attempts to relate it to very early epochs in the HBBC may turn out to be misplaced and futile.

The work on structure formation in the QSSC has begun. *S.K. Banerjee* and *Narlikar* have shown that the QSSC solution is stable against small perturbations in the metric and the density of matter. Thus, it is unlikely that large units of inhomogeneities will arise as galaxies from a growth of small perturbations. Instead, as Fred Hoyle has suggested, large scale structure may arise from the creation process itself which selectively operates near a few compact massive distributions of matter. A preliminary investigation has begun with numerical work carried out by *Ali Nayeri* and *Narlikar* in which the Hoyle's concept is followed up by generating a set of random points in an expanding area, and letting these points seed more points near them as per the basic requirements of the creation process. Following this technique, very suggestive patterns with filaments and voids emerge after only a few iterations. These simulations are being linked to a physical theory.

Approximations to gravitational clustering

Over the last two decades, as a consequence of the continual interplay between theory and observations, a picture of the origin and evolution of large scale structure has emerged. According to this picture, the universe was almost homogeneous during the early phase, but had some small 'ripples' — inhomogeneities having a small amplitude and a characteristic spectrum. As the universe expands, these inhomogeneities grow by gravitational instability finally leading to the formation of non-linear objects such as galaxies and clusters of galaxies. During early stages, the growth of density fluctuations can be described in terms of linear theory — by solving the Euler-Poisson system to linear order in perturbation theory. However, a fundamental feature of our universe is the existence of large mass concentrations, with densities far larger than the mean density of cosmic material. To explain the existence of such massive bound objects one has to progress significantly beyond perturbation theory. So far no solution is known which addresses the problem of gravitational clustering in the non-linear regime exactly. Some insight can, however, be gained by using analytical approximations which appear to work remarkably well in this regime such as the Zel'dovich approximation.

The growth of density perturbations in a homogeneous and isotropic universe can be studied in essentially two distinct ways. In the *Eulerian* approach (pioneered by Jeans and Lifschitz), perturbations to the density are evaluated at *fixed* points in space. In the *Lagrangian* approach on the other hand, one considers perturbations to the trajectories of fluid elements. This was the method used by Zel'dovich who related the initial and final positions of a fluid element through a simple mapping. In recent years, efforts have been made to generalise the Zel'dovich map to higher orders. Such extensions are frequently referred to as n^{th} order Lagrangian perturbation series *L(n)* (in analogy with Eulerian perturbation theory which we denote by *E(n)*).

As shown by *D. Munshi, V. Sahni* and A. Starobinsky (1994), higher order extensions to the Zel'dovich approximation do have important attractive features. For instance, results derived from *L(n)* match those derived from *E(n)* as long as the system is weakly non-linear. A fundamental issue which needs to be addressed is the domain of convergence of the Eulerian and Lagrangian series. Addressing this important issue, *Sahni* and Shandarin show that, when applied to spherically symmetric overdense regions, Lagrangian perturbation theory gives excellent results. In particular, higher order *L(n)* outperform lower order, during all stages of gravitational collapse until shell crossing. (After shell crossing Lagrangian approaches cease to be valid.) However, the analysis of underdense regions ("voids") presents some surprises. Discussing the evolution of spherical voids in the framework of Lagrangian perturbation series *L(n)* (of which the Zel'dovich approximation is the first order solution) *Sahni* and Shandarin find that *L(n)* with n-even overestimate the density in voids, whereas L(n) with n-odd underestimate it. On the whole, they find that *L*(*n*=odd) provide better descriptors of void expansion than *L*(*n*=even). Surprisingly, the Zel'dovich solution *L*(1) outperforms *L*(3), *L*(5),... at late times which is typical for asymptotic or *semiconvergent series*. The results of the work by *Sahni* and Shandarin strengthen that conclusion and show that the Zel'dovich approximation is the best non-linear approximation to apply to the late time study of spherical voids. *Sahni* and Shandarin suggest that a generic property of the Lagrangian and probably Eulerian perturbative theories of gravitational instability may be that they are described not by a *uniformly convergent* but by an *asymptotically convergent* series. If true, this could be of great importance in understanding the behaviour of gravitational clustering in the strongly nonlinear regime.

Topological and geometrical quantifiers of gravitational clustering

The most common statistical tool used to quantify gravitational clustering has traditionally been the two point correlation function. A positive value of this statistic signifies that galaxies cluster more strongly than they would in a purely Poisson sample. However, important as the correlation function is, it still does not tell us about the *topology* of clustering. Or, in other words, its connectivity. One is typically interested in the question of how the individual filaments, sheets and voids join up and intersect to form the global pattern. Is the pattern cellular, having isolated voids surrounded by high - density sheets, or is it more like a sponge in which under - and over - dense regions interlock?

Looking at 'slice' surveys gives the strong visual impression that we are dealing with bubbles; pencil beams perhaps re-inforce this impression by suggesting that a line-of-sight intersects at more-or-less regular intervals with walls of a cellular pattern. One must be careful of such impressions, however, because of elementary topology. Any closed curve in two dimensions must have an inside and an outside, so that a slice through a sponge-like distribution will appear to exhibit isolated voids just like a slice through a cellular pattern. It is important, therefore, that we quantify this kind of property using well-defined topological descriptors.

One such method, applied by *Sahni*, Sathyaprakash and Shandarin to N-body simulations, makes use of a topological invariant known as the *genus*, related to the *Euler-Poincare* characteristic, of the iso-density surfaces of the distribution. Simply speaking, the genus for a single surface is the number of handles the surface possesses; a sphere has no handles and has zero genus, a torus has one and, therefore, has a genus of one. One of the great advantages of using the genus measure to study large scale structure, aside from its robustness to errors in the sample, is that all Gaussian density fields have the same form of the genus. Another topological indicator is percolation: By studying the density field (obtained either from galaxy catalogues or from N-body simulations) at different density threshold, one can construct *percolation curves* which are sensitive indicators as to how the distribution percolates. Both genus and percolation complement conventional indicators of clustering by providing an estimate of the 'connectedness' of structure missed by standard estimators such as the two-point correlation function (which lacks phase information vital to an understanding of large scale coherence).

Sahni, Sathyaprakash and Shandarin assess the relative merits of the genus curve and the percolation curve by applying both to the same set of three dimensional N-body simulations. They find that as the simulation advances, the density distribution rapidly begins to develop non-Gaussian features reflected in the changing shape of the percolation curve and the changing amplitude and shape of the genus curve. The aim of percolation analysis is to study the connectedness of structure as a function of the density threshold. In an infinite medium, varying the density threshold leads to a 'percolation transition' as the volume fraction in the largest cluster changes rapidly from almost zero to unity when the density threshold crosses a critical value. In reality, one deals with finite systems and by an 'infinite' structure one means a structure that spans the entire simulation box or observational sample. Gaussian random fields percolate at the critical filling factor $FF_C \simeq 16\%$ regardless of the spectrum (filling factor - henceforth *FF* - is the total volume in all clusters/ voids above/below the density contrast threshold divided by the simulation volume). Density fields that have evolved under gravitational instability typically percolate at lower levels of FF_C, and in models such as CDM FF_C can be as low as $FF_C \leq 5\%$.

Sahni, Sathyaprakash and Shandarin find that both genus and percolation curves differentiate between the connectedness of overdense and underdense regions if plotted against the density. When plotted against the filling factor, the percolation curve alone retains this property. Extending their discussion to underdense regions (voids) *Sahni*, Sathyaprakash and Shandarin show that voids find it easier to percolate as the simulation evolves, as a result the range in densities when both phases percolate initially increases, enhancing the extent of *sponge-like topology* in the distribution.

Discussing the genus curve, *Sahni*, Sathyaprakash and Shandarin find that the amplitude of *genus* decreases very pronouncedly as clustering advances. This evolution is caused by non-linear mode coupling and phase correlation during advanced gravitational clustering and could be used as a sensitive probe of the primordial spectrum, since the genus shows more pronounced evolution for initial spectra with greater small scale power.

Gravitational clustering and nonlinear scaling relations

Over the years, *Padmanabhan* and collaborators have been trying to understand the evolution of gravitational clustering from the point of view of "nonlinear scaling relations" (NSR). These relations allow one to express true, nonlinear correlation functions in terms of the *known* linear correlation functions, thereby allowing one to understand the simulation results from first principles.

The earlier work by *Padmanabhan* in 1996 provided a theoretical model for the NSR related to the two-point correlation function. Recently, *Munshi* and *Padmanabhan* have extended this work in two directions. To begin with, they show how similar NSR's can be obtained for *higher* order correlation functions. The comparison of their theoretical models with simulations show good agreement. This success implies that one can now - in principle - model the actual density field in the nonlinear regime analytically. Secondly, they have now taken into account the fact that the initial density field has fluctuations of different amplitudes. For example, a particular region might have an initial density which is far higher than average, just because of random fluctuations. It is necessary to average over these fluctuations to get a more precise estimate of the NSR. *Munshi* and *Padmanabhan* have done this and they find that the results are again in good agreement with simulations.

This work allows one to understand the evolution of dark matter perturbations in a semianalytic way, starting from first principles. Further, it allows one to do away with dark matter simulations to certain extent.

Numerical study of scaling in the strongly nonlinear regime

Computationally, it is very difficult to estimate S_N parameters due to several spurious effects. *Munshi*, Bernardeau, Melott and Schaeffer have developed a completely new method based on factorial moments to compute higher order moments of probability distribution function (Pdf). Various corrections to these parameters can easily be computed using this method. Comparison of their method with other existing techniques (based on central moments) clearly proves superiority of their method. They have studied the evolution of S_N parameters using this new method. It is possible to study the evolution of Pdf in various regime which was found to be in agreement with their earlier theoretical predictions (*Munshi, Sahni* and Starobinsky, 1994). Using both 2D and 3D simulation data, *Munshi* et al. also estimate the void probability function and other scaling functions for a wide range of scale free power law models which are found to be in good agreement with scaling models in the nonlinear regime.

Late stages of gravitational clustering

The evolution of large number of particles under their mutual gravitational influence is a well-defined mathematical problem. If such a system occupies a finite region of phase space at an initial instant, and evolves via Newtonian gravity, then it does not reach any sensible 'equilibrium' state. The core region of the system will keep on shrinking and will eventually be dominated by a few hard binaries. Rest of the particles will evaporate away to large distances, gaining kinetic energy from the shrinking core.

The situation is drastically different in the presence of an expanding background universe characterised by an expansion factor $a(t)$. Firstly, the expansion tends to keep particles apart thereby exerting a civilising influence against Newtonian attraction. Secondly, it is now possible to consider an infinite region of space filled with particles. The average density of particles will contribute to the expansion of the background universe and the deviations from the uniformity will lead to clustering. Particles evaporating from a local overdense cluster cannot escape to "large distances" but necessarily will encounter other deep potential wells. Naively, one would expect the local overdense regions to eventually form gravitationally bound objects, with a hotter distribution of particles hovering uniformly all over. As the background expands, the velocity dispersion of the second component will keep decreasing and they will be captured by the deeper potential wells. Meanwhile, the clustered component will also evolve dynamically and participate in, for example, mergers. If the background expansion and the initial conditions have no length scale, then it is likely that the clustering will continue in a hierarchical manner *ad infinitum*.

Most of the practising cosmologists will broadly agree with the above picture of gravitational clustering in an expanding universe. It is, however, not easy to translate these concepts into a well-defined mathematical formalism and provide a more quantitative description of the gravitational clustering. One of the key questions regarding this system which needs to be addressed is the following: Can one make any general statements about the very late stage evolution of the clustering? For example, does the power spectrum at late times 'remember' the initial power spectrum or does it possess some universal characteristics which are reasonably independent of initial conditions? This question is closely related to the issue of whether gravitational clustering leads to density profiles which are universal.

Padmanabhan and *Sunu Engineer* have made some progress in understanding the *late time* evolution of the gravitational clustering in an expanding universe. Their work is based on the nonlinear scaling relations (NSR) which connect the nonlinear and linear two point correlation functions. Earlier work by *J.S. Bagla* and *Padmanabhan* have suggested that the evolution of clustering has certain "critical indices" for power spectra. Roughly speaking, the evolution tends to proceed towards power spectra with these critical indices. This also suggests that the evolution may proceed towards a universal density or correlation profile which does not change its shape at late times. If the evolution should lead to a profile which preserves the shape at late times, then the correlation function should grow as a^2 (in a $\Omega = 1$ universe) even at nonlinear scales. *Padmanabhan* and *Engineer* prove that such *exact* solutions do not exist; however, there exists a class of solutions ("psuedo-linear profiles", PLP's for short) which evolve as a^2 to a good approximation. It turns out that the PLP's are the correlation functions which arise if the individual halos are assumed to be isothermal spheres. They are also configurations of mass in which the nonlinear effects of gravitational clustering is minimum and hence can act as building blocks of the nonlinear universe. This result has the potential of providing an interesting technique for studying nonlinear gravitational clustering.

Observational Cosmology

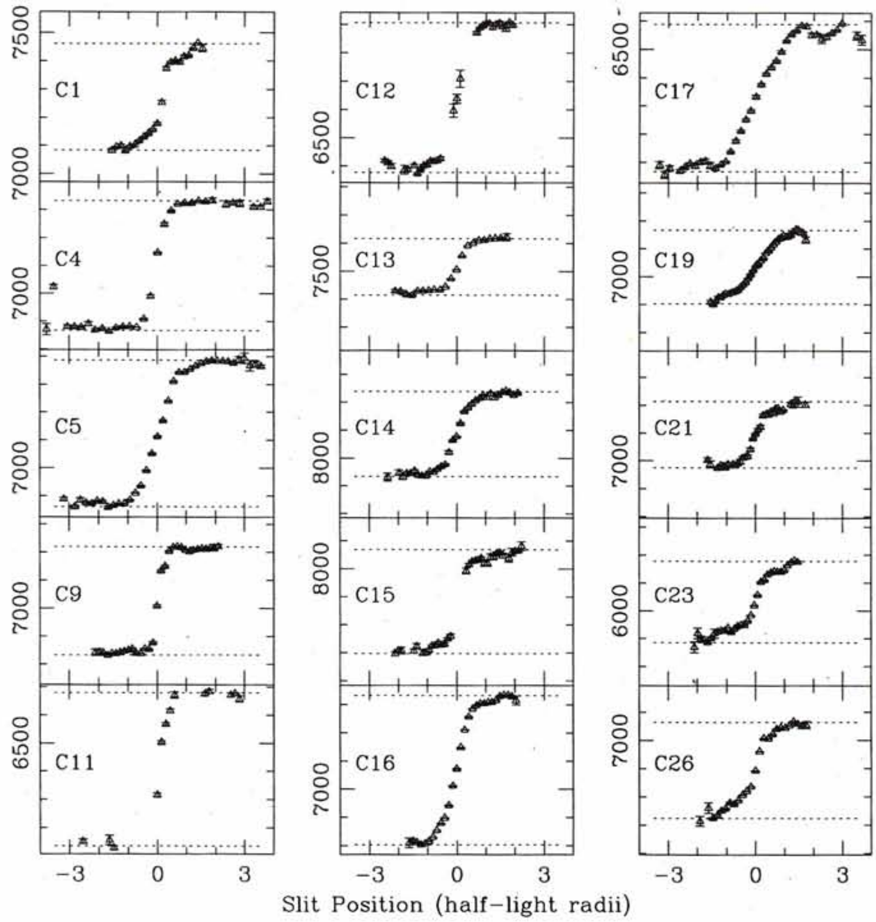
Studies of the Tully-Fisher relation for spiral galaxies

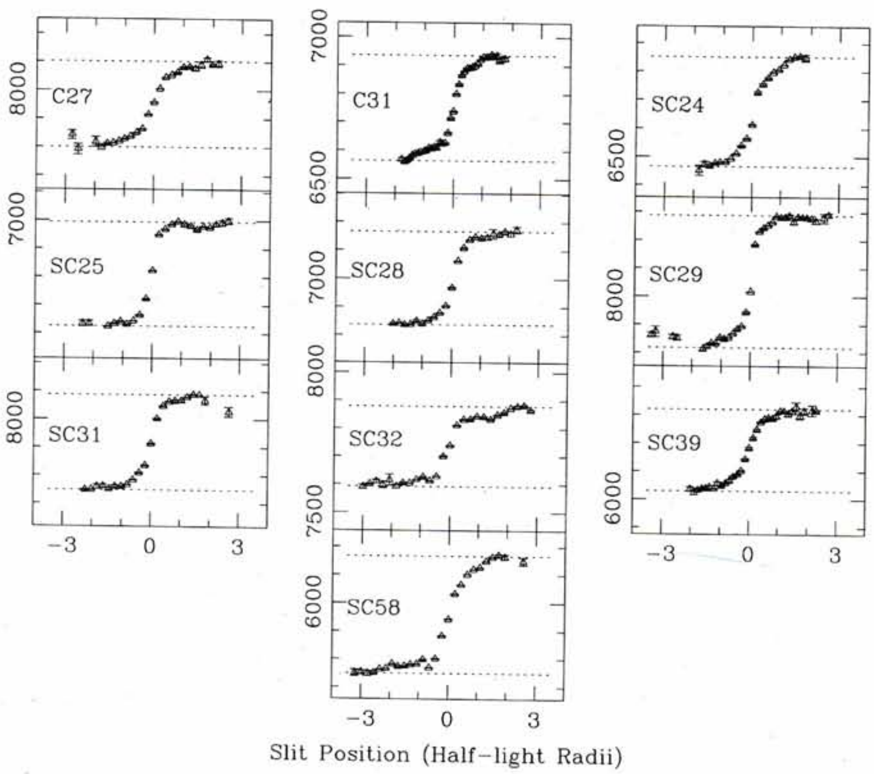
One of the most effective ways of mapping the distribution of matter in the universe is to measure the peculiar velocities of galaxies, i.e., their deviation from the Hubble expansion. However, measuring peculiar velocities beyond the Local Supercluster requires very precise distance indicators to galaxies. The currently popular secondary distance indicators (D_n - sigma, Tully-Fisher) claim to measure distances accurate to about 15%.

Together with Gary Bernstein (University of Michigan, USA) and Puragra Guhathakurta (Lick Observatory, USA), *Somak Raychaudhury* has been measuring distances to galaxies to several clusters in the range cz=7,000-10,000 km/s (including the Coma cluster) using the Tully-Fisher relation for spiral galaxies. Photometry is done in the optical (I-band) and near-IR (H-band), and velocity widths are measured using both 21-cm profiles from Arecibo and long-slit H_α rotation curves from the Multiple Mirror telescope in Arizona. Since part of the motivation of the project is to study the Tully-Fisher relation itself and quantify its intrinsic scatter, they have carefully chosen *a priori* sample of galaxies that have regular isophotes and "clean" velocity profiles. The surprising result is that the galaxies in the sample exhibit an extraordinarily low scatter of 0.10 mag and 0.14 mag RMS in the *I* magnitude Tully-Fisher relation, when 21-cm widths or their (optical) H_α rotation curves are respectively used to measure the rotation parameter. They have also examined several ways of measuring the rotational speed of spirals from the long-slit rotation curves, and find that the scatter and form of the Tully-Fisher relation are not appreciably affected by the choice of algorithm for the extraction of velocity widths.

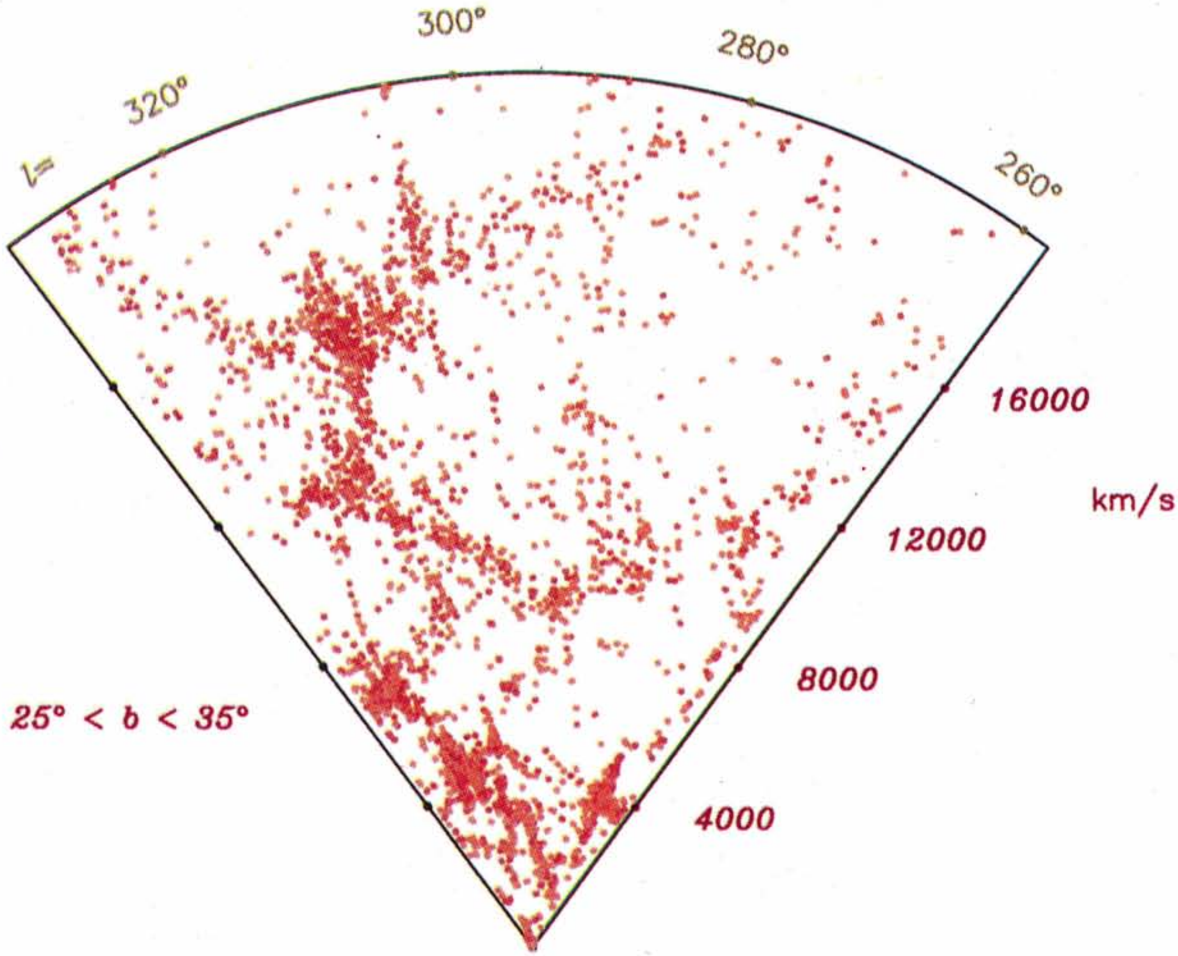
A redshift survey of galaxies in the direction of the local bulk flow

Galaxies over a large volume of the local





Rotation curves for late spirals in the Coma cluster, obtained from long-slit spectra using the H_a emission line. The x-axis is in units of each galaxy's half-light radius $r_{1/2}$, and the y-axis is recession velocity in km per sec, where each vertical tick represents 100 km per sec. (Somak Raychaudhury, Kaspar von Braun, Gary Bernstein and Puragra Guhathakurta, Astronomical Journal, 1997)



The distribution of galaxies in the direction of motion of the local group, as seen in the latest status of the FLAIR redshift survey. All galaxies seen here lie in a 70 ' 10 degree strip and are brighter that $B_J = 16.7$. Early-type (E, S0) galaxies are coloured *tomato*, and late-types *salmon*. The overwhelming radial structure towards the left of the wedge is caused by the large velocity dispersion of galaxies in the Shapley Supercluster. Clusters belonging to the Hydra-Centaurus supercluster are seen as "fingers of God" closer that 5000 km/s (Somak Raychaudhury, Ron Hola, Matthew Colless).

universe have been found to be moving in a bulk flow of surprisingly high amplitude under the gravitational influence of the surrounding distribution of matter. One of the main sources of this motion is believed to be a large concentration of galaxies, called the 'Great Attractor', which lies in the general direction of the Hydra-Centaurus and Shapley superclusters of galaxies. *Somak Raychaudhury*, together with Matthew Colless and Ron Hola (Mount Stromlo and Siding Spring Observatories, Canberra, Australia), has been obtaining redshifts for a complete sample of galaxies brighter than $B_J = 16^m.7$ in a $70^0 \leftrightarrow 10^0$ strip in the direction of the motion of the Local Group. They are using the FLAIR II system on the UK-AAO Schmidt telescope at Siding Spring, obtaining 92 spectra simultaneously over $6^0 \leftrightarrow 6^0$ Schmidt field with the help of optical fibres.

This sample is drawn from *Raychaudhury's* earlier survey of galaxies in an extended region in this direction which was compiled by scanning glass copies of UKSTU Sky Survey plates with the APM facility in Cambridge, England. This sample spans an area on the sky which is almost the same as the CfA redshift survey: albeit it goes three times deeper in effective depth. It covers the general direction of the peculiar motion of the Local Group and of the putative *Great Attractor*, in order to further our understanding of the distribution of galaxies responsible for the large-scale motion of the Local Group. The data will also provide the best study yet of large scale-structure in the Local Supercluster and of the luminosity function of galaxies.

Of the 4200 galaxies in the target list, about 3200 now have measured redshifts. The initial results from this survey have been striking, as is apparent in the large-scale structures seen in the distribution of galaxies in redshift space (see figure).

X-ray studies of clusters of galaxies

Most of the baryonic mass in clusters of galaxies, the most massive bound aggregates of matter in the universe, is in the form of hot gas at a temperature of $\sim 10^6$ degrees. This gas emits synchrotron radiation in the X-ray region of the electromagnetic spectrum. *Somak Raychaudhury* has been involved in the study of the distribution of galaxies, dark matter and hot gas in rich clusters in the Shapley Supercluster. Together with Christine Jones and Bill Forman (Harvard-Smithsonian Center for Astrophysics), he has obtained ROSAT and ASCA images of several clusters of galaxies in the core and periphery of the Shapley Supercluster.

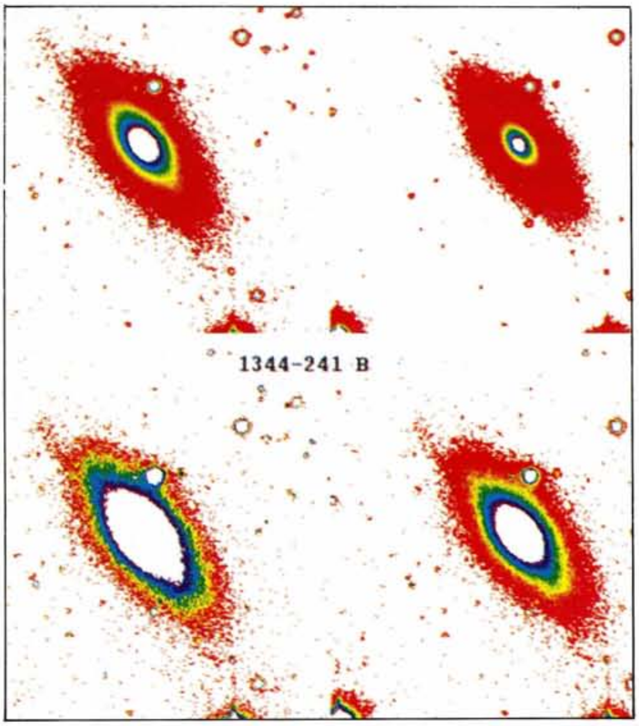
The Shapley Supercluster is the richest association of galaxy clusters within $z = 0.1$ in the Abell/ACO catalogue, lying between 12,000 and 16,000 km/s beyond the Hydra-Centaurus Supercluster. Six of the 46 X-ray brightest clusters in the sky ($|b|>20^0$) belong to this Supercluster. The sum of the masses of the separate clusters estimated from their X-ray luminosity is $M > 1.4 \leftrightarrow 10^{16}\ h^{-1}_{50}\ M_O$ for the Supercluster, which is consistent with the mass estimated from optical dipole measurements. The ratio of mass density in observed clusters to the mean density of the universe, exceeds 0.8 Ω_0^{-1} over the core region of radius 37 h_{50}^{-1} Mpc.

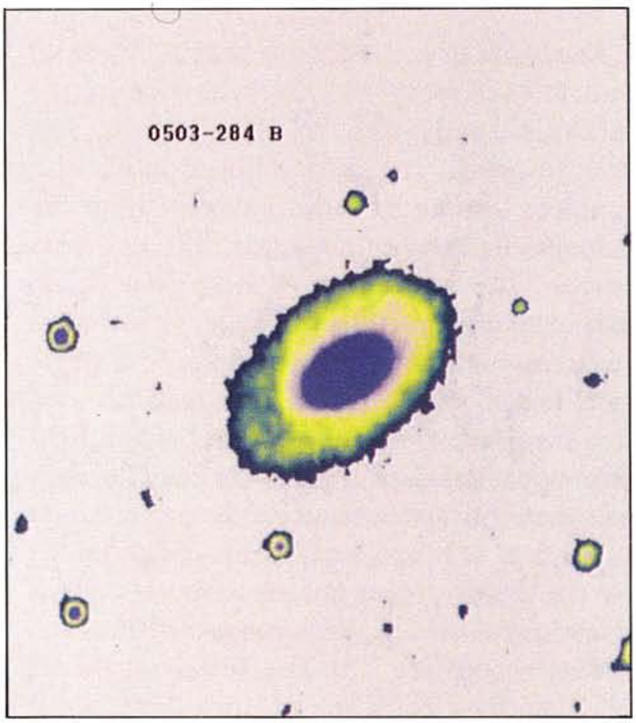
Raychaudhury and his collaborators have been studying the distribution of light and mass, and the internal dynamics of the supercluster by relating X-ray observables (temperature of the hot intergalactic medium, emitted X-ray flux, substructure, metal abundance) to optical properties (richness, optical luminosity, morphological content, etc.) and redshift information of clusters in the Shapley Supercluster.

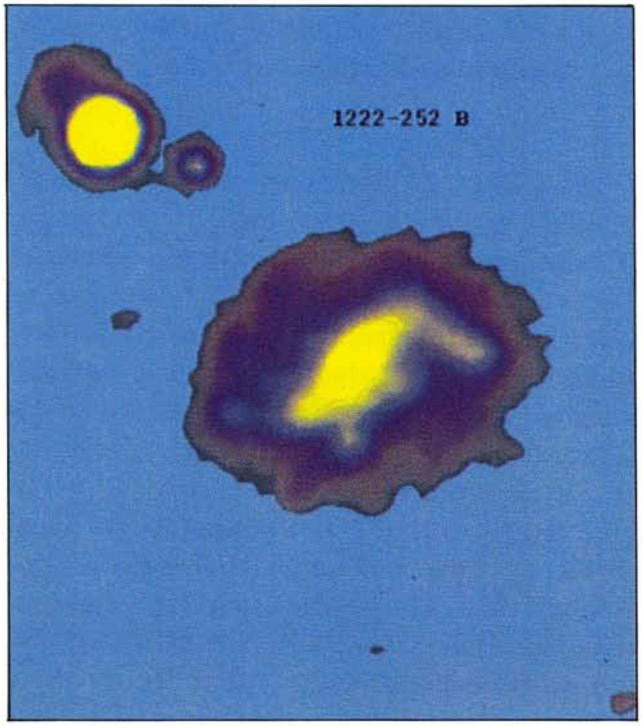
Extragalactic Astronomy and Quasars

Morphology of galaxies

It is a great mystery as to why a small fraction of galaxies harbour powerful radio sources. At optical wavelengths, these radio galaxies have the general appearance of normal ellipticals and do not show any special features which could set them apart for playing host to radio sources. It is possible to examine this issue further using sensitive and high dynamic range broad band CCD observations centered on different







Examples of the optical counterparts (B band of radio sources from the MRC. These were obtained by Ashish Mahabal and Patrick McCarthy with the 1.0 m Swope telescope at Las Companas Observatory in Chile.

wavelengths. In addition to the increased sensitivity offered by CCDs, modern image processing techniques allow very deep examination of galaxy morphology, making it possible to detect faint features which could provide testimony to violent events like mergers which happened in the past and set off, due to some special set of circumstances, not only an active galactic nucleus but also the ingredients, like relativistic jets of charged particles, which are necessary for the development of radio structures.

A. Kembhavi in collaboration with *A. Mahabal* and P. McCarthy of Observatories of the Carnegie Institution of Washington, has obtained optical images in different bands of a complete sample of radio galaxies from the Molonglo Reference Catalogue (MRC) of radio sources. The morphology of these galaxies has been examined in different ways, to see what structures, not immediately obvious on a single direct image, can be found. The methods used have involved: (1) Fitting ellipses to the light distribution, developing idealized model images from these fits and subtracting the models from the original to reveal small scale structures. (2) The use of two-colour images to reveal regions which have unusual colours because of emission or dust absorption. (3) The fitting of model galaxy profiles using one and two dimensional techniques to investigate the possible presence of disks and other structures. (4) The use of morphological image processing techniques to look for the presence of spiral arms, bridges, arcs and so on.

The result of the investigation has been that a large fraction of the radio galaxies show significant departures from simple elliptical shape. A disk is found in a significant number of cases, and in at least one case symmetric spiral arms have been seen. Features like multiple nuclei, distorted morphology, bridges and dust are seen in many cases. These are being correlated with large scale galactic structure, radio properties and the environment.

Optical identification of FIRST survey regions

The FIRST radio survey has mapped large areas of the sky at 20 cm to levels as faint as 1 mJy. A programme to find quasars identified with the radio sources from this survey has been undertaken by *Y. Wadadekar* and *A. Kembhavi* in collaboration with P. McCarthy. This involves taking optical images of the sky with telescopes at the Carnegie Observatory in Chile and at other sites. Several nights of observations have already been obtained and the process of identification is on.

Galaxy simulations

The decomposition of galaxies into bulge, disk and point source component is quite complex, and misleading results can be obtained, either because of genuine departures from simple intensity profiles which are assumed in the decomposition, or because of contamination by stars, the difficulty in obtaining a good point spread function and so on. It is very important to have a quantitative idea about the effect such factors can have on the extraction of parameters. Again, the detection of faint features involves the subtraction of idealized model approximations from original images, and quite often it is difficult to distinguish between genuine faint features and artifacts introduced by the processing.

Y. Wadadekar, B. Robbason, *A. Mahabal* and *A. Kembhavi* have developed programs for simulating galaxies using simple standard luminosity profiles and taking into account atmospheric point spread functions and realistic noise. They have also developed programs which can fit these simulated galaxies to observed ones, which means model parameters can be extracted taking into account the full 2 dimensional image. The program has been applied to a large number of simulations as well as to real data. The availability of the simulated galaxies allows input and output parameter values to be compared, so that the adverse effects of various factors as well as applicability of various parameter extraction techniques can be tested.

Radiation induced void in the spectrum of TOL 1038-2712

R. Srianand has investigated the effect of ionizing radiation from the foreground QSO TOL 1037-2704 on the Ly α forest in the spectrum of the background QSO TOL 1038-2712. He has identified a void exactly at the position of the foreground QSO. Using a numerical simulation he estimated the probability of finding a gap similar or greater than the observed void by chance to be few times 10^{-3}.

Srianand has estimated the upper limit on intensity of background radiation field to be $-21.47^{+0.04}_{-0.03}$ ergs s^{-1} cm^{-2} $Hz^{-1}Sr^{-1}$ assuming the void is produced by the proximity effect of the foreground QSO. Based on the I-model and Ly α lines along four QSO sight lines, he has shown that the actual background intensity is higher than the estimated upper limit. Two possibilities are considered in order to account for this difference.

If QSOs emit isotropically, the presence of the void will give another observational proof against long lived population models of QSOs. If the QSO does not vary within few times 10^7 Yrs, his result suggests a narrow collimated cone emission toward the void (with flux an order of magnitude higher) in addition to the isotropic emission being a possible source of the void.

Most of the available observations of pairs of QSO spectra till date fail to detect voids near foreground QSOs. Even in the two cases where voids have been detected one is found at the redshift of the foreground QSO and the other is at redshift less than that of the foreground QSO. If the beaming picture is correct, one would like to see displaced a void towards higher wavelength side also. Thus a case with a void displaced towards the higher wavelength side will confirm the beaming arguments.

Lyman alpha forest towards B2 1225+317

Srianand and his collaborators have extracted a clean sample of Lyman alpha forest lines, free from contamination by heavy element line systems, from the spectra of B2 1225+317, taken at a resolution of 18 km s^{-1}. Lyman alpha forest lines blended with heavy element lines falling inside the forest have been deblended whenever possible and included in the sample. The sample consists of lines with redshifts between 1.7 and 2.2.

The average velocity dispersion parameter of the sample is 29.4 ± 7.9 km s^{-1}. 19% of the lines have b values below 20 km s^{-1}. Low b values are more common among weak lines, 44% of lines with log $N_{HI} < 13.5$ and 8% of lines with log $N_{HI} > 13.5$ have $b < 20$ km s^{-1}.

They have shown a single power law does not give an acceptable fit to the column density distribution for log $N_{HI} \geq 13.2$. For log $N_{HI} \geq 13.4$, a single power law is acceptable, the slope of the distribution, however, increases with increasing minimum column density cutoff, indicating a steepening or break in the power law. A double power law is fitted to the extended sample of lines, obtained by combining lines observed towards Q1331+170, Q1101-26 and Q2206-199. The slopes for log $N_{HI} \leq 14.0$ and ≥ 14.0 are -1.15 and -2.05 respectively.

They have found an evidence for N_{HI} - b correlation, it being significant up to 3.2 σ level. The correlation is, however, mainly due to the narrow ($b \leq 20$ km s^{-1}) lines. Exclusion of these lines weakens the correlation to 1.25 σ. Their study also revealed excess of line pairs with velocity splitting smaller than 100 km s^{-1}, the correlation coefficient being 1.35 ± 0.42 and 3.14 ± 1.19 for lines with log $N_{HI} \geq 13.2$ and > 13.7 respectively.

Galactic Astrophysics and Dynamics

Dynamics at the centres of galaxies

The density of stars in elliptical galaxies, and bulges of disc galaxies, rises toward the centre in a power-law cusp. These galaxies could also harbour supermassive black holes at their centres. Numerical explorations of orbits in model potentials, over the last decade, have led to the belief that "scattering" by these central density spikes turns elongated box orbits into chaotic ones; the latter fill a region of space that is too round for the construction of strongly triaxial, self-consistent models. Thus, there is a growing notion that elliptical galaxies with central cusps and black holes must necessarily be axisymmetric. Recent work by *S. Sridhar* and J. Touma argues that this need not be the case; there is a class of (Stäckel) potentials, generated by density cusps and black holes, for which the Hamilton-Jacobi equation separates in parabolic coordinates. They have constructed mass models of non-axisymmetric discs which demonstrate that cusps, black holes, and non-axisymmetry are not incompatible with integrability. Future work in this newly opened up area will decide whether elliptical galaxies may once again be imagined as triaxial objects.

MHD turbulence

There is good support, from both theory and observation, that turbulence in the ionized interstellar medium is magnetohydrodynamic (MHD) in origin. *S. Sridhar* and P. Goldreich had developed a theory of this turbulence, based on nonlinear interactions between colliding Alfvén waves. In two papers published in *ApJ*, they explored *weak* and *strong* turbulent regimes. Recently, they have discovered a new regime of wave turbulence, which they call *intermediate* turbulence; MHD turbulence turns out to be an example - the first - of this new category. In intermediate MHD turbulence, individual collisions between wave packets are weak, but successive collisions being correlated, perturbation theory diverges just like in strong turbulence.

Stellar Astrophysics

Modelling of X-ray sources

R. Misra and F. Melia have modeled the soft X-ray flux from the black hole X-ray nova, GS 1124-68 (Nova Muscae) as emission from an optically-thick disk with comptonization. They show that the observations are consistent with an optically thick accretion disk with an inner hot region as predicted by several models. They find that the dependence of the inner radius of the optically thick on the accretion rate is a power-law with different slopes at different spectral states. The inner hot disk is probably the source of the hard X-rays, although its structure appears to be different during the soft and ultra-soft states.

Cygnus X-1 is a bright X-ray source and is a well known black hole candidate. *R. Misra*, V.R. Chitnis, F. Melia and A.R. Rao have fitted the broad band (2-500 keV) data of this source from EXOSAT, OSSE and XMPC balloon observations, to the transition disk model. In this recently formulated model, the emission is from the inner region of an accretion disk where the temperature is a rapidly varying function of radius. They find that the transition model spectrum is a better fit compared to previously applied standard models.

Stellar astronomy and stellar populations

Ever since the subject of stellar populations is recognized as a branch of astronomy which has applications to the galactic and extra galactic astronomy, the interest in stellar astronomy has revived. Modern concept of stellar populations is based on determination of basic properties of stars in the solar neighbourhood, which in turn are transported to interpret integrated spectra of distant galaxies for which individual stars can be resolved with the present state-of-art of the instruments. With the advent of modern instruments and detectors, it has become possible to observe stellar spectra not only in the solar neighbourhood, but also in nearby star clusters. In the modern era of spectroscopy, a large growth of spectral data over a broad wavelength range is inevitable. In order to analyze this data efficiently, we will require modern computational methods.

Several projects for developing these methods are underway worldwide to analyze a bulk of galaxy and stellar spectra by using statistical and novel methods like artificial neural networks (ANNs). Over the past few years *Ranjan Gupta, R.K. Gulati* and their collaborators have been involved in investigating the potential of these methods for analysis of stellar spectra. Earlier they have applied the methods to classify ultraviolet and optical stellar spectra. With the limited data they have shown that the methods are capable of classifying low dispersion spectra to an error of 2 subclasses.

In a continuing effort of application of Artificial Neural Network to stellar spectra, they now have evolved the following new areas in which there have been successful results:

(i) Stellar effective temperatures by ANN method

In an attempt to use stellar atmospheric model generated synthetic spectra and its comparison with observed spectra, *Gulati, Gupta* and N.K. Rao (IIA, Bangalore) have determined effective temperatures of cool G-K dwarf stars by ANN and χ^2 minimization methods. This was a first ever attempt to apply ANN for determination of effective temperature of stars. The results based on ANN method are compared with those of Gray and Corbally where they used conventional methods to classify synthetic spectra in terms of MK system. The results are in good agreement within the expected errors. This opens up a new area where ANN could be used to determine basic stellar atmospheric parameters, effective temperatures, surface gravity and chemical composition, for a large sample of stellar spectra.

(ii) E(B-V) determination for O and B stars using ANN method

The ANN method was further applied by *Gulati, Gupta* and H.P. Singh (Sri Venkateswara College, New Delhi) to determine reddening properties of O and B stars. The colour excess E(B-V), which characterizes the quantity of interstellar material lying between a star and observer, is conventionally determined by computing the difference between the observed colour, (B-V) of a given star and the intrinsic colour, $(B\text{-}V)_0$ corresponding to the spectral type of the star. The broad absorption feature around 2200 Å are also used as the probe of interstellar extinction and the colour excess is estimated by using a average extinction law with varying values of E(B-V) until the broad features are ironed out. They have used the ANN method to determine the E(B-V) from low dispersion spectra for O and B stars. The technique could replicate the E(B-V) values of the classical method within an error of 0.08 magnitudes. Next step will be to use this E(B-V) value from the UV spectra and combine with the absolute magnitude Mv, obtained from the luminosity diagnostic line at 1550 Å to determine the distance to the star and this gives an independent distance measuring method.

(iii) The strength of CIV 1550 Å line as a luminosity indicator for O and B stars

It is well known that the CIV 1550 Å resonance doublet is a good indicator of luminosity class for OB stars. In order to quantify these results, A.A. Athalye (Shivaji University, Kolhapur), *Gulati, Gupta*, M. Parthasarthy (IIA, Bangalore) have derived an empirical calibration of CIV line strength with luminosity. A sample of stars in the IUE low dispersion catalog with reliable parallaxes have been used for establishing the calibration. This methods is envisaged as an independent method to determine distance for galactic clusters and galaxies where hot stars can be observed with space telescopes.

(iv) Use of principal component analysis method and ANN for spectral classification

H.P. Singh, *Gulati* and *Gupta* are working on refinement of ANNs methods and recently we have explored the use of principal component analysis (PCA) for data preprocessing prior to classification with artificial neural networks. Performance of ANN with this compressed data shows that the test library of spectra can be classified to the similar accuracies achieved in our previous investigation, but with less computational load. This is envisaged as a efficient way towards analyzing large spectral databases by using ANN.

(v) Spectroscopic observations from Kitt Peak

A major observing program has been undertaken in collaboration with the group at University of N. Carolina for building a homogeneous stellar spectral library. The team consists of *Gupta, Gulati*, Lewis Jones (University of N. Carolina) and Frank Valdes (NOAO). *Gupta* had undertaken 10 nights of observation from the 1 meter Coude Feed telescope at Kitt Peak, KPNO, Tucson, USA during December 1995. About 200 stars were observed and their spectra obtained. Another observing run was undertaken by *Gulati* in April 1996 during which about 500 spectra were obtained. It is proposed to build a spectra library of stars from O to M and all luminosity classes which will be extremely useful for the stellar population studies. Most of the library has been already completed in terms of wavelength coverage and stellar types and the complete library will be used for several purposes. First the library, which will be unprecedented in scope in terms of covering a very large number of stars of different atmospheric parameters, will be used to calibrate the effects of atmospheric temperature, surface gravity, and chemical composition on stellar spectra through an empirical analysis. Second, the recently developed technique of artificial neural networks will be applied to the spectral database with the goal of finding the optimum set of spectral diagnostics for uniquely distinguishing the effects of stellar atmospheric parameters. Third, the new set of indicators will be applied to the integrated spectra of star clusters and galaxies with the goal of understanding the integrated light of composite stellar systems. The ultimate goal will be to unravel the star formation histories of galaxies.

Interstellar dust and extinction modeling

Gupta and D.B. Vaidya (Gujarat College) have been developing models for scattering by interstellar dust and extinction processes. They have used the discreet dipole approximation to calculate extinction efficiencies for a combination of silicate and graphite porous interstellar grains and have succeeded in reproducing the general interstellar extinction law to a good degree of accuracy by this method for a wide spectral region from UV to near IR at 3.4 μ.

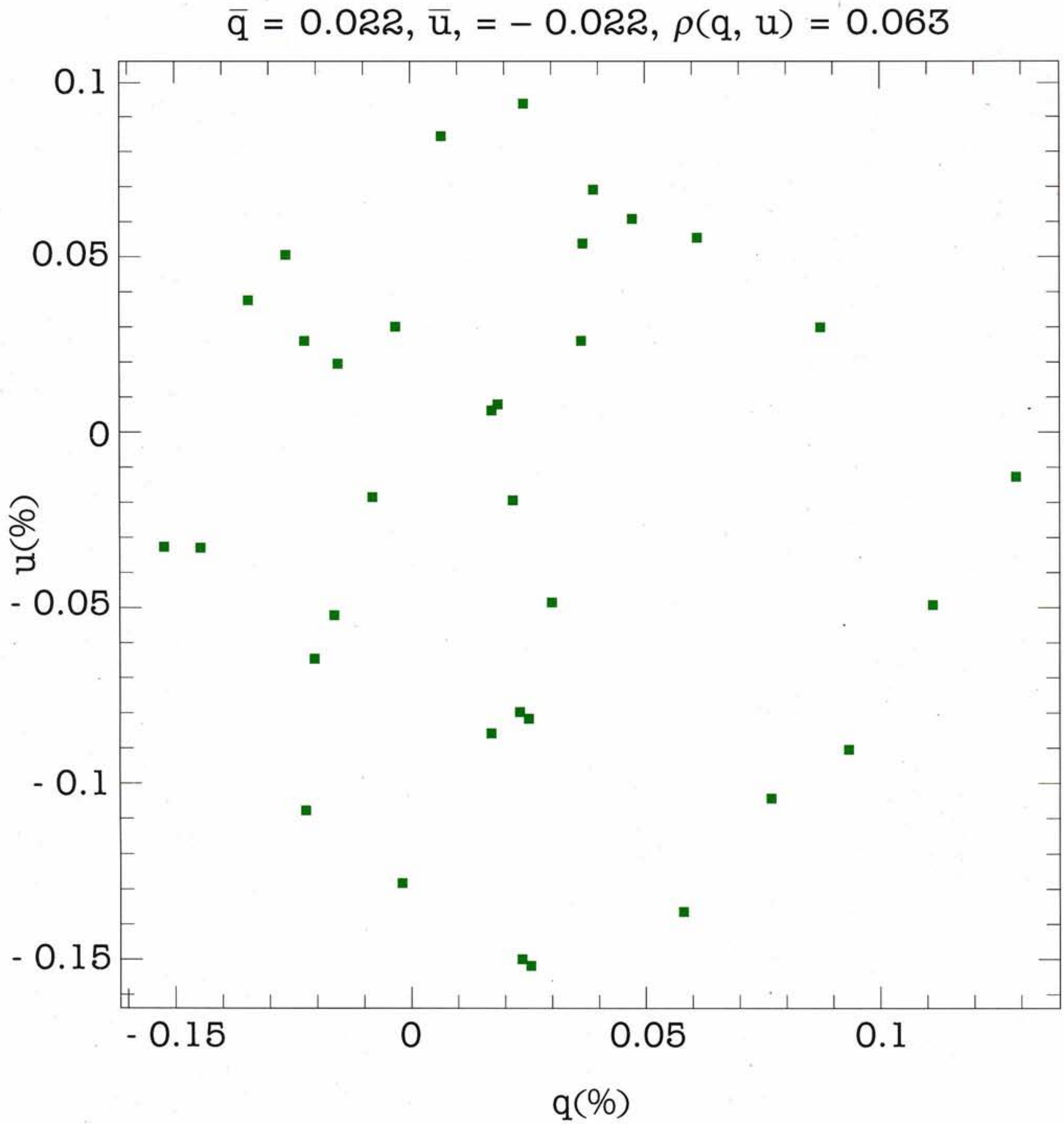
Instrumentation

Imaging polarimeter (IMPOL)

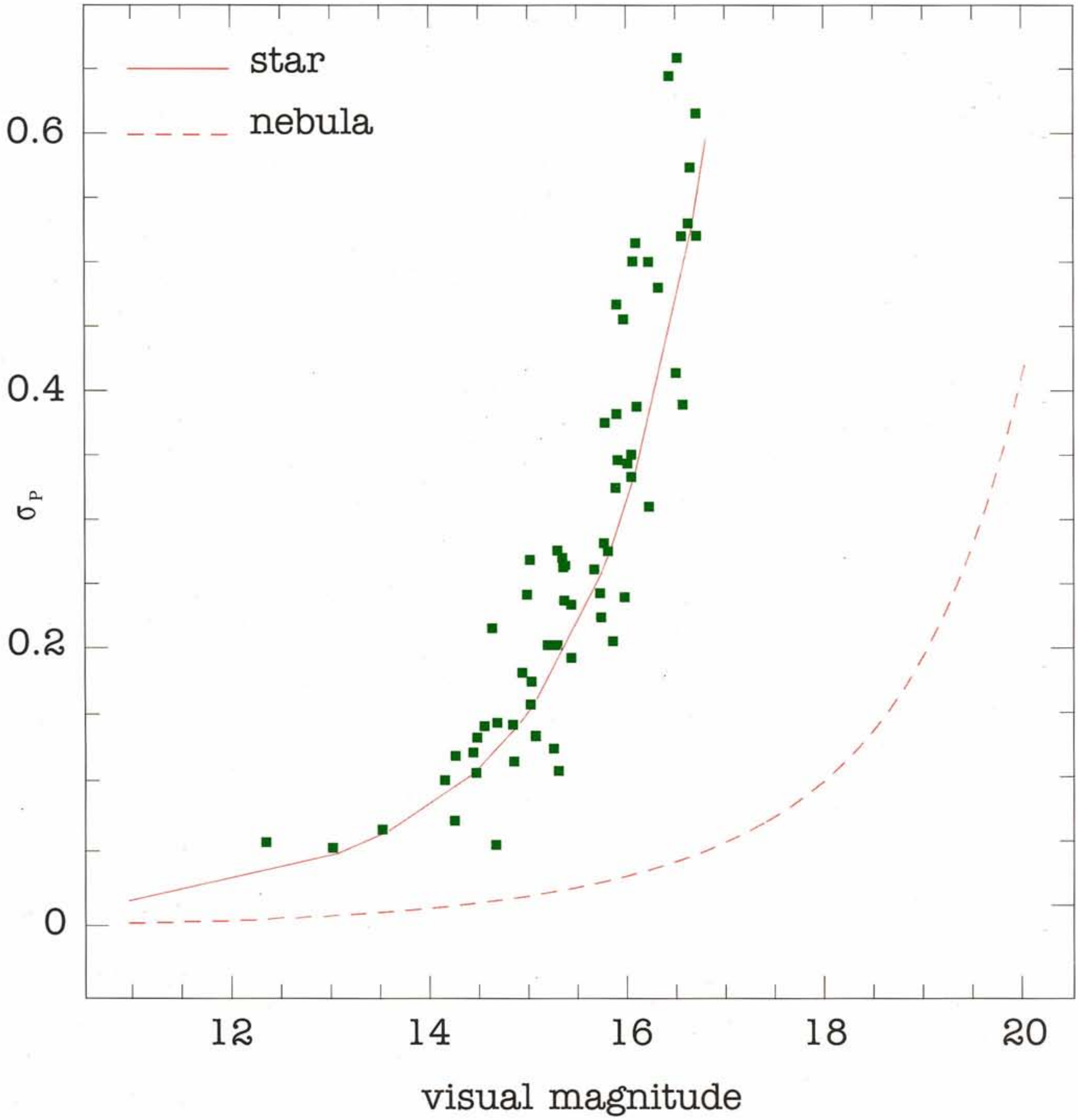
Last year saw the successful completion of the project (supported by the Department of Science and Technology of the Government of India) for developing an imaging polarimeter (IMPOL) at IUCAA's instrumentation laboratory. The project was conceived to design, develop and commission a CCD imaging polarimeter suitable for observations of linear polarization in the optical band, at some of the telescope facilities in India. A half-wave plate is used in the instrument to modulate the plane of polarization of incoming light and an image is taken at four position angles of the half-wave plate fast axis, each separated from the other by 22.5^0. Simultaneous measurements are made of the two orthogonal components of polarization at each half-wave plate orientation, to eliminate effects of scintillation, etc. which alter light flux at the telescope. By paying careful attention to the various sources of errors like repeatability of moving parts, reflection from surfaces, tracking, etc., photon noise limited performance is achieved for polarization > 0.05%.

As projected in last year's annual report, the laboratory phase of the commissioning tests was completed in early 1996 and the instrument was taken for a three night observation at the ϕ 1.2 m infrared telescope at Mt. Abu, Rajasthan operated by the Physical Research Laboratory, Ahmedabad. Several polarized and unpolarized standard stars were observed at that time to characterize the instrument performance at various wavelengths. Observations were also made to determine the parameters needed to interface the acquisition and guidance unit of the instrument to the telescope. During a second observation run in late May, the acquisition and guidance unit was successfully incorporated, thereby completing the commissioning of the instrument.

The highlights of the commissioning tests are as follows: Measurements with 100% polarized light in the laboratory give upper limits of 0.5% depolarization in the B and V bands and 6% in the R band. The instrument polarization was found to be



Normalized Stoke's parameter *q* is plotted against *u* for a number of unpolarized standard stars. The correlation coefficient of the points is about 0.06 and the average values of *q* and *u* give a value of *p* = 0.03%.



The errors due to photon noise alone, for wideband measurements of fractional polarization *p* are shown as a function of the brightness of the source. The solid curve refers to the case of stars while the dashed curve is for an extended object, for which the x-axis represents the surface brightness of the source in magnitudes per sq. arcsecs. The background is assumed to be 20th magnitude per sq. arcsec and a software aperture of 30 sq. arcsec has been used during data reduction. The squares represent the errors in actual polarimetric measurements made with instrument on a field at the periphery of the dark cloud B133.

less than 0.03% in the B band 0.06% in a wideband filter which is roughly the same as the V and R bands combined. Plotted in the Figure on page no. 41 are the normalized Stoke's parameters q against u for all the unpolarized standard star measurements made. The extremely low correlation coefficient (0.06) of the points indicates the negligible level of systematic effects in the measurement of polarization, which if present, should make these points tend to cluster. The mean values of $\overline{q}$ and $\overline{u}$ are equal to 0.022 and -0.022 respectively, which give an instrumental polarization floor of about 0.03%. These results, a complete description of the instrument itself and its operation, are presented in a recent report (IUCAA preprint 3/97).

The data analysis is carried out from within the IRAF environment using a polarimetry package that has been developed for the purpose. The data is in the form of a set of image frames for each filter, with about 12-20 frames per set, the exact number depending on the nature of the source and the accuracy of measurement demanded vis-a-vis the photon noise. The polarization information is extracted in terms of the ratios of the ordinary and extraordinary images in these frames and hence is devoid of the effects of atmospheric scintillation, variation in effective exposure times, etc. These ratios correspond to the normalized Stoke's parameters q and u and a non-linear chi-square fitting technique is used to estimate the polarization parameters and the errors.

The members of IUCAA who are involved in the project are *S.N. Tandon, Gupta* and *A.N. Ramaprakash*. A.K. Sen, who is now at the Assam University, Silchar, was also involved during the early design phase of the project.

The first scientific application of the Imaging Polarimeter (IMPOL), developed at IUCAA, was made during the observations in May 1996 at the ϕ 1.2 m telescope at Mt. Abu operated by the Physical Research Laboratory, Ahmedabad. The aim was to study the nature of the magnetic fields near isolated dark globules and molecular clouds in the interstellar medium. The dust grains get aligned due to the magnetic field and shows a polarization dependent extinction. Thus, the light of the stars lying behind the clouds shows polarization which carries information on the magnetic fields. The preliminary result of polarimetry of stars shining through the periphery of the Bok globule B133 is presented in Figure on page no. 42. The points marked are the 1σ errors in the measurement of polarization of stars behind B133 as a function of their visual magnitudes. The solid curve in that figure is the theoretical estimate of the errors based on photon statistics alone, which is the dominant noise source. This curve rises fast around 15th mag. because of the high sky brightness during the observations due to the presence of the moon.

The following collaborative observations with the instrument are now underway with astronomers at other institutes. (i) A group led by U.C. Joshi at PRL, Ahmedabad with interests in studying galactic dark molecular clouds and active galactic nuclei, (ii) T. K. Sridharan of CfA, USA and Jayadev Rajagopal of RRI, Bangalore to study the role of magnetic fields in the formation and evolution of cometary globules. Two more successful observing runs have been made with the instrument, one in November 1996 and the second in February 1997. The analysis and interpretation of the data from these observations are in progress at present and will be completed soon.

Site-testing for the IUCAA telescope

As described in the last year's report, several instruments (differential image motion seeing monitor, CCD camera for extinction and sky brightness measurements, and a CCD camera for recording cloud cover) were developed for the purpose of site-testing. In order to get a measure of the contribution of the surface layer of the atmosphere to the seeing, a microthermograph was added to this set of instruments. Some of the results of the site-testing, done by *H.K. Das, A. Paranjpye* and *Tandon*, are reported under the heading **The IUCAA Telescope**.

CCD camera

Liquid nitrogen cooled CCD cameras are being developed in the Instrumentation Laboratory by *P. Chordia, M.S. Deshpande, D.V. Gadre* and *Tandon*. The CCD Camera is composed of the CCD Controller and host acquisition system. The new versions of CCD camera include host computer under Linux as well as the DOS OS.

As reported in the last year's annual report, the new CCD controller (which is referred here as V2) incorporating front end circuitry with improved read noise performance, programmable waveform generator and an optical fibre link to the host computer was completed. The testing of the controller was done with the help of a MS-DOS based machine. From a preliminary estimate, the noise performance is expected to be around 5 electrons rms.

The DOS version of the new camera includes a PC host has an optical communication card to communicate with the controller. The communication card allows transmission and reception of data to and from the controller on a byte wide basis. The host acquisition, display and image storage program acquires the CCD image from the controller byte by byte and displays the image. Subsequently, the image can be stored as a FITS file.

The required image parameters are input to the host program using a parameter file method. Since the V2 controller has a programmable waveform generator, the user can devise a suitable waveform table (as a ASCII file) and download the file to the controller. This method allows the user to adapt the controller to different CCD detector chips without any modification on the CCD controller as long as a suitable clock waveform file is downloaded from the host to the controller. They have used this approach to test the controller for the EEV (585 $\leftrightarrow$ 385 pixels) and the TEK (1024 $\leftrightarrow$ 1024) CCD chips.

There are many advantages in using a Linux type OS as a camera host over a DOS based host. Linux being a multitasking OS, allows the user to acquire, display, analyze and store images, all at the same time. Unlike DOS, these activities need not be sequential.

To connect the V2 controller to a PC under Linux, they modified the DOS based optical communication card to include a 2K deep buffer. To be able to use the hardware, they also wrote a suitable device driver for communicating with the controller and to acquire CCD images. A prototype user program has been written and tested with a CCD controller simulator to acquire and store the images. The images which are stored in ASCII as well as FITS formats are displayed using the SAOIMAGE software.

Additional work is in progress to develop a more user friendly acquisition program.

(II) RESEARCH WORK 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 necessarily partial.

G. Ambika

Collaborative work of G. Ambika and A.K. Kembhavi of IUCAA was started on the analysis of the light intensity curves of variable stars with a view to identify any chaotic nature in them. It is found that the irregular pulsations which are of an intrinsic nature show deterministic chaos in typical cases like R-Scuti belonging to the R V Tauri type. They expect to establish chaos further by studying other quantitative features like fractal dimensions, Lyaponov Exponent and F-α spectrum. Moreover, an extensive search for chaos in other variables is intended using embedding techniques, usual in the time series analysis of chaotic systems. Literature survey and preliminary analysis are completed and the required data, viz the light intensity curves of variables, is expected from AAVSO (American Association for Variable Star Observation).

Different dynamical systems, with the pendulum system forming their unperturbed part as a common feature, are analysed for the stability of their periodic modes. The equations are reduced to the Mathieu type so that stability zones and boundaries can be isolated. By adding secondary perturbations of the parametric and quasiperiodic type, the suppression of chaos is studied using analytic procedure. It is found that there are certain regions in parameter space where suppression and hence control of chaos occurs under secondary forcing.

M.N. Anandaram and B.A. Kagali

M.N. Anandaram and B.A. Kagali continued Automated Photometric Telescope (APT) project and the following functions have been carried out: (a) A parallel port interface card linking the photometer and the computer has been assembled, tested and installed. (b) The APT control software program has been debugged to a large extent and has been made more user friendly. Final improvements are to be made after some field tests and operation of the APT. (c) The Autoscope operation mode software in C-language is being studied and is being modified for implementation. (d) An operating manual is under preparation.

Narayan Banerjee

Among the different topological defects that might have developed during phase transitions in the early universe, cosmic strings attracted the interest of a lot of workers for two reasons. First, they give rise to direct observational effects such as producing double images of quasars and second, they pose themselves as the possible seeds for galaxy formations. Thus it is important to investigate the gravitational field of cosmic string. N. Banerjee has found out the gravitational field of an infinite straight static and non-static global string. It is found out that there is a singularity at finite radial distance from the core of the string.

Recently, Brans-Dicke theory is being seriously considered by some investigators as an alternative to general relativity, particularly for the early stages of evolution in the cosmological scenario. He has also worked on the field of a cosmic string in this theory. It is shown that a local string, arising out of the breaking of a local gauge symmetry, is inconsistent with Brans-Dicke theory, whereas a global string is quite consistent. The latter may or may not have a singularity at a finite distance depending on the choice of certain constant.

He has also studied the graceful exit problem in Brans-Dicke theory. A decaying potential, function of the Brans-Dicke scalar field, is coupled to the potential of the scalar field driving inflation and it is observed that the second field evolves to an oscillation phase after the end of the potential.

S. Banerji

Cosmologists have not been able to discover a satisfactory method of formation of galaxies and their clusters. Some believe that the spontaneous breakdown of symmetry in the early universe led to the formation of topological defects called "cosmic strings" which acted as the "seeds" for galaxy formation. It is interesting to see how straight strings behave in an expanding universe. A model of a sourceless Abelian gauge string in Robertson-Walker (RW) universe with flat space sections was considered by Morris, who showed that a radial inflow of energy may create or destroy the string. S. Banerji generalised Morris's result to the case of RW universe with nonzero spatial curvature. He found that creation or destruction of the gauge string is not possible if the spatial curvature is nonzero.

Astronomical observations in the last decade have indicated the existence of regions in the universe which appear to be empty called *voids*. Later evidence indicated that the voids are deficient in luminous matter but are not completely empty. He considered the model of a spherical void containing low density conducting fluid surrounded by a thick spherical shell of radiation embedded in a RW universe with flat space sections. The void has a metric which is the special case of a solution given by Maiti (1982) surrounded by Vaidya metric. He also assumes the RW universe to be filled with a perfect fluid with a linear equation of state. The matching conditions indicate that if the time coordinate in each region is future-directed then the void appears to go on contracting to a comoving observer in the universe as the latter expands until it disappears. However, if the pressure in the RW universe vanishes, (approximately the present day condition), the void remains static.

Oppenheimer and Snyder (1939) considered the collapse of a sphere of pressureless dust whose exterior metric is that of Schwarzschild according to Birkhoff's theorem. It is known that at spatial infinity, the Schwarzschild metric reduces to the Minkowski metric of flat space. They proved that in this idealised situation an observer comoving with the collapsing sphere will find it shrinking to a point after a finite time. However, an observer at a large distance from the sphere and at rest in Schwarzschild coordinates will find the sphere taking infinite time to reach the Schwarzschild radius $r = 2m$. In the actual case, we live in an expanding universe which does not reduce to flat space at spatial infinity.

Unlike Oppenheimer and Snyder, Banerji considered the collapse of a homogeneous dust sphere (Region I) in a RW Universe (Region III) matched with a Schwarzschild metric in the form of a spherical shell (Region II) between the inner collapsing sphere and the expanding RW metric. The inner sphere is also a spherical slice cut out of an RW universe. All combinations of K_1 and K_3 (the spatial curvatures of Regions I and III respectively) are taken. It is found that a comoving observer in Region III will find the collapse of Region I to a black hole to take place in a finite time only when $K_3 = +1$, no matter what the value of K_1 is. However, the event horizon is reached only when the universe changes from the expanding to a collapsing phase. The time taken is infinite in all other cases.

Indira Bardoloi

The COMPTEL telescope aboard the CGRO Satellite has revealed highly significant 1.8 MeV emission lines from the galactic plane region of the Milky Way Galaxy. According to Knodleseder et al, the observed concentrated emission region may contain single object or superposition of multiple objects. To explain the observed emission features, novae and neutron stars with ^{26}Al yield have been considered as possible source candidates. In these stars, during explosive events, radioactive isotope ^{26}Al are ejected into the interstellar matter, wherein it decays emitting 1.8 MeV emission lines. To fit the COMPTEL detection of the significant 1.8 MeV flux of 3.3×10^{-5} photons cm^{-2} s^{-1}, variation of calculated flux at different times and at different distances from the earth, have been studied.

S.P. Bhatnagar

IUCAA, Bhavnagar University and Gujarat College have proposed to build up a Photoelectric Telescope at Bhavnagar and this proposal has been accepted by the Department of Science and Technology (DST) for funding. This project will hopefully begin from July 1997.

The 14 inch Automatic Photoelectric Telescope designed and developed at IUCAA is being replicated for Bhavnagar University. The mechanical fabrication and testing will be done at IUCAA and the telescope will then be transported to Bhavnagar. This telescope would be primarily used for the students at M.Sc. as well as B.Sc. level. The study of variable stars, spectrophotometric studies, cometary studies, etc. will also be carried out with this telescope. During his first visit to IUCAA recently, he has had extensive discussions with Ranjan Gupta and collected the related literature from him.

Bishwanath Chakraborty

Completion of the typed script of the book, Principles of Electrodynamics, containing several chapters on electrodynamics of rotation and other noninertial motions. These chapters have been prepared on the basis of about sixty papers in research and review journals since the times of reports of Einstein on the general theory of relativity. Thus electrodynamics of rotation and other acceleration has been covered avoiding Hiemann tensors as much as possible for readers accustomed to the flavour of vector form of classical electrodynamics. The scope of a critical approach to the foundations of electrodynamics offered by extension to the difficulties of noninertial formulation of electrodynamics has been utilized for the first time in a text book on electricity and magnetism. The typed script has been submitted to New Age International Publishers, (formerly Wiley Eastern), New Delhi.

Plasma dynamics has been studied in presence of populations of negatively charged cortex elements having mass per particle of the order of ionic mass (the existence of which has been suspected in laser produced plasma) along with the populations of free electrons and ions. The problem of wave induced growth of instability at an obliquely developed inhomogeity by an elliptically polarized wave has been studied.

D.K.Chakraborty

Some six years back, D.K. Chakraborty started photometric observations of elliptical galaxies. The analysis of the data revealed the complex structure of these objects, the isophotes are not simple ellipticals, the colour maps show existance of dust lanes and star forming regions and so on. The complexities of these objects are further revealed by kinematical measurements, as reported by several workers.

He now intends to make a detailed study of the structure and dynamics of these objects. The Council of Scientific and Industrial Research (CSIR) has already approved his research project.

Somenath Chakrabarty

It is expected that the magnetic field at the core of a new born neutron star is very high ($\sim 10^{18}$ Gauss). In a series of works, S. Chakrabarty has studied the effect of such strong magnetic field on the bulk properties of nuclear matter, quark matter and on the quark hadron phase transition at the core of a compact neutron star. The stability as well as bulk properties of quark star in presence of a strong magnetic field has been investigated. The effect of magnetic field on the mass, radius and some other bulk properties have been studied.

So far, the effect of strong magnetic field on nuclear matter has been investigated using non-interacting nuclear matter. For the first time, such a calculation has been done for an interacting nuclear matter in presence of strong magnetic field. He has assumed a sigma-omega-rho meson exchange type mean field model and solved relativistic Hartee equation in presence of a strong magnetic field. In this work, he has also predicted the possibility of stable "proton stars".

In the past, he has studied the phase transition from nuclear matter to quark matter at the core of a neutron star in presence of strong magnetic fields assuming non-interacting quark matter as well as nuclear matter. He studied the change in bulk properties, stability and also first order and second order (which is metal-insulator type transition) phase transition to quark matter.

Recently, he has also developed a fully relativistic model of Landau Theory of Fermi Liquid in presence of a strong magnetic field. As an application of this model, he studied the stability and bulk properties of interacting quark matter in presence of strong magnetic fields.

For the first time, a fully relativistic version of Hartee-Fock model has been solved in presence of a strong magnetic filed. He applied this model to study the stability, bulk properties of interacting quark matter in presnec of strong magnetic fields. The phase transition to quark matter at the core of a compact neutron star in presence of strong magnetic fields using this result has been investigated. It turns out that the interacting term for nuclear matter comes from Hartee calculation (mentioned above), where as for quark matter it is only from exchange term (Fock term), which he developed recently in presence of a strong magnetic field.

Suresh Chandra

S. Chandra worked on two types of interstellar molecules (i) asymmetrical top molecules, and (ii) diatomic molecules. For asymmetrical top molecules H_2D^+ and D_2H^+ and -C_3H^2, he calculated Einstein A-coefficients (Line strengths) for rotational transitions in the ground vibrational state. The c-C_3H_2 (Cyclopropenylidene) is the first hydrocarbon ring molecule detected in space and it may be a useful molecule for probing the physical conditions in the astronomical objects where it is observed. Work on the transfer of radiation for the molecule is in progress.

Some molecules in the astronomical objects are not only found in the ground vibrational state, but also in the vibrationally excited states. Hence, in order to investigate H_2O in the vibrationally excited ν_2 state, the Einstein A-coefficients for rotational transitions in the ν_2 state have been calculated.

In order to get reliable information (data) about a diatomic molecule, an accurate information about the potential energy curve for the molecule is essentially needed. Therefore, various methods for calculating accurate potential energy curves for diatomic molecules have been proposed by scientists from time to time. He has now proposed a new method for the evaluation of the RKR potential-integrals for diatomic molecules. This method is straight forward and fast, and the calculations for turning points in the potential energy curve can be performed to an accuracy of 10^{-7} Å, which is better than that achieved by any other method. Using this method for obtaining potential energy curve, Einstein A-coefficients for vib-rotational transitions in CO have been calculated. Carbon monoxide has been observed in almost all the astronomical objects and is most abundant molecule after H_2. Hence, it has been a molecule of great interest for astrophysicists. Further work, on CO using these data, is in progress.

S. Chatterjee

Higher dimensional spacetime is an active field of research in its attempts to unify gravity with other forces of nature. On the other hand, using suitable scalar field it was shown that phase transitions in the early universe can give rise to such objects which are nothing but the topological knots in the vacuum expectation value of the scale field. S.Chatterjee studied a class of solutions around a global monopole resulting from the breaking of a SO(3) symmetry in a 5D spacetime.

He has also noted that the spacetime interpolates between a 5D Schwarzchild-like solution with a singularity at the origin or a nonsingular solution representing a soliton. Interestingly this nonsingular behaviour breaks down when viewed from an affective 4D formalism.

Currently, he is working on a radiating monopole solution which would extend the well-known Vaidya metric through the inclusion of an external scalar field.

D.P. Datta

A major conceptual problem that confronts canonical quantum gravity is the issue of time. In short, a concept of time needs to be generated intrinsically from the relative motion of component degrees of freedom of a closed dynamical system such as a quantized gravity - matter system.The problem, however, turns out to be a nontrivial one. Recently, D.P. Datta has shown that the nonadiabatic geometric phase in a quantal evolution generates just such an intrinsic time. Although this happens to be the only naturally available concept of time in quantum gravity. In ordinary quantum mechanics on the other hand, this relates inversely (dually) to the external Newtonian time in the large fluctuation (short time) limit of the quantal evolution.The time translation invariance of the ordinary Schrodinger equation is thus extended to the SL(2,R) group invariance. As a by-product, he also proves nontrivial scaling relations in a general time dependent quantal evolution, thus establishing a self-similar structure in the quantal fluctuations. Further, time itself could be interpreted as fractal, with the golden mean $\sqrt{5} + 1/2$ as the corresponding fractal dimension. He interpretes the vanishing of the vacuum energy of the universe (the cosmological constant problem) as an effect of this fractality in time. An experimental possibility in probing this fractal time in a high precision determination of the geometric phase is also suggested. Further implications of the fractal time both in quantum mechanics and quantum gravity are under investigation.

S.S. De

Hadrons, nowadays, are considered as extended objects. This extension of hadronic matter in the microdomain has been discussed recently in a series of articles by S.S. De in which the microdomain has been regarded as the anisotropic space-time. Also, this anisotropic character of the space-time has been identified with the Finslerian character of the space. That is, to the small length-scale the space-time is regarded as Finslerian. Further, the geometry of this specific Finslerian inner space has been formulated. On the basis of it, the fields and particle states of hadrons which are compositions of fundamental particles (partons, quarks or leptons) have been constructed. The internal symmetry of hadrons can also be accomplished.

It is necessary for a theory of extended hadrons to provide a dynamical theory for hadrons also. After formulating the fields and particle-states of hadrons, it has been shown that in the field theory of hadrons the perturbation techniques are applicable even in strong interaction. Thus, the anisotropic Finslerian character of the micro-local space-time has direct bearing in providing a consistent dynamics of the strongly interacting subatomic particles.

The space-time describing large-scale structure of the universe and also the space-time of common experience (the Minkowski space-time) which are all manifested in the larger length-scales can be recovered from the micro-space time which is manifested in the very small length-scale to the order or less than some fundamental length. This is achieved through a mathematical procedure 'averaging' of the metric of the Finsler space. The field or wave equation in this space has been derived from a specified property of the field and through the quantization of the space-time at very small length-scale. The important aspect is that if the field (or wave) function is separable in the functions of coordinates of associated Riemannian space and of the directional variables (which characterizes Finslerian geometry of space-time) then the former function satisfies the usual Dirac equation in Minkowski space or the Dirac equation in curved space according as the nature of the associated spaces. These associated spaces are, in fact, the macrospaces describing, for example, the space-time of common experience or the space-time describing large-scale structure of the universe. The other part of the wave function is important as it is responsible for generating the internal symmetry of hadrons. Also as a by-product it has been shown that the masses of the elementary particles may be epoch-dependent, particularly in Robertson-Walker matter or radiation dominated universes. It is not, of course, epoch-dependent in steady-state universe or in the inflationary state or early universe.

The cosmological consequences of the epoch-dependence of particle-masses have been discussed earlier. It has been shown that the universe can have a nonsingular origin with matter and entropy productions in its very early stage of evaluation. The matter and entropy productions were considered in the framework of thermodynamically open universe originally proposed by Prigogine with the incorporation of the mass relation (the relation which expresses the epoch-dependence of particle-masses). The phenomenological approach was also supplemented by a quantum mechanical consideration for creation of matter in the Planck-era time. The totality of the produced particles and the specific entropy per bary on as calculated in these approaches were seen to be in good agreement with the observational data. In addition to the consideration of the nonsingular origin of the universe from anisotropic perturbation of the Minkowski flat space-time, it is also argued that (De, 1995) the cosmological constant problem can be resolved if one adopts the changing gravity approach.

Finally, from this space-time approach of hadron structure it is possible to generate an extra quantum number, the 'internal' helicity of hadron-constituents. This, in turn, can give rise to the internal symmetry of hadrons.

A.D. Gangal

Attractors of some dynamical systems, isoscalar surfaces for advected scalars in certain turbulence problems, typical Feynman and Brownian paths are, among many others, examples of occurence of continuous but highly irregular (nondifferentiable) curves and surfaces. Frequently their graphs are fractal sets. Ordinary calculus is inadequate to characterize and handle such curves and surfaces. A.D. Gangal evolves the notion of local fractional derivative (LFD) by suitably modifying the concepts from fractional calculus, a branch which allows one to deal with derivatives and integrals of fractional order. In particular he establishes a direct quantitative connection between the local scaling behaviour (or dimension) and the order of differentiability. The bigger the fractal dimension, the smaller is the extent of differentiability. He has shown that the method developed here provides a powerful tool to analyse irregular and chaotic signals. It is further noted to be suitable to deal with fractal processes. He also established a local fractional Taylor expansion, which should be of value in the approximation of scaling signals and functions has been extended. This definition has been extended to directional-LFD for functions of many variables and demonstrated its utility with the help of simple examples.

New kind of differential equations, called local fractional differential equations, has been proposed for the first time. They involve local fractional derivatives introduced recently by him. Such equations appear to be suitable to deal with phenomena taking place in fractal space and time. A local fractional analog of Fokker-Planck equation has been derived starting from the Chapman-Kolmogorov condition. Such an equation is solved, with a specific choice of the transition probability, and shown to give rise to subdiffusive behaviour.

Ashok Goyal

It is now widely believed that at high temperatures in the early universe or at high densities in the core of certain neutron or collapsing stars, the matter undergoes a confinement-deconfinement phase transition from normal nuclear matter to deconfined quark gluon plasma. It has been argued that enegetically it is favourable for a 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 almost equal number of u-d-s quarks with electrons to guarantee charge neutrality may indeed be the "true ground state" of matter. It is possible that in the early universe during phase transition, quark matter may have been trapped in what are called "Quark Nuggets" and if sufficiently big might survive to this date. Ashok Goyal and Deepak Chandra have studied the possibility of formation of such objects in the early universe, both at the time of electro-weak symmetry phase transition and at QCD transition and their possible survival against surface evaporation and boiling (bubble nucleation). The possibility of identifying these objects with newly discovered MACHOS in the galactic halo is an exciting idea.

A. Goyal, V.K. Gupta, J.D. Anand and S. Singh have also studied the conversion of two flavour quark matter into strange matter in neutron star cores and in the supernovae. The conversion in supernova 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. The strange supernova core has also been used to put constraints on the properties and interactions of neutrons and other exotic particles like axions, majorons, etc. Indeed, Ashok Goyal, S. Dutta and S.R. Choudhury have used this to obtain some of the best bounds on neutrino magnetic moment.

The Strange Star has many interesting properties and the ways in which it can be distinguished from neutro stars has been studied in collaboration with Pragya, V.K.Gupta and J.D.Anand viz. transport properties like viscosity which governs the damping of radial pulsations in newly born neutron stars is quite different for normal nuclear and strange matter. In addition, the presence of strong magnetic field would modify the cooling rates of neutron stars and may dramatically alter the composition of the core. Primordial magnetic field on the other hand would have the effect of modifying the baryon number density contrast and therefore helium production. Helium production would also be affected by the modification of weak interaction rates.

At high densities, the core may also develop meson condensates which would also result in modified cooling rates and would shorten the duration of the observed neutrino burst from SN1987A, thereby severly constraining the properties and interactions of weakly interacting particles. This has been used to constrain (with S. Dutta) the right handed vector boson masses in Left Right symmetric model and holds promise for studying other related problems.

V.B. Johri

The genesis of matter and radiation in the early universe is a fundamental question in cosmology. The ad hoc assumption of the pre-existence of matter or its instantaneous creation from the big-bang singularity does not make any scientific contribution. In fact, the physics of creation should be an integral part of cosmology since the universal laws of nature remain incomplete without incorporation of creation mechanism in cosmology.

Several attempts have been made to explain the creation of matter in the universe by introducing a scalar C-field, vacuum energy field or a bulk viscosity field in the standard FRW model. Mathematically, any negative energy field may lead to genesis of matter; then how to determine the correct mode of creation in the universe? Undoubtedly, the decisive factor would be the cosmological observations - as to what extent they match with the theoretical predictions of the creation model in question. Besides this, there is a seminal result given by Landau & Lifshitz, supported by Zel'dovich and discussed analytically by Cooperstock, Rosen, Johri, Kalligas, Singh & Everitt which states that the total energy (material + gravitational) of the closed universe is zero. It puts a constraint on any possible creation mechanism in the universe. This implies that so long as there is no matter creation, the total amount of material (radiation) energy is separately conserved and the gravitational energy is conserved separately but if there is matter creation, it takes place at the cost of gravitational energy, i.e., any increase in material energy must be accompanied with a corresponding decrease in gravitational energy so that the total energy of the universe remains zero.

For instance, if the scalar C-field is used for the matter creation in Hoyle-Narlikar steady state theory, then it must also cause an equal amount of decrease in gravitational energy embedded in the space-time curvature for the sake of compatibility. Therefore, the gravitational energy seems to be the ultimate source of genesis of matter in the universe, be it primeval vacuum fluctuation leading to cosmogenesis or inflationary expansion involving stupendous amount of energy. Ilya Prigogine has shown that the transfer of gravitational energy to matter field to gravitational field is forbidden.

This is the basic theme of the recent work done by Johri. A new model of the early universe is proposed in which the universe starts expanding from a vacuum fluctuation accompanied with creation of particles out of gravitational energy. A suitable choice of the particle creation function leads to inflation and subsequent change-over to Friedmann era. Growth of density fluctuations during inflations is investigated.

K.N.Joshipura

Molecules like O_2, O_3, NO, CO, CO_2, H_2S, OCS, O_2 and C_2H_2, C_2H_4, CH_3X (X = CH_3, OH, F) are important, as they occur in different astrophysical and atmospheric systems. K.N. Joshipura has investigated the interactions and scattering of electrons colliding with these molecular targets. He builds up the theoretical models to calculate the total cross sections (TCS) of electron-molecule scattering and draw conclusion, by comparisons with experimental data. The comparisons serve a useful purpose also in cases where measurements are not done, owing to experimental difficulties. He examines the TCS as functions of energy for a particular molecule. It is interesting to study the behaviour of these quantities for isoelectronic systems, Ne (atom), HF, H_2O, NH_3 and CH_4. The TCS do not simply depend on the number of electrons and bond lengths alone, they are also sensitive to the dipole moment and the electric polarizability of the target molecule.

Pushpa Khare

High resolution (FWHM = 18 km s^{-1}) data of absorption lines in the spectra of B2 1225 + 317 were analysed using profile fitting analysis. The sample of Lyman alpha forest line was studied for statistical properties. A single power law is inconsistent with the column density distribution and a steepening in the distribution is indicated. The average velocity dispersion parameter is 29.4 km s^{-1} are excluded. They find 3 σ evidence for a correlation between column density and the velocity dispersion parameter. The correlation, however, is mainly due to narrow lines and weakens to 1.2 σ if lines with velocity dispersion parameter smaller than 20 km s^{-1} are excluded. An excess of line pairs with velocity separation $\leq$ 100 km s^{-1} over the expected number is found.

She has analyzed high and low resolution data of absorption lines of Si and C in the absorption systems observed in the spectra of QSOs, in order to study the ionization state and the overabundance of Si with respect to C in the absorbers and also to study the change in these properties with redshift. An overabundance of Si over C can be ruled out in some of the damped Lyman alpha as well as other intervening systems. For these systems, the radiation field is completely dominated by the AGN background, with negligible contribution from stellar sources. No overabundance is needed in other intervening systems if the radiation field from stellar sources contributes significantly to the UV background.

S.P. Khare

Reliable ionization cross sections of molecules by electron impact are required in the study of plasma diagnostics, astrophysical and fusion applications, radiation physics, mass spectrometry, ionization in gas discharge, planetary and cometary atmospheres, etc.

However, quantum mechanical evaluation of the ionization cross section of the molecules is an involved problem. S.P. Khare has developed a simple method which requires only photoionization cross sections of the molecules as input. It is employed to obtain cross sections for the total ionization and for the formation of the parent ions of H_2, N_2, O_2, NH_3, H_20 and CO_2 by electron impact for the incident energy varying from the threshold of ionization to 3 MeV [1,2]. His method is based on the plane wave Born approximation but includes exchange and relativistic corrections, the longitudinal interactions through the static unretarded Coulomb field and the transverse interaction through emission and reaborption of the virtual photons. The calculated cross sections are in good agreement with the experimental data over a wide energy range (E ⊕ 50 eV) and the same holds for the ratios of the partial to the total ionization cross sections. Its extension to the heavier molecules is in progress.

V.H. Kulkarni

Dust of various sizes from broken planets, planetesimals, comets and rockets exhausts are introduced in Space Plasmas. These acquire very large charges. Dusts of micron and submicron size acquire negative charges and neutral change behaviour of plasmas. Here the analysis of waves of very large amplitudes show that the localized high potential region known as double layers, are unlikely. Dust can be treated as negative ions, which possesses charge fluctuations. Effect of these charge fluctuations seem to reduce the non-linear Brillouin scattering. Other interesting problem is that steaming charged dust grains can excite waves . These waves can couple the solar wind plasma and cometary dust tails. It is interesting to note that the viscous interaction between cometary dust and the solar wind can form dust tails even in the region where solar radiation is weak, because the wind extends far away regions without any decrease in its energies.

V.C. Kuriakose

Recently, the language of squeezed states of quantum optics has been adopted to explain the physical process of cosmological particle creation. Using the formalism of two mode squeezed states, the problem of the scalar particle creation has been studied by evaluating the expectation values of the stress-energy tensor of the scalar field in curved space-time. In terms of the squeezing parameters, the validity of the semi-classical theory of gravitation is also analysed by evaluating the fluctuations in anisotropic density and pressure.

P.S. Naik

P.S. Naik has completed the design and construction of a stellar Photometer at the IUCAA instrumentation laboratory and tested its performance with C8 - plus cellestran telescope and they were found working satisfactorily.

The complete unit facilities are now available at Gulbarga University for continuous use by students and staff for the study of Photometric observations such as secondary standards, binaries and objects in solar system. In particular, measurements were made using laboratory source and a given star namely, Sirus to test the instrumental aspect of stellar photometer. It is noticed that, the temperature of laboratory source for different rating were found agreeing with the expected ones. Further, he has measured the astronomical parameters of a given star (Sirus) using Julean data, such as ST, HA, air mass (X), etc., and compared these with existing data and found that the measurement are accurate up to 10% error.

V.M. Nandakumaran

The collaborative work with A.K.Kembhavi and M.K.Das on the evolution of tidal capture binaries is in progress. The differential equations for the different modes of tidal oscillations when nonlinearities arising as a result of inclusion of higher powers of density fluctuations, are currently under investigation.

The study of chaos in modulated logistic systems has been completed during the current year. Under this, three different systems have been investigated. One of the systems, namely, the combination map, shows interesting scaling relations of the Lyaponov exponents, at the onset of chaos.

Another work which was completed during this period is the study of the dynamics of the parametrically perturbed logistic map. This system shows very interesting feature such as the phenomenon of phase locking.

Udit Narain

It is now quite well-known that the outer atmospheres, particularly the coronal regions of the Sun and other stars have temperatures of the order of million degree Kelvin. They lie in between two cooler regions in spite of their extremely high thermal conductivity. These coronae consist of electrons, protons and highly ionized ions of helium and other heavy atoms such as Calcium, Iron, Nickel, etc. The coronal material loses energy predominantly by thermal conduction, radiation and solar/stellar winds. In order to replenish these losses, some source of energy must be present.

Since the thermal and electrical conductivities of the coronae are very large, hence the surrounding regions will receive energy from them via thermal conduction and the temperature will soon equalize. Also, the matter density in the corona is quite low hence it cannot absorb enough energy from electromagnetic radiation from inner regions to maintain its high temperature.

The solar observations show numerous open and closed magnetic field regions in the solar corona. The closed-field regions have stronger magnetic fields and are brighter than open-field regions(coronal holes). This implies that the stellar magnetic fields play an important role in the coronal heating.

Various mechanisms have been put forward to explain the high coronal temperatures. Basically, the sources of heating are of two types, e.g., external and internal. For example, the accretion of matter by a star leads to atmospheric heating and it comes under external source category. The source of heating for all internal mechanisms is the convection zone which produces acoustic, magnetoacoustic and Alfven waves and magnetic fields and currents. These waves propagate through photosphere, chromosphere and transition region to corona. Different sources heat different regions of the stellar atmosphere, predominantly.

Due to turbulent motions in the convection zone, acoustic waves are produced. When these waves propagate outwards their velocity increases continuously because of decreasing matter density. In the lower chromosphere, they become shocks and lose most of their energy via thermal conduction and viscosity of the medium and hence they can not heat the coronal plasma.

In presence of magnetic field, the convective motions generate a complex pattern of magnetohydrodynamic (mhd) waves. The fast and slow mhd waves, together, are called magnetoacoustic waves. Similar to acoustic waves, these waves become mhd shocks in the upper chromosphere and lose energy through the ohmic resistivity and the viscosity of the medium. Hence, these waves do not have sufficient energy to heat the corona.

The Alfven waves are purely magnetic waves in which magnetic field variations are transverse to the ambient uniform field. When these waves propagate to corona from the site of their origin they suffer little dissipation due to the resistivity and the viscosity of the ambient medium if the magnetic field exceeds 10-20 Gauss. But in presence of non-uniformity in density or magnetic field, some more efficient dissipative mechanism such as resonant absorption, phase-mixing, nonlinear mode-coupling and intermittent magnetic levitation are at work. The production mechanism, generated fluxes and aforesaid dissipation mechanisms need further precise study.

Heating by magnetic field dissipation seems more appropriate for active regions where many magnetic field dissipation seems more appropriate for active regions where many magnetic flux tubes (coronal loops) exist. Foot point motions due to granular and supergranular flows as well as due to differential rotation can lead to a build up of magnetic energy in coronal loops. This energy dissipates at the current sheets in the bipolar regions of the corona. The dissipation is episodic so that the magnetic energy is converted to thermal energy in small transient bursts, called nanoflares.

A new proposal, velocity filtration heating, postulates the existence of extremely high energetic particles at the base of the corona. Because the Coulomb cross sections get rapidly smaller as the particle energy increases, these super-energetic particles reach coronal heights and raise the temperature of the corona to values in excess of million degree Kelvin. The mechanism of production of these highly energetic particles is not known. The predicted ultraviolet emission line intensities do not match with the Skylab because the calculations neglect Coulomb ambipolar diffusion.

S.K. Pandey

Detailed surface photometric analysis of early-type galaxies to search for the presence of dust patches/lanes faint disks, shells and other faint features embedded in them was continued during the year. Analysis of the CCD data, in broad band BVRI, of E-SO galaxies obtained from UPSO, Nainital, VBT, Kavalur, as well as the B, R and K-band data obtained from LCO, Chile during September 1994 is nearly complete. The results are being compiled for publication. This work will constitute major part of the Ph.D. thesis of D.K. Sahu, who worked as JRF/SRF in the DST sponsored project. Observations of some additional dusty ellipticals were taken during January 11-13, 1997 at UPSO, Nainital for the sake of completeness of earlier work.

As an extension of the work on E-SO galaxies, it is planned to obtain multicolor (Optical and possibly in near-IR) surface photometry for a sample of early-type spiral galaxies with an objective to derive stellar populations and radial gradients in bulges. This in turn will be useful to investigate whether the correlation between colours, gradients and luminosities are similar in bulges and in ellipticals. The study is likely to provide important clues regarding star formation history of bulges, and the comparison between bulges and ellipticals.

Astronomy using small aperture (~ 10") optical telescopes equipped with low cost stellar photometer and/or CCD camera in the university campus can provide a big boost to teaching of Astronomy & Astrophysics at the post graduate level. This can also be used for carrying out serious astronomical observations, e.g., photometry of various types of variable stars. Indeed, this programme turned out to be very successful for teaching as well as research.

L.K. Patel

Many researchers have paid serious attention to the possible existence of dimensions greater than four. The theories like Kaluza-Klein (KK) theory and superstring theories require that the dimension of the underlying space is more than four. These theories aim to unify all forces including gravitation. It is also envisioned that the extra dimensions contract as the universe expands leaving behind the 4-dimensional observable universe. Therefore, for a better understanding of early universe physics and the unification of gravity with other forces, it would be interesting to find higher dimensional cosmological models. L.K. Patel and N.K. Dadhich constructed some exact cosmological models in KK theory admitting dimensional reduction. Some of them have Kasnerian time evolution. L.K. Patel has been successful in incorporating the dissipative effects of heat flow in such KK models.

L.K. Patel and R.S. Tikekar have investigated the problem of charged fluid spheres in general relativity. They have constructed a method to generate a new solution for a charged fluid sphere from a known solution of similar kind. As an application of the method, they have obtained a physically reasonable new solution for the interior of a charged fluid sphere. Such solutions could be used to describe the equilibrium states of collapsing spherical distributions of matter whose collapse to a point singularity is countered by the repulsive electrical force due to the presence of charge.

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 has been able to express higher dimensional Vaidya metric in the cosmological backgrounds of Einstein static universe and de Sitter universe.

S.R. Prabhakaran Nayar

During this period, there was very active and meaningful collaboration between IUCAA and the Kerala University. In addition to the setting up of image processing facility and the e-mail connection, a long term memorandum of understanding was signed between the University and IUCAA. Under this agreement, active programme has already started for a joint astronomical observation, involving teachers from various colleges, universities and students. In addition, serious discussions were made for the establishment of an astronomical data centre at the University with support from IUCAA and Astronomy Data Centre, Strausbourg, France.

Image processing facility at the observatory: With the support of IUCAA, the observatory has acquired and installed the image processing software IRAF in the sun work station. The sun work station and the IRAF were utilised to train their M.Sc. and M.Phil. students and now it is equipped enough to take up observational programme in astronomy.

A workshop on Astronomical Image Processing and the Internet was organised at the Kerala University with the support from IUCAA. The workshop covered different aspects of image processing, computer networking and communication using the Internet. There were nearly 60 participants from different colleges and universities of Kerala and from outside Kerala. In addition to the discussions on various aspects of image processing and the elctronic communication, there was also an exhibition of computer networking using inexpensive hardware and software and image processing tools. The exhibition was made possible with the use of Observatory computers along with the computers brought from IUCAA for this purpose.

E-mail connection at the Kerala University: IUCAA has provided e-mail connectivity at the University Observatory which is working satisfactorily. This facility has been effectively utilised to establish communication to IUCAA and other centres to develop astronomy related studies at the University. This facility is also open to teachers from other departments. The extension of this facility to other departments is actively being considered. He participated in the discussions organised by IUCAA with representatives from few universities and main persons dealing with the ERNET. As a result of this meeting, the University has already decided to go for the setting up of a VSAT facility at the University with IUCAA support.

Memorandum of understanding between IUCAA and Kerala University: Most important activity during this period was the signing of a MOU between the University and IUCAA during December 1996. The agreement was signed between J.V. Narlikar, Director of IUCAA and N. Babu, Vice-Chancellor of the University. The MOU is meant to help the University in developing basic facilities in astronomy & astrophysics at the University, to develop research activities in the area and to improve curriculum by designing courses in astronomy and other frontier areas to provide exciting opportunities in science and technology. IUCAA has also agreed to provide technical support in acquiring computer software, maintenance of computer networks, maintenance of the laboratory. The MOU also envisages the starting of a joint observational programme. As per this agreement, a course on image processing techniques has been already introduced under the credit and semester system of the University and active work on image processing has already been started.

A programme on astronomical observation and analysis is being initiated by the Observatory of the University of Kerala in collaboration with IUCAA regarding the programme of observation with 16" telescope, computer image processing, data analysis, analysis of archival data obtained using internet, and theoretical modelling. This activity is intended to the college and university teachers, PG students and Ph.D. students.

Homepage for the University of Kerala: With the support from IUCAA, they have made a homepage of the University on internet with the details of the University departments, bodies of the University, features of Trivandrum city and Observatory. This homepage is kept as part of the IUCAA homepage.

Student project at IUCAA: This year three students of the University carried out their project work at IUCAA on image processing using IRAF and preparation of homepage of the University.

Asim K. Ray

During the period under review, A.K. Ray's efforts have been directed to understand the following problems related to High Energy Physics, Astroparticle Physics and Cosmology.

(i) Neutrino mass and magnetic moment in extended gauge models.
(ii) Black hole thermodynamics, black hole horizon and its relation to information loss.
(iii) Possible candidates of dark matter.

R. Ramakrishna Reddy

Chalcopyrites have received recently considerable attention due to their importance for the development and fabrication of solar, optical fibre, sensors, communication and other technological devices. A simple relation between energy gap and electronic polarizability is given for the chalcopyrites. The estimated electronic polarizability values are in good agreement with the values reported in literature. These values are considered better than the values obtained using the dielectric theory of Phillips, Van Vechten and the bond charge model of Levine.

R.P. Saxena

In collaboration with P. Dasgupta and N.M. Upadhyaya, Saxena has worked on the possibility of baryogenesis by the Hawking evaporation of primordial black holes (BH). These BH's are produced during the inflationary phase transition when the bubbles of true vacuum are formed and begin to expand. This expansion can cause pockets of false vacuum outside these bubbles to get compressed. When the size of these pockets of false vacuum become smaller than their Schwarzschild radius, self gravity will cause them to collapse into BH's. These BH's immediately start taking part in two processes : (a) Accretion of matter from the surrounding radiation bath, and (b) Loss of mass due to Hawking radiation.

The mass of BH, therefore, initially rises and becomes a constant (when accretion and Hawking radiation just balance each other) eventually, the BH decays due to increasing rate of radiation. If the temperature of BH is high enough (like 10^{15} Gev) it can emit X bosons of Grand Unified Theories by Hawking radiation, thereby causing a net production rate for baryons in the early universe. They have calculated these processes and obtained a number for n_B/S which is quite reasonable. The important point about the above scenario is that this generation of baryons takes place rather late in the evolution of the universe, viz. at the ambient temperatures of the universe of about 40 Gev or so, well beyond the electroweak phase transition temperatures (~100Gev) so that the inflationary processes have been stopped long ago and the baryon asymmetry so generated cannot be washed away.

In collaboration with N. Panchapakesan, A. Mukherjee and Hatem Widyan, he has also done work on the computation of bounce action for electroweak phase transition. This computation is important, because it enables one to decide whether the phase transition is of first order or of the second order. The order of phase transition is found to be dependent on the value of the symmetry breaking parameter in the Higgs potential of the theory.

S. Sreedhar Rao

Digital spectra of stars obtained by electronic linear detectors like a CCD have systematically replaced the photographic spectra due to their linear response to light and high QE and sensitivity, reaching fainter magnitudes at relatively short exposure times. It is imperative, therefore, for the purpose of classification of digital spectra of stars, one has to build a grid of the digital spectra of standards, for instance, the entire MK standard star atlas has to be reproduced with their digital spectra, obtained in classification resolutions. However, since these are essentially brighter ones and are accessible by fainter magnitudes using CCD and large telescopes with improved spectrographs, it is increasingly becoming necessary to provide fainter standards. In addition to this, since many a star turn out to be peculiar at higher resolutions with spectral signatures located at different regions of the spectrum, for a comprehensive description of the nature of such spectra, one has to evolve a multi-dimensional classification scheme under the domain of the MK process. It would require suitable standards (with peculiarities!) observed from different parts of the sky so that they would be available from many locations. A methodology to carry out the above process is being worked out and the idea of forming a working group of spectroscopists drawn from various centers in India and abroad was mooted in the Sampurnanand 1m UPSO telescope Silver Jubilee workshop held in April 1997 at Naini-Tal.

A set of digitized photographic spectra of the MK standards and Am stars are ready for classification under the ANN scheme in collaboration with Ranjan Gupta.

The Meinel spectrograph is under modification to adopt a CCD camera to carry out the above work besides other spectroscopic projects with the 1.2m telescope of the J-R observatory, Osmania University. The modernization of this telescope is nearing completion.

D.C. Srivastava and S.S. Prasad

Pulsars are one of the important objects of continuous gravitational radiation (GR). The GR signal is extremely weak and accordingly, a long observation time of the order of few weeks to months is required for the enhancement of S/N ratio. But a long observation time introduces amplitude modulation as well as frequency modulation. The amplitude modulation arises because of the quadrupole nature of the detector, whereas, the frequency modulation is due to translatory motion of the detector acquired from the motion of the Earth. A study of noise free response of the laser interferometer to the GR signal from a continuous source viz., a Pulsar has been made and following two problems has been investigated:

All sky search of pulsars as sources of gravitational radiation: To extract the signal in a simple Fourier transform of the data, one would require as much of signal power as possible to be in a small frequency range. If the measurements were made over a short enough time, the accelerations of the detector may be ignored, but, of course, the signal to noise ratio would not be ideal. Hence a natural query is: How much time can pass before corrections for the accelerations are neccessary? For a frequency of 1Khz, the maximum time of observations before the effects of the Doppler effects caused by the Earth's rotation starts to become important would be approximately 70 minutes. If the modulation of the frequency caused by the motions are understood, i.e., the positions of the source were known and the phase of the wave understood then the variation of frequency could be reversed and the signal can be derived out of the Doppler spread feature. This can only be done if we already know the source location (e.g., a known pulsar). But if we are using this to find a previously unknown source then the effect gives us a certain angular resolution defined as how close two points on the sky may be in order to have indistinguishable corrections. The angular resolution gives us the size of the patches, that is, the area for which similar corrections are made. An estimate of independent number of patches, as made by Schutz (1991) is 1.3 x 10. Thus, the problem with reference to the search of unknown pulsars is extremely time consuming even for the best computers available to the present day.

D.C. Srivastava and S.S. Prasad have adopted an alternative method of expanding the response of the detector into spherical harmonics Y and find the values of m and l that are required in this space. The earlier investigation has been generalised incoporating the earth's rotational motion. The results are the reduction in the effective l and m parameter in the Y space.

Srivastava has also reviewed the various investigations on this topic and an overview of reviews on exact solutions of Einstein's equations have been presented at 18th IAGRG Conference. The various stationary axi-symmetric fields and anisotropic cosmologies have been reviewed.

S.K. Srivastava

Trace of field equations, from the action for higher-derivative gravity, yields Klein-Gordon equation for the Ricci scalar suggesting that at high energy level above 10^{10} GeV, Ricci scalar not only behaves like a geometrical field but also like a physical field.The physical aspect of Ricci scalar, is represented by Riccion. These things have been discussed in some earlier papers. During the period of the report, one-loop quantum correction to Riccion has been computed and renormalization has been done adding counter-terms. Renormalization Group equations are also solved and these results imply a symmetry breaking around the energy scale 1.96×10^{17}GeV indicating decoupling of gravity from the other fundamental forces. In another work, it is discussed that riccion also behaves as an instanton giving rise to primordial inflation.

T. Subba Rao

Nearly half million asteroids were found between Mars and Jupiter. Dynamical collisional parameters such as impact strength, orbital and population parameters of Koronis, Eos and Themis were determined by F. Marzari et al. Reflection spectra of shocked ordinary chondrites were measured and discussed interms of mineralogical compositions of main belt asteroids. They also found black veins and black chondrites by shock involving shock induced localised melting a result of localized stress and temperature concentrations and excursions at the interfaces of mineral grains of different shock impedance. (Stoffler at al 1991). Water vapourization on Ceres asteroid were measured by long exposure IUE spectra by Michael F., A. Hearm and Paul D. Feldman. They found that the amount of water varies with time and also with location on the planet. A new version of algorithm for computing asteroid proper elements and the effects on the overall dynamical behaviour of many asteroids of non linear secular resonance studies were performed by Andres Milani and Zoran Knezevic. Proper elements for 12, 573 asteroids including the accurate orbit were determined and discussed by Andres Milani and Zoran Nezer. Velocity distributions among colliding asteroids were calculated using collision probabilities between bodies with fixed semi major axes, eccentricities and inclinations, integrating over uniform distributions of longitudes of apsides and nodes by William F., Bottke Jetal and M. Di Martino.

In the present project, the main aim was to fabricate astronomical telescope and to carry out observation of asteroids data to calculate physico-chemical studies of near search and main belt asteroids. The orbital axes, collision behaviour, velocity of rotation and resonance, etc., were studied. Literature collection were done on the project work. Discussion was also held with IUCAA scientists for telescope and asteroids studies. Theoretical calculations were under progress for main belt asteroids. Few papers were published in some physical properties of asteroid materials.

Ramesh Tikekar

Einstein's field equations with anisotropic spherical distribution of matter in equilibrium as source and their exact solutions are being critically examined. The relevance of these solutions in describing models of superdense stars is investigated. Models of superdense stars in equilibrium having cores in the form of fluid with anisotropic pressure surrounded by smoothly matching envelope of fluid with isotropic pressure are constructed and their physical suitability is investigated.

Solutions of Einstein's field equations with string dust source in the context of cylindrically symmetric space-times were examined and it is shown that singularity-free solutions are admitted only when the string dust is accompanied by presence of a perfect fluid with non-vanishing pressure.

A new family of spherically symmetric non-singular models filled with imperfect fluid and accompanied with radial heat flow has been obtained. It complies with the requirements of the strong and weak energy conditions. The anisotropy in pressure and the heat flux tend to vanish for large t. The metric of the spacetime contains an arbitrary function of time which can be chosen to achieve non-singular character and there exist multiplicity of such choices. (This work, which was initiated by N.K. Dadhich was carried out in collaboration with him and L.K. Patel).

D.B. Vaidya

Recent studies indicate that the cosmic dust grains are porous and fluffy. The optical properties of these porous irregular particles should be quite different from those of solid homogeneous particles. Unfortunately, it is not yet possible to rigorously treat the absorption, scattering and extinction of light by porous or irregularly shaped particles. In order to calculate the scattering, absorption and extinction for the porous and irregular particles, approximate methods are required. D.B. Vaidya uses the discrete dipole approximation (DDA) to study the extinction by porous grains. He calculates the extinction efficiencies of the porous silicate and graphite grains at several wavelengths between 3.4μ m and 0.20μ m. He studies the extinction as a function of grain size and porosity. His results clearly show the effects of porosity on the extinction of the porous grains. At certain wavelengths, the enhancement in the extinction is indicated while at other wavelengths, the extinction for the porous grains deviates considerably from that of the solid grains. He also finds that for the graphite grains the wavelength of peak extinction (near 2200Å) shifts as the porosity increases. As an application of these porous grain models, he uses the extinction efficiencies of the porous silicate and graphite grains to evaluate the interstellar extinction curve. He finds the model curve to fit well with the average observed interstellar extinction curve. However, further calculations in the uv spectral region (< 0.20μ m) are required to explain the variation in the width of the 2200Å feature and the shift in the central peak wavelength in the extinction curves of the graphite grains. These calculations are in progress.

Sarita Vaishampayan

S. Vaishampayan obtains group invariant solution of 2-D wave equations. Two parameter subgroups of full Lie group are used to find the solutions.

Lie group provides a corresponding Lie algebra of dimension 10. Since Lie algebra of 2-D wave equation is non-degenerate, Killing form is used to reduce the general vector field with the help of adjoint representation table and Lie equations.

Gauss approach reduces the Newtonian equation $M_0 t q = Q$ with constraints $Aq = b$ to $M_0 q = Q + Qc$ where Qc is a force of constraints determined in terms of A,b & M. To determine the equations of motion of constrained system, Lagranges multipliers are used. These multipliers are calculated with the help of constrained equation to get the equations of motion of constrained system.

To relate the equations of motions in Newtonian form and equations of motion in Lagranges form for constrained system, it is necessary to determine the relation between Lagranges multipliers obtained by using constrained equation and constrains for Qc.

P. Vivekananda Rao

Continuation of the analysis of the light curves of the Algol type binaries in various passbands using modern synthetic light curve techniques like Wilson-Devinney is being pursued in order to derive reliable elements which can provide valuable information on some general aspects of the evolution and the coherence of the theoretical evolutionary scenario developed. For this, Vivekanand Rao has selected a few Algol type binaries (data obtained from Japal-Rangapur Observatory and also from other Centres) for which good photoelectric light curves are available. The results obtained on two such binaries are given below:

From the solution of the V and B light curves of EU Hya, obtained by Kulkarni, using W-D method, he concludes that the system EU Hya is a semi detached one with the secondary filling its Roche lobe. It consists of an F2V(Pri) and K0-4V-IV(Sec) stars as its components with a mass-ratio (m_c/m_h) of 0.212. The satisfactory fit of the theoretical light curve to the B observations and not too good a fit to the V observations might be explained as due to the presence of gases, most probably of Hydrogen, favourably situated in the system to cause enhanced brightness during some phases. Even though this mismatch could be attributed partly to observational scatter and partly to the use of normal points, in both the studies, much of the discrepancy in the yellow light curves may be explained as due to the transient nature of the Hydrogen (H) gas pattern in the system. As no detailed spectroscopic studies of this system are available, evidence for the presence of gases in the system is lacking. Since the system is semi-detached with the seconday filling its lobe, one can presume mass loss from this component which will be a source for gases in the system. From a study of their new ephemeris and period, Gu Shenghong et al. (1993, Ap & SS, **203**, 189) found that the period of EU Hya became short gradually at the rate of $dP/dE = -3^d.29 \times 10^{-10}$. This may indicate loss of mass from the secondary and through that the probable presence of gas in the system. The presence of gases affecting the light curves of the semi detached systems of TT Hya (Vivekananda Rao & Sarma 1994, BASI, **22**, 459), HU Tau (Parthasarathy et al. 1995, A & A, 297, 359), and R CMa (Sarma et al. 1996, ApJ, 458, 371) was already reported.

The above conclusions are of tentative nature as the spectroscopic mass ratio of the system is not available. He suggests that obtaining radial velocity curves of both the components and further photometric studies in UBVR passbands of this interesting system is very much needed for obtaining its absolute elements. These results are published in PASP, 1996, November issue.

His analysis, with W-D method, of the original UBV light curves of RY Gem of Hall et al. (1982, Acta Astron., **32**, 411) yielded elements similar to those derived by them from corrected light curves using R-M and Roche model solutions. The present analysis indicated that the contribution from the third light l_3 was very small and is about 1% of the total light of the system in the U passband only. From this he concludes that the gas present in the system has not distorted the light curves to such an extent as to yield inaccurate elements. From his analysis, the most probable value of the photometric mass-ratio, q=0.1925, was obtained. This value was found, within observational errors, to be equal to the spectroscopic mass-ratio derived by Popper. Hence, he concludes that the presently derived absolute elements are most reliable.

From the properties of the components of the RY Gem, they conclude that it is an ordinary semi detached system, probably having more circumstellar material in the vicinity of its components. The results on this system are sent for publication to the Astronomical Journal.

Analysis on two more Algol types systems namely V Crateris and AU Monocerotis systems is near completion and will be shortly sent for publication to a reputed journal.

G. Yellaiah

A campaign was carried out with the Indian MST radar at Gadanki (13.5^0 N, 79.2^0 E) during the active periods of Geminid meteor shower (12/13 and 13/14 December 1995), Perseid meteor shower (12/13 August 1996), and Leonid meteor shower (15/16 November 1996) for simultaneous observations of meteor activity and Sporadic E.

The MST radar data format has the advantage of observing meteor trail signatures simultaneously in different range bins. Eight micro second narrow transmitter pulses were used for meteor observations. The meteor echo is recorded as amplitude variations with time, which usually show bodily motion of the trail in each range bin.

The Doppler spectra of the amplitude variations for meteor trails and sporadic E layers have simultaneously been recorded continuously throughout the nights of meteor shower activity for Geminids, Perseids, and Leonids.

The data obtained during Geminid shower period (12/13 and 13/14 December, 1995) is analysed and the analysis of the data obtained during other shower periods is in progress.

From the Doppler shift as well as the SNR curves corresponding to the peak occurence period of the Geminid meteor shower activity indicates that the ionisation produced at higher height regions i.e., around 100 km is slowly drifting towards the lower heights (ie., about 85 km) on the peak day (12/13 December 1995). The same effect is not observed for the data obtained on 13/14 night, when the shower activity is less, at the same time period. On 12/13th night, it is also found that the detectable signal height is continuously decreasing and reaching a minimum height of 88 km at the time of peak activity of the shower.

These results show a clear experimental evidence of occurence of sporadic-E due to meteoric ionisation.

The night sky photometer has been constructed and tested at Instrumentation Laboratory, IUCAA, under the guidance of S.N. Tandon, in the month of July 1996. The photometer is working well. It is observed that minimum voltage developed across the output terminals of the photometer is about 7 mv (corresponding to the dark current) and the maximum (saturation) voltage is about 8 volts.

The photometer is mounted on a six inch reflecting telescope available in the Department of Physics, Kakatiya University, Warangal. Comet Hale-Bopp, visible in the evening sky during third week of March 1997 was selected for photometric observations. The observations were carried out during this week and on 31st March 1997 the light intensity variations from comet Hale-Bopp and also from planet Jupiter were recorded successfully. These observations show that the voltage developed across the output terminals of the photometer is about 1.1 volts when the telescope is focussed for comet and it is about 3.6 volts for the planet Jupiter.

Zafar Ahsan

Since it was initiated some thirty years back, Petrov type N solutions of Einstein vacuum field equations are amongst the most interesting but rather difficult and little explored of all empty space-time metrics. From the physical point of view they represent space-time filled up entirely with gravitational radiation, while mathematically they form a class of solution of Einstein equations which should be possible to be determined explicitly. Considering the free gravitational field to be the transverse gravitational wave zone which can be identified as Petrov type N fields, Z. Ahsan focusses his attention on the interaction of pure electromagnetic radiation field. These interacting radiation fields are known as pure radiation (PR) fields. Using the Newman-Penrose formalism, a metric describing the behaviour of PR fields is obtained.

For a given distribution of matter, the construction of gravitational potentials satisfying Einstein field equations is the principal aim of all investigations in gravitational physics, and this has been often achieved by imposing symmetries on the geometry compatible with the dynamics of the chosen distribution of matter. The geometrical symmetries of the space-time are expressible through the vanishing of the Lie derivative of certain tensors with respect to a vector. In this direction, he has explored the symmetries of the space-time including electromagnetic fields. This symmetry of the space-time is termed as matter collineation and is defined in terms of the space-matter tensor.

(III) PUBLICATIONS

by IUCAA Academic Staff

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

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b) Proceedings

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(IV) PEDAGOGICAL ACTIVITIES

a) IUCAA-NCRA Graduate School

N. Dadhich	Mathematical Physics
Sayan Kar	Extragalactic Astronomy and Cosmology
T. Padmanabhan	Electrodynamics and Radiative Processes
Somak Raychaudhury	Astronomical Techniques
Varun Sahni	Extragalactic Astronomy and Cosmology
Sukanya Sinha	Statistical and Quantum Mechanics
S. Sridhar	Dynamics of Galaxies

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

Sukanta Bose	Astrophysics II
S.V. Dhurandhar	Astrophysics II
R. Gupta	Laboratory Course in A & A
Biman B. Nath	Astrophysics I

c) Supervision of Projects

N. Dadhich

K. Narayan (JNCASR Summer Fellow)
Gravitational global monopole and the third law of black hole dynamics

R. Gupta (jointly with **R.K. Gulati**)

Arundhati Athalye (VSP)
Luminosity effect in B-type Stars

A. Mahabal

S.K. Bhosale, T.V. Cholakar, S.S. Gadre and C.P. Joshi (School Students' Summer Programme)
Making a Zeeman machine to demonstrate catastrophes

J.V. Narlikar

Jayashree N. Sancheti
Madhura D. Sane
Pradnya T. Panchange
Meena C. Pardeshi
Vikas J. Patil
Pranav Lele
Raunaq Pungaliya
Sujata S. Kanade
Santosh P. Unecha
Gautam Grover
(School Students' Summer Programme)
Foucault pendulum

Bhushan Dhabekar (Introductory Summer School on Astronomy and Astrophysics)
Newtonian cosmology

B. Dhar (VSP)
Energy sources in astrophysics

Biman B. Nath

Nilesh Chavan (B.Sc.)
Structure and evolution of solar mass stars

T. Padmanabhan

R. Mukund (IIT, Bombay)
Quantum fields in curved spacetime

Pinaki Chatterjee (Cambridge University)
Nonlinear gravitational clustering

Abhinav Gupta (University of Delhi)
Radiation reaction

Somak Raychaudhury

Anil Seth
(Wesleyan University, Connecticut, USA)
Looking for signatures of dust in surface brightness profiles of spiral galaxies

Rakesh Kumar (M.Sc., N. Wadia College, Pune)
Measuring the Hubble flow using central galaxies of clusters

Aparna Ganti (M.Sc., N. Wadia College, Pune)
Molecular gas in spiral galaxies

Smarajit Triambak (B.Sc., Fergusson College, Pune)
Redshifts of galaxies from their spectra

S. Sowmini (Introductory Summer School on Astronomy and Astrophysics)
Opacity of spiral disks

A. Balaji (Introductory Summer School on Astronomy and Astrophysics)
The mass of the galaxy from its satellites

Pratap Sahoo (Introductory Summer School on Astronomy and Astrophysics)
IUCAA telescope site survey

A Kuldeep (JNCASR Summer Project Student, IIT, Mumbai)
Measuring the temperature of the intracluster gas in the cluster Abell 3571 from ROSAT x-ray data

Analabha Roy (St. Xavier's College, Mumbai)
Stellar evolution and compact remnants

Kaustuv S. Saikia (Cotton College, Guwahati)
Orbits under central forces

Sukanya Sinha

Abhay Parvate(VSP)
Anisotropic universes

S. Sridhar

Kishore Darak (M.Sc.)
Gravitational dynamics in one dimension

S.N. Tandon

Abhijeet Brahme (B.Sc.)
Observing the Fraunhofer lines of Sun
(jointly supervised with **A. Paranjpye**)

Shantanu Ghosh (B.Sc.)
Making a photometer and observing scintillations with it

Sven Sattler
Fabricating a thermoelectrically cooled CCD camera

d) Tutorial Assistantship

Shiv K. Sethi

Astrophysics I, M.Sc. (Physics), University of Pune (for Biman B. Nath).

K. Srinivasan

Electrodynamics and radiative processes, M.Sc. (Physics), University of Pune (for T. Padmanabhan).

(V) IUCAA COLLOQUIA, SEMINARS, ETC.

a) Colloquia

M. Banerjee: *Nucleon in nuclear matter*, May 27.

K.B. Marathe: *Recent developments in gauge theory*, August 12.

J. Touma: *The phase space adventure of Earth and Moon*, September 2.

T.J. Arhens: *SPH calculations of impact of Comet Shoemaker-Levy 9 on Jupiter,* November 6.

R.V. Moody: *Mathematical quasi-crystals: Quasi-lattices, self-similarity and diffraction,* November 13.

b) Seminars

K. Harikrishna: *Dynamical systems and surfaces of sections*, April 3.

P. Roy : *The Dirac seesaw for the neutrino mass*, May 8.

K.K. Nandi: *Induced quantum fluctuations in the spherically symmetric spacetime*, June 20.

V.H. Kulkarni: *Dusty plasma dynamics*, June 28.

K. Narayan: *Blackhole with global monopole charge*, July 2.

V. Korchagin: *Nonlinear interaction of global modes in prostellar disks*, July 2.

S. Surya: *Analysis of the theta sectors of quantum gravity*, July 10.

R. Hola: *A flair redshift survey in the direction of the motion of the local group*, July 18.

R. Mukund: *Effective Lagrangian in external fields*, July 24.

D. Munshi: *Certain aspects of the formation and evolution of large scale structure in the universe*, August 9.

J.S. Bagla: *Gravitational clustering in an expanding universe*, August 13.

K.P. Singh: *X-ray astrophysics in the 21st century*, August 28.

R. Tomaschitz: *Cosmic evolution by global metrical deformations of spacetime*, October 10.

R.P. Saxena: *Baryogenesis from evaporation of primordial black holes*, October 11.

Y. Shchekinov: *Post-reheating dynamics of cosmological conductive / cooling fronts and the Ly α forest clouds*, October 16.

S. Ragland: *High angular resolution in the infrared*, November 7.

R. Rangarajan: *Gravitational baryogenesis during inflation*, December 3.

B. Bhawal: F*ast dynamical simulation of interferometric gravitational wave detector*, December 20.

V.B. Johri: *Genesis of matter out of gravitational energy*, December 26.

Jean-Claude Pecker: *The roughening effect and the determination of abundances of elements in sun and stars*, January 2.

R.P. Malik: *Integrability in nonlinear realization scheme*, January 3.

A.A. Zdziarski: *X-rays/Gamma-rays from black holes*, January 7.

G. Burbidge: *An outsider's view of scientific controversies in Cambridge*, January 11.

H.C. Arp: *Creation and evolution in the local supercluster*, January 15.

J.A. Klobuchar: *Real time radio science - The new reality*, January 16.

C. Murali: *Globular cluster evolution in M87 and the specific frequency problem*, January 24.

G. Vekstein: *Solar coronal heating: MHD models and possible observational signatures*, January 28.

P. Biermann : *Gamma rays and neutrinos from AGN*, January 29.

G. Vekstein: *Collisionless magnetic reconnection and acceleration of charged particles*, January 30.

K. Griest: *Results from microlensing search for dark matter*, February 6.

H. Schnopper: *What have we learnt about the X-ray sky?*, February 13.

F. Genova: *CDS as an astronomical information hub*, February 25.

M. Whittle: *Ionized gas kinematics in galactic nuclei*, February 27.

c) Extramural Talk / Public Lectures

R. Ramachandran: *Comprehensive Test Ban Treaty (CTBT)*, June 25.

T. Sen: *Light in Space*, August 30.

S. Swaminathan: *Paintings of the Ajanta caves,* October 29.

J.C. Pecker: The Sun: our star.

Jean Abitbol and Vasant Oswal: *Vocal hygiene for singers and actors,* February 4.

d) PEP Talks

S.D. Mohanty: *Some general statistical techniques used in gravitational wave data analysis*, August 2.

T. Padmanabhan: *Clever but lazy? Try dimensional analysis*, August 8.

D. Munshi: *Statistics and dynamics of gravitational clustering*, August 29.

S.N. Tandon: *Sub-wavelength microscopy*, September 5.

S. Bose: *Hawking radiation and the information-loss paradox*, September 19.

K. Jotania: *Gravitational waves a new astronomy?*, October 4.

J.S. Bagla: *Cosmological N-body simulations*; October 17.

S. Kar: *Geometry and physics of amphiphilic membranes*, October 31.

N. Jayaram Chengalur: *The measurement equation: Polarimetric interferometry made easy*, November 21.

R. Balasubramanian: *Geometry in statistics*, February 20.

Y. Shtanov: *Pilot wave quantum cosmology,* February 27.

e) IDG (Informal Discussion Group) Meetings

Ramesh Bhatt (NCRA): *Spatial structure of pulsar radio emission*, June 13.

A.K. Kembhavi: *Fluctuations in the X-ray background: Recent results*, June 13.

J.S. Bagla: *Detecting dark matter using ancient mica*, June 27.

K. Subramanian (NCRA): *A 3-Gyr-old galaxy at redshift 1.55*, June 27.

S. Bhatnagar (NCRA): *Optimal image modelling and the maximum residual likelihood criterion*, July 11.

N. Dadhich: *Minimally curved spacetime and global monopole*, July 11.

D. Oberoi (NCRA): *A new kind of high energy source towards the galactic centre*, July 25.

S. Sridhar: *Chaos and the shapes of elliptical galaxies*, July 25.

S. Sethi: *Constraints on the extragalactic background light from Gamma-ray observations of high-redshift quasars*, August 8.

R.K. Singh (NCRA): *A simple model for the cometary appearance of ultra-compact H-II regions*, August 8.

R. Athreya (NCRA): *Mini jets in mini quasars*, September 6.

A. Mahabal: *Parapsychology in ellipticals: Amazing correlations between the central and global properties*, September 6.

P. Gothoskar (NCRA): *Supernovae as standard clocks*, September 19.

L. Sriramkumar: *Hawking radiation: Could it be discrete?*, September 19.

N. Kanekar (NCRA): *Primordial deuterium: The number game*, October 3.

R. Balasubramanian: *Cosmological parameters from gravity waves*, October 3.

C. Ishwara-Chandra (NCRA): *Dust and gas at high redshift*, October 24.

B. Nath: *Molecular hydrogen and the formation of galaxies*, October 24.

B.C. Joshi (NCRA): *Globular clusters in M87: HST observations*, October 31.

S. Mohanty: *LISA: A proposed gravitational wave detector*, October 31.

Pramesh Rao (NCRA): *Is there a black hole in the galactic centre?*, November 14.

S. Sridhar: *The shapes of elliptical galaxies*, November 14.

Yeshwant Gupta (NCRA): *Magnetic spiral arms of NGC 6946*, November 28.

Jayaram Chengalur (NCRA): *Anisotropies in the distribution of satellite galaxies*, November 28.

(VI) TALKS AT WORKSHOPS OR AT OTHER INSTITUTIONS

a) Seminars, Colloquia and Lectures

J.S. Bagla

Transfer of power in non-linear gravitational clustering, (Mehta Research Institute, Allahabad, April 11).

Non-linear gravitational clustering, (TIFR, Mumbai, September 3).

Sukanta Bose

Quantum string cosmology with matter, (Discussion Meeting on Big Bang and Alternative Cosmologies: A Critical Appraisal, JNCASR, Bangalore, January 6-8).

N. Dadhich

On non-singular cosmological models, (Workshop on Inhomogeneous Cosmological Models, North-Bengal University, November 14-18).

On singularity - free cosmological spacetimes (Discussion Meeting on Big-Bang and Alternative Cosmologies: A Critical Appraisal, JNCASR, January 6-8).

Introductory general relativity, (Workshop on Introductory General Relativity and Applications, Tezpur University, January 27-29).

Black holes, (North Eastern Region Institute of Science and Technology, Itanagar, January 30).

Energy extraction from black holes, (Delhi University, March 28).

S.V. Dhurandhar

A hierarchical search strategy for the detection of gravitational waves from coalescing binaries, (Mini-semester on Mathematical aspects of the theories of gravitation, Stefan Banach International Mathematical Centre, Warsaw, Poland, March 25).

Data analysis strategies for detecting gravitational wave signals from coalescing binaries, (VIRGO meeting of the VIRGO project, Annecy, France, June 13).

Gravitational waves: sources and detectors, (7th Asia-Pacific Regional Meeting of the IAU, Pusan National University, Pusan, Korea, August 20).

Computational aspects in gravitational wave detection, (Symposium on Computational Astrophysics, IIA, Bangalore, January 9).

Detecting gravitational waves from coalescing binaries, (Albert Einstein Institute, Potsdam, Germany, April 30).

A hierarchical search strategy for the detection of coalescing binary signals, (Observatory du

Meudon, France, May 30).

Data analysis techniques for the detection of coalescing binary signals, (University of Tokyo, Tokyo, Japan, August 27).

On the instabilities of optical cavities of laser interferometric gravitational wave detectors, (Institute of Space and Aeronautical Science, Japan, August 29).

Detecting gravitational waves from coalescing binaries, (Cosmic Ray Research Institute, Tokyo, Japan, August 30).

Estimating coalescing binary parameters, (Raman Research Institute, Bangalore, January 10).

R.K. Gulati

Employing an artificial brain for stellar spectral classification, (Keele University, Keele, Staffordshire, UK, June 5).

Classification of stellar spectra using artificial neural networks, (Center for EUV Astrophysics, University of California, Berkeley, USA, April 23).

Synthesis of stellar spectral features for stellar population studies, (Department of Astronomy, University of Kiel, Kiel, Germany, April 19).

R. Gupta

Optical Observations in Astronomy, (VSP, IUCAA, June 6).

Observational astronomy, techniques in instruments and photometry, (DST contact programme, IUCAA, June 19-21).

Observational astronomy, (N. Wadia College lecture series, N. Wadia College, Pune, June 26).

Stellar spectroscopy and *Stellar spectral classification*, (Workshop on Astrophysical Spectroscopy, Anantapur, February 13, 14).

Stellar spectroscopy: New frontiers, (Sri Venkateshwara College, New Delhi, March 6).

Stars, colours and neural networks, (Astrophysics Week, Fergusson College, Pune, March 10).

A.M. Kane

The world from your desktop: WWW and its Applications, (CSMCRI, Bhavnagar, Seminar, November 6).

Features of the internet, (2 lectures, Data Communications and Networking Workshop, CIRT, Pune, August 1).

Concept of networking - LANs and WANs, (2 lectures, Workshop on Computer Based Information Systems, CIRT, Pune, September 5, 6).

Internet and banking, (2 lectures, Networking and Communication for Banks and Financial Institutions, NIBM, Pune, December 10).

TCP/IP and how it all works, (2 lectures, Workshop on Image Processing and Internet, University of Kerala, Thiruvananthapuram, December 21).

LAN-WAN technologies and communication protocols, (2 lectures, Refresher Course at Department of Electronics-Science, University of Pune, January 7, 8).

Introduction to LAN technology, (1 lecture, Data Communications and Networking Workshop, CIRT, Pune, February 11).

S. Kar

The Raychaudhuri equations in string and membrane theories, (Mehta Research Institute, Allahabad, December, 6).

A.K. Kembhavi

Black holes, (Exploratory, Pune, April 20).

Krishna vivar [in Marathi], (Exploratory, Pune, May 1).

Dust and the number of quasars in the universe, (Indian Institute of Astrophysics, Bangalore, May 15).

Computer image processing, (University of Cochin, May 17).

Astronomical image processing, (Introductory Summer School on Astronomy and Astrophysics, June 1).

Shape of galaxies, (Introductory Summer School on Astronomy and Astrophysics, June 3).

Optical morphology of radio galaxies, (Les Houches, France, September 23).

Effect of dust of quasars, (University of McMaster, Hamilton, Canada, October 4).

Are there any missing quasars?, (University of Virginia, Charlottesville, USA, October 8).

Quasars obscured by dust, (Columbia University, New York, October 10).

The birth and death of stars, (Ramnarain Ruia College, December 11).

Networking and image processing, (Workshop on Astronomical Image Processing and the Internet, University of Kerala, Thiruvananthapuram, 2 lectures, December 20 & 24).

Stellar evolution, (Workshop on Introductory General Relativity and Applications, Tezpur University, Tezpur, 2 lectures, January 27 & 28).

White holes to black holes, (NERIST, Itanagar, January 30).

The birth and death of stars, (R&DE, Dighi, Pune, February 28).

Island universes, (Fergusson College, Pune, March 8).

Photons, pairs and quasars, (University of Delhi, March 26).

A.A. Mahabal

On quantifying distortions in a statistically complete sample of radio galaxies from the MRC, (University of Sydney, Australia, September 3).

Applying morphological processing to astronomical images, (Workshop on Astronomical Image Processing and the Internet, Thiruvananthapuram, India, December 22).

R. Misra

Radiative mechanisms and X-ray sources, (IUCAA-TIFR winter school on gamma-ray astronomy, Pachmarhi, November 14-18).

Black hole X-ray binaries, (Delhi University, February 14).

Do black holes exist?, (Fergusson College, March 5).

D. Munshi

Scaling in gravitational clustering, (TIFR, Mumbai, September 25).

J.V. Narlikar

The quasi-steady state cosmology : achievements and challenges, (Department of Physics, University of Pittsburgh, USA, April 4).

An alternative to big bang cosmology, (Department of Physics and Astronomy, University of Maryland, USA, April 8).

The variable mass hypothesis, (International Conference on Modern Mathematical Models of Time and Their Applications to Physics and Cosmology, University of Arizona, Tucson, April 12).

An alternative to big bang cosmology, (University of Wyoming, USA, April 17).

Crisis in cosmology : big bang and alternatives, (University of California, San Diego, USA, April 23).

The big bang cosmology : Problems and alternatives, (Stanford University, USA, April 26).

Myths and pre-conceptions in Astronomy, (Introductory Summer School on Astronomy and Astrophysics, May 20).

Cosmology, (Introductory Summer School on Astronomy and Astrophysics, May 23).

Cosmological models, (DST Contact Programme for students in Astronomy and Astrophysics, June 17).

Cosmology, (Vacation Students' Programme, IUCAA, June 24 and 25).

The universe as a scientific laboratory, (National Talent Scholarship Awardees, Physics Department, University of Pune, June 24 and 27).

Distance scale of the universe and its implications for cosmology, (Invited talk at the Perspectives in High Energy Astronomy and Astrophysics Symposium in the Golden Jubilee Year at TIFR, Mumbai, August 16).

An alternative to big bang cosmology, (Invited talk at the VII Asian Pacific Regional Meeting of the IAU at Pusan University, South Korea, August 21).

Some challenging problems in astronomy, (Part of the IUCAA Lecture Series at N. Wadia College, Pune, October 29).

Astronomy and Astrophysics: challenges for the next decade, (Panelist in the Discussion at the IUCAA-North Bengal University Workshop, Bagdogra, November 16).

Big bang cosmology: problems and alternatives, (Invited talk at the PRL Golden Jubilee Symposium, Ahmedabad, December 14).

The quasi-steady state cosmology: some recent developments, (Second Zel'dovich Meeting on Large Scale Structure and Cosmology, IUCAA, December 20).

The revival of the cosmological constant, (Second Conference of the South African Relativity Society, The University of South Africa, Pretoria, February 7).

Light nuclei, radiation background and structures in the quasi steady state cosmology, (University of Cape Town, South Africa, February 11).

Black holes, (University of Zululand, South Africa, February 19).

The Physics-Astronomy frontier, (Department of Physics, University of Rajkot, March 8).

T. Padmanabhan

Understanding nonlinear gravitational clustering, (Fermilab, Chicago, USA, April 30).

Power transfer in nonlinear gravitational clustering, (Caltech, USA, May 24).

Large-scale structure of the universe, (VSP lecture, IUCAA, June 26-27).

Understanding gravitational clustering using nonlinear scaling relations, (Second Zel'dovich Meeting on Large Scale Structure and Cosmology, IUCAA, December 16-20).

Constraints from structure formation and dark matter, (Discussion Meeting on Big Bang and Alternative Cosmologies: A Critical Appraisal, Bangalore, January 6-8).

High redshift universe: An overview, and Hydro simulations of the high redshift universe, (Discussion Meeting on High Redshift Universe, Coorg, February 23-27).

Somak Raychaudhury

Our motion in the universe and other

applications of pattern recognition in astronomy, (Indian Statistical Institute, Calcutta, April 10).

Where we are in the universe and *The local group*, (Introductory Summer School on Astronomy and Astrophysics, IUCAA, May).

Our position in the universe, (DST Contact Programme, IUCAA, June 19).

Observational cosmology, (Vacation Students' Programme, June, 27).

Galaxies at $z > 6$*?*, (IUCAA/NCRA Journal Club, July).

Constraints on cosmology from large-scale structure studies, (SUJAYATA, TIFR Golden Jubilee Celebrations, Mumbai, September, 2).

Cosmological constraints from clusters of galaxies, (Second Zel'dovich Meeting on Large Scale Structure and Cosmology, IUCAA, December 16-20).

Astronomical data processing using the Internet, (Workshop of Astronomical Image Processing and the Internet, Thiruvananthapuram, December 21-24).

V. Sahni

Large scale structure of the universe and the cosmic microwave background, (Delhi University, Physics Department, Platinum Jubilee Celebrations, March 28).

Large scale structure of the universe, (Physics Department, Fergusson College, March 11).

Aspects of large scale structure in the universe, (Mehta Research Institute, February 14).

Probing large scale structure using percolation and genus curves, (Second Zel'dovich meeting on Large Scale Structure and Cosmology, IUCAA, December 17).

Topological aspects of structure formation in the universe, (Los Alamos National Laboratory, USA, September).

Probing large scale structure using percolation and shape statistics, (Canadian Institute for Theoretical Astrophysics, Toronto, Canada, September).

Probing large scale structure using percolation and shape statistics, (Fermilab, USA, September).

Dynamical and statistical aspects of gravitational clustering in the universe, (Seventh Asian-Pacific Regional Meeting of the IAU, Pusan, Korea, August).

Growth of non-Gaussianity during cosmological gravitational clustering, (Second International Conference: Astronomy and Astroparticle Physics, Moscow, Russia, June).

Shiv K. Sethi

The ionization state of intergalactic medium at high redshifts, (Canadian Institute of Theoretical Astrophysics, Toronto, Canada, October 3).

Observation of He II in IGM: Constraints of sources of ionization, (Observatory de Strasbourg, Strasbourg, France, September 15).

Radiatively decaying neutrinos and ionization of IGM at high redshifts, (Conference on Identification of Dark Matter, Sheffield, England, September 11).

On the sources of ionization of IGM at $z \sim 2.5$, (Queen Mary and Westfield College, London, England, September 6).

R. Srianand

Redshift distribution of Lyman alpha clouds, (IAP, Paris, September 6).

On the origin of B-K colours of quasars, (Workshop on Quasar Hosts, Tenerife, Spain, September 26).

Lyman alpha clouds and structure formation, (Second Zel'dovich meeting on Large Scale Structure and Cosmology, IUCAA, December 16).

A summary of the workshop on Quasar Hosts, (NCRA, December 20).

Quasar absorption lines, (Discussion meeting on High Redshift Universe, Coorg, February 20-26).

L. Sriramkumar

Aspects of quantum field theory in non-trivial classical backgrounds, (Raman Research Institute, Bangalore, Febraury 6).

Quantum field theory in classical backgrounds, (Physical Research Laboratory, Ahmedabad, TPSC seminar, Febraury 25).

S.N. Tandon

Observing colours of stars, (DST Contact Programme, IUCAA, June 17).

Single object and multi object spectroscopy, (Workshop on Astrophysical Spectroscopy, Sri Krishnadevaraya University, Anantapur, February 12-14).

b) Lecture Courses

Sukanta Bose

Quantum black holes, (Raman Research Institute, Bangalore, January 9 - February 6), 3 lectures.

N. Dadhich

General relativity (Minischocl on Cosmology, Lucknow University, February 3-10), 6 lectures.

S.V. Dhurandhar

Gravitational wave data analysis: Are wavelets the answer? (Mathematics Department, University of Pune, October-November), 6 lectures.

A.K. Kembhavi

Photometry, (TIFR-IUCAA Winter School on Gamma-ray Astronomy, Pachmarhi, November 12-14), 3 lectures.

Stellar structures and compact objects, (VSP, IUCAA, June 4-5), 3 lectures.

J.V. Narlikar

Electrodynamicss and cosmology, (IUCAA, January 13-31), 10 lectures.

T. Padmanabhan

Structure formation in the universe, (IUCAA-NCRA-2100 series, November 96), 15 lectures.

Somak Raychaudhury

Observational cosmology, (Minischool on Cosmology, Lucknow University, February 7-11), 6 lectures.

V. Sahni

Advanced Topics in Cosmology, (Minischool on Cosmology, Lucknow University, February 3-12), 4 lectures.

R. Srianand

High redshift universe, (Minischool on Cosmology, Lucknow University, February 9-12), 3 lectures.

S. Sridhar

Interstellar scattering and turbulence, (IUCAA-NCRA-2100, May 15-20), 4 lectures.

c) Popular Lectures

N. Dadhich

Our universe, (Professor P.C. Mahanta Memorial Lecture, Assam Space Science Association, Gauhati University, February 1).

Going from Newton to Einstein, (Fergusson College, March 5).

R. Gupta

Comet visitor of this century, (Science Day lecture, IUCAA, Pune, February 28).

Sky and Telescopes, (Cosmos, Techkriti '97, IIT, Kanpur, March 2).

A.M. Kane

Internet and You, (Manoharbhai Patel Institute of Engineering and Technology, Gondia, April 11).

J.V. Narlikar

Astronomy in India: Past, present and future and Introducing IUCAA to the Indian community in Washington DC, (April 8).

IUCAA, (to the Indian community in Washington DC, USA, April 8).

The discovery of new planets, (The Asiatic Society, Calcutta, May 6).

Antaralatun udbhavanare sambhavya dhhoke (in Marathi: Possible dangers from space), (Vasant Vyakhyan Mala, Pune, May 18).

Paragrahavaril jeevasrushticha shodh (in Marathi: The search for life on other planets), (Indian Medical Association, Sholapur, July 7).

Falajyotish he shastra ahe ka? (in Marathi: Is astrology a science?), (Andhashraddha Nirmoolan Samiti Lecture Series in Dadar, Mumbai, July 31 and August 1).

The technologies of new telescopes, (K.B. Talwalkar Memorial Lecture at Cusrow Wadia Institute of Technology, Pune, September 25).

Vishvat apan ekte ahot ka? (in Marathi : Are we alone in the universe?), (Ahmednagar College, Ahmednagar, October 3).

Nature of the universe, (Public Lecture in Gangtok, November 17).

New challenges in astronomy, (Saint Anthony's College, Shillong, November 19).

Myths, beliefs and facts in astronomy, (Saint Stephen's College, Delhi, November 22).

Myths, beliefs and facts in astronomy, (Kumari L.A. Meera Memorial Lecture at Bangalore, November 28).

Science education and the search for talent, (Law College, Pune, December 5).

Adventures in space, (to the students of Exploratory, MACS, Pune, December 10).

New challenges in astronomy, (Kerala University, Trivandrum, December 23).

Shaleya vidnyanatale khagolashastra (in Marathi: Astronomy in school curriculum), (School teachers at Maharashtra State Board of Education, Pune, December 31).

Manavi samaj ani vidnyan (in Marathi: Science and the human society), (Camp of Higher Secondary School students, Lokabodhini, Nimgaon Mhalungi, Shirur, January 12).

Nature of the universe (Rajkumar College, Rajkot, March 8).

T. Padmanabhan

Making a Universe, (Nowrosjee Wadia College, Pune, Joint programme of lecture series in Astronomy and Astrophysics, October 28).

Somak Raychaudhury

Our motion in the universe, (Nowrosjee Wadia College, Pune, August).

How massive is the Universe?, (Fergusson College, Pune, March 3).

Comet Hale-Bopp and other comets, (S.V.

Union High School, Pune, March).

Sukanya Sinha

Black holes, (Nowrosjee Wadia College, Pune, October 30).

d) Radio/TV Programmes

S.V. Dhurandhar

Search for gravitational waves, Australian National Radio, November.

J.V. Narlikar

Interview on IUCAA and Indian Science, Indian TV channel in Washington D.C., April 7.

Puranatil vidnyan khare kiti ani khote kiti? (in Marathi: Science in the old scriptures: how much of it is real and how much imagined?), Radio Talk in two parts on All India Radio, August 11, 18.

Interview on IUCAA to the C-DIC, Trivandrum on Doordarshan Channel 4, March 11.

Interview on Lonar in the Surabhi Programme, Doordarshan Channel 1, March 16.

Interview in Hindi on the National Programme of talks, All India Radio, Delhi, March 24.

A. Paranjpye

Comet Hale-Bopp, All India Radio, March 25.

(VII) SCIENTIFIC MEETINGS

DST Contact Programme for Students in Astronomy and Astrophysics

An introductory astronomy and astrophysics course, sponsored by the Department of Science and Technology (DST), Government of Inida, was organised under the DST contact programme for students at IUCAA during June 17-21, 1996. Lectures and demonstration sessions were delivered by N.K. Dadhich, M. Vivekanand, J.V. Narlikar, S.N. Tandon, A.N. Ramaprakash, Ranjan Gupta, Somak Raychaudhury, N.C. Rana, Shiv Sethi and Arvind Paranjpye. Night sky observation was possible only on June 21, as all other evenings were cloudy. A total of 13 students preselected by the DST on all India basis, attended the workshop. A trip to the GMRT site was organised on June 20 and Parveen Farooqui of DST accompanied the participants. Ranjan Gupta was the coordinator of this programme.

Introductory Summer School on Astronomy and Astrophysics

An Introductory Summer School on Astronomy and Astrophysics (A & A), funded by the Department of Science and Technology, Government of India, and hosted by IUCAA and NCRA, was held at IUCAA during May 20 - June 8, 1996. This was the seventh in the series of summer schools, the venue for which alternates between Pune and Bangalore. In this summer school, 26 students of physics and engineering from all over the country, took part.

There were 50 lectures of various topics in A&A, which were delivered by leading scientists from different A&A centres in the country. In addition, the students also took part in individual projects under the supervision of academic members of IUCAA and NCRA. Observations through an optical telescope, a visit to the GMRT site and computer image processing demonstrations were also some of the activities arranged during the school. The school provided adequate exposure to A&A and emphasized the thrust areas in the field. S. Sridhar from IUCAA and D.J. Saikia from NCRA were the coordinators of this school.

Seminar on Astronomy and Astrophysics

A one day seminar on Astronomy and Astrophysics for college and university teachers affiliated to the University of Bombay was organised on August 31, 1996. The main theme of the seminar was to highlight research activities in astronomy and astrophysics and the support extended by IUCAA. This seminar was chaired by A.A. Rangwala from University of Bombay and was inaugurated by K.P. Singh from TIFR, Mumbai. A.K. Kembhavi and N.K. Dadhich, both from IUCAA, introduced the recent trends in astrophysics. There were lively discussions with the participants for more than one hour. Thirty seven teachers, 34 research scholars, M.Sc. and B.Sc. students participated in this seminar.

Les Houches School on Starbursts : Triggers, Nature and Evolution

IUCAA was one of the sponsors of a school on Starbursts: Triggers, Nature and Evolution which was organised at the Centre de Physique, Les Houches, France during September 17-27, 1996. The school was organized jointly by Ajit Kembhavi of IUCAA and Bruno Guiderdoni of the Institut d'Astrophysique de Paris. Several distinguished speakers from different countries delivered lecture courses covering observational and theoretical aspects of various topics ranging from star formation to interacting galaxies. There were seminars by experts on areas of current interest as well as short seminars by students. About 60 participants, including 7 from India were present at the School. A book containing notes of lectures delivered at the School is being published.

Workshop on Astronomical Image Processing and the Internet

A Workshop on Astronomical Image Processing and the Internet was organised by Prabhakaran Nayar at the Observatory, University of Kerala, Thiruvananthapuram, during December 20-24, 1996. Lectures covering different aspects of Image Processing, Computer Networking, Computer Communication and the Internet were presented by experts from IUCAA and other organisations in Pune, Bangalore and the host city. There were about 60 participants from different Universities in Kerala as well as a few from other states. A special feature of this workshop was a complete computer network which was set up using computers from IUCAA and the Observatory. The state-of-the-art network was set up using easily obtainable and inexpensive hardware. The software used was wholly obtained from the public domain without having to pay any charges. E-mail connection has now been provided to the Observatory as well as to St. Thomas College, Kozhencherry, Kerala.

Workshop on Inhomogeneous Cosmological Models

A workshop on Inhomogeneous Cosmological Models (solutions of Einstein equations) was held at the North Bengal University, Siliguri, during November 14-18, 1996. It was attended by about 25 outstation participants. There was a lively discussion and critical appraisal of inhomogeneous cosmological solutions (particularly singularity-free ones) spearheaded by A.K. Raychaudhuri. In addition, there was also a discussion on conceptual issues related to black holes (radiation, entropy, etc.) and quantum cosmology. The other veteran, P.C. Vaidya, provided the inspiring backdrop by his excellent account of growth of GR in India. The last two days proceedings were held at the Government Sikkim College, Gangtok, the capital of the Himalayan state, Sikkim. The workshop ended with a visit to Chongu lake at the height of 14500 ft.

Winter School on Gamma Ray Astronomy

A winter school on Gamma Ray Astronomy was organised jointly by the Tata Institute of Fundamental Research (TIFR), Mumbai and IUCAA during November 14-18, 1996. The venue was the High Energy Gamma Ray Observatory at Pachmarhi in Madhya Pradesh, a field station of TIFR. The school co-ordinators were P.N. Bhat and P.R. Vishwanath from TIFR and A.K. Kembhavi from IUCAA. This was the first time that a school, devoted mainly to Gamma Ray Astronomy, was organized. It was targeted primarily to bright post graduates from the Universities interested in the field of Gamma Ray Astronomy. The response was very good and about 25 students from various Universities and Institutes were selected. One of the highlights of the school was the opportunities provided to the participants to have a first hand experience with gamma ray observations and observational techniques. Participants were also provided hands on experience with the laboratory equipments and detectors employed in the detection of TeV Gamma Rays using the

Participants of the School on Gamma Ray Astronomy

ground based Atmospheric Cerenkov Technique.

Some of the topics covered during the school were Gamma Ray Astronomy covering the entire energy range of MeV to PeV, X-ray and Optical Astronomy and Cosmic Rays. The lectures during the 5 busy days of the school included both observational aspects as well as theoretical understanding of the respective fields. The topics covered were deliberately kept simple & concise without the unnecessary details, just to give a flavor of the field. The speakers included B.S. Acharya, P.N. Bhat, K.P. Singh, K. Sivaprasad and P.R. Vishwanath from TIFR and A.K. Kembhavi & Ranjeev Mishra from IUCAA as well as A. Mitra from BARC. There were also technical talks given by the TIFR engineers on the hardware and software aspects of instrumentation. The topics included computer controlled data acquisition and telescope orientation systems as well as computer networking employed in the gamma ray observations at Pachmarhi.

Due to the encouraging response and enthusiasm shown by the participants we have decided to continue this activity as an annual event. The laboratory sessions which were enjoyed and appreciated by the participants most will continue to be the highlight of the future schools.

Second Zel'dovich meeting on Large Scale Structure and Cosmology

The second Zel'dovich meeting on Large Scale Structure and Cosmology was held in IUCAA during December 16 - 21, 1996. It was attended by experts from different Indian Institutes and universities as well as from Italy, United Kingdom, U.S.A., Germany, Portugal, Canada and Russia. The meeting included extensive discussions on fundamental issues in Cosmology such as: Structure formation and the Cosmic Microwave Background, Clusters and Superclusters of galaxies, Redshift survey's of the universe, N-body simulations, Gravitational lensing, Lyman alpha clouds and extent of neutral hydrogen at high redshifts etc.

Discussion Meeting on Big Bang and Alternative Cosmologies: A Critical Appraisal

An informal and lively discussion meeting on the above topic took place at the Jawaharlal Nehru Centre for Advanced Scientific Research in Bangalore from January 6 to 8, 1997. It was sponsored by the JNCASR, Bangalore, IUCAA, the Mehta Research Institute, Allahabad and IIT, Kanpur.

There were about 40 participants at the meeting

Participants of the Scond Zel'dovich meeting on Large Scale Structure and Conmology

from the leading astronomy and physics institutions and universities in India. Participants from abroad included Tarun Souradeep (CITA, Canada), Gustav Tammann (Basel, Switzerland), Geoffrey Burbidge (UCSD, La Jolla), Chip Arp (MPI, Munich), J.-C. Pecker (College de France, Paris), David Roscoe (Sheffield University).

The meeting was conducted with short talks followed by discussions. The "spectrum" of the meeting had, however, been structured to begin conservatively with talks on microwave background, evolutionary evidence from galaxies and quasars, synthesis of light nuclei, the measurements of Hubble's constant, etc. on the first day. From then on the shade began to change to discussions of problems with the big bang paradigm, e.g., ages of globular clusters, constraints of dark matter and structure formation, and the possibilities offered by alternative cosmologies like the Brans-Dicke class of models, string cosmologies, the quasi-steady state cosmology, and so on.

On the final day, there were discussions of data that apparently cannot be accommodated within the standard expanding universe hypothesis. Anomalous redshifts, quantized redshifts, alternative explanation of flat rotation curves, etc. were presented. Although the meeting allowed ample time for interventions and impromptu remarks, the panel discussion at the end was perhaps the liveliest of them all.

Is the big bang still flourishing? Or is it down and out? The meeting hardly changed the beliefs of the participants; but it surely made them more aware of the other point of view. It is hoped that the meeting will be a trend-setter for others to follow. C.N.R. Rao, the President of JNCASR had, in his inaugural talk, expressed the Centre's desire to host such meetings annually.

Workshop on Introductory General Relativity and Applications

A workshop on Introductory General Relativity and Applications was held at the newly founded Tezpur University during January 27-29, 1997. There were about 25 participants from colleges and universities in the North East region. The main aim of the workshop was to give an expose to some aspects of general relativity and relativistic astrophysics. All the lecturers were unanimous that it was perhaps the keenest lot, and was a pleasure to lecture to them.

Mini-School on Cosmology

A mini-school on Cosmology was held at Lucknow University during February 3-12, 1997. The school was organised by Sunil Datta and P.P Saxena of

Participants of the Mini-School on Cosmology

Participants of the Workshop on Astrophysical Spectroscopy

the Mathematics Department, Lucknow University, and was aimed at advanced graduate students, post-docs and other researchers. An attempt was made to cover all the basic aspects of Cosmology - both theoretical and observational. Lectures were given on general relativity, the early universe: (Nucleosynthesis, Baryogenesis, Inflation), structure formation in the universe, the cosmic microwave background, the high redshift universe, clusters and superclusters of galaxies, gravitational lensing, etc. Lecturers at the school included members of the IUCAA faculty (N. Dadhich, S. Raychaudhury, V. Sahni, R. Srianand) as well as physicists from other parts of the country (S. Bharadwaj, P. Das Gupta, V.B. Johri, N. Panchapakesan, D. Sahdev, R.P. Saxena).

Workshop on Astrophysical Spectroscopy

An IUCAA-sponsored workshop on Astrophysical Spectroscopy was held at Sri Krishnadevaraya University, Anantapur during February 12-14, 1997. P.R. Naidu, Vice-Chancellor, Sri Krishnadevaraya University inaugurated the workshop and N. Kameswara Rao, IIA gave the key note address. Some of the other main lecturers were Sunetra Giridhar, K.R. Subramanian, S.P. Bagare (all from IIA), S.N. Tandon and Ranjan Gupta (IUCAA), J.N. Desai (PRL), D.B. Vaidya (Gujarat College). A sky-watch programme was arranged in the night on February 13. T.V. Ramakrishna Rao and R. Ramakrishna Reddy from Sri Krishnadevaraya University were the convenors and Ranjan Gupta was the coordinator from IUCAA.

(VIII) VACATION STUDENTS' PROGRAMME 1996

The VSP-96 was conducted during June 3 - July 12, 1996. Six students, selected from various universities, participated in this programme. There were 21 lectures covering all aspects of Astronomy and Astrophysics. In addition, each student worked on a project during this period. The students were graded based on their performance in the project work and a written test was conducted at the end of the programme. This year, two students were pre-selected for the Research Scholarship starting from August 1997. Sukanya Sinha was the coordinator for this programme.

Facilities

(I) Computer Centre

The IUCAA computer centre has a number of state-of-the-art workstations and personal computers, along with varied software to satisfy the diverse needs of the many in-house users as well as visitors. Efforts are made to keep the hardware and software in tune with the latest developments as well as the growing needs of the large user community.

There has been a phenomenal increase in the requirement for disc space as well as data transfer within IUCAA. The network which consisted of a thick Ethernet backbone and thin Ethernet distribution proved to be inadequate to handle the required data transfer rates. The network has therefore been updated and now uses a fibre optic backbone, UTP cabling and Ethernet switches. This has led to substantial increase in the bandwidth available to users. The network will shortly switch to the ATM technology.

The SGI Power-Challenge machine, which did not live up to its expectations, has now been upgraded using two R10000 processors, and it is hoped that there will be a substantial increase in its performance. Several workstations which provide high computing power have been added to the network. New visualization software has been added. In all these improvements the accent has been on cost effectiveness and full advantage of the improvement in technology and the fall in prices has been taken.

The computer centre has taken the lead in making high performance software available on personal computing machines. The centre provides all help to users from the university sector to develop sophisticated but low cost networks and to install on them advanced software packages available in the public domain. As a part of this activity, workshops which deal with computer networking, communication and astronomical image processing have been conducted, sometimes away from IUCAA. Full networks have been carried for demonstration purposes to the venues of such meetings.

The ERNET node at IUCAA now makes use of radio technology to transfer data to the commercial fibre optic network which provides the pathway to NCST in Mumbai. In addition to the 64 kbaud dedicated link, IUCAA also has a VSAT which uses a satellite based pathway for data transfer.

(II) Astronomical Data Centre

The Astronomical Data Centre (ADC) at IUCAA was set up with funds from the DST. Even though these funds are no longer available, the activities of the ADC have been continued for the benefit of the astronomical community. New catalogues are continuously being added to the holdings of the ADC, and all effort is being made to remain current with the catalogues available at the data centre in Strasbourg.

A new addition to the facilities has been the development of a program which interfaces with the user through NETSCAPE. The program provides very easy access to the catalogues and can be used to retrieve data in useful form. Some graphical applications are available. The program is entirely based on software which is either as standard to UNIX machines or can be easily installed. The entire suite of programs, software and catalogues to the desired level of completeness are provided to users for installation at their site.

(III) Library

The IUCAA Library collection amounts to 13,757 items which includes books, bound volumes, audio-visual material, etc. Library is subscribing to 155 periodicals and also receives several Reprints, Preprints, Newsletters, Bulletins and Annual Reports. The highlights of the period under review are as follows:

Complete automation of the library services, including the issue of books based on magnetic bar coding, has been introduced. We are currently using, for this purpose, the SLIM (System for Library Information Management) Version 2.0

which have the following components: Acquisition System; Serials Control System; Cataloguing System; Circulation System; OPAC (Online public access catalogue) and "User Module". This is interfaced with compatible barcode technology accessories (CCD Scanner, Decoder, Portable Data Capturing Unit, Barcode Printing Software, etc.) to implement complete automation of circulation system.

To protect valuable library resources from theft, Electronic Article Surveillance system has been installed in the Library. This system sounds an alarm if an attempt is made to remove library material which is not properly issued out at the counter.

User services provided by the library include of reference service through Internet Resources, Inter-Organizational library loan, Reprographic help, Selective dissemination of information and current awareness service.

More information about the library is available on the IUCAA home page at the address: http://iucaa.iucaa.ernet.in/~library/library.html.

(IV) Instrumentation Laboratory

The laboratory has facilities for the design, construction, and testing of the instruments for observations. Visitors from the universities/ colleges have used the facilities to develop photometers for their use. A thermoelectrically cooled CCD Camera, suitable for small telescopes at the universities/ colleges, is under development; based on this design, groups from universities/ colleges would be able to make CCD Camera in the laboratory and take it for their observations. Support has been provided to Gorakhpur University and Mahatma Gandhi University for selecting the telescopes and accessories for their use, and the groups from these universities would soon be testing their telescopes in the laboratory.

A new CCD Camera with optical-fibre link for communication with the control computer is assembled and is under test. Instruments were developed for site-testing, and the work of site-testing for the IUCAA telescope was undertaken by the laboratory. More details on these can be found under the head Instrumentation in the section Research at IUCAA.

(V) The IUCAA Telescope

About two years back IUCAA telescope was proposed as a facility to be primarily used by astronomers from the Indian university sector. The telescope project was approved by the UGC about a year back and around the same time work was started towards monitoring some prospective sites with differential-image motion seeing monitors and other instruments. After making enquiries with several reputed suppliers of 1-2 m class telescopes, an order has been placed with the Royal Greenwich Observatory, Cambridge, England for a 2 m telescope. The telescope would have a altazimuth mount and would incorporate several other modern features to give a pointing accuracy of ~ 2 arc sec and a sub arc sec tracking accuracy. Based on the discussions at a meeting of the astronomers, from the university sector and from the national observatories, an optical imager cum spectrograph and a near infrared imager cum spectrograph have been chosen as the first two instruments.

Based on detailed monitoring of two sites in the Harishchandragarh Range (north - northeast of Pune) a site near the village Giravali, in tahasil Junnar of Pune district, has been chosen for the observatory; the site is at a height of about 1000 metres, and it is at a distance of about 80 km by road from IUCAA (Latitude ~ 19 deg 4.4 arcmin North, and Longitude ~ 73 deg 50.8 arcmin East). A summary of the site parameters measured during November 1996 to February 2997 is given below:

Median Seeing ~ 1.4 ", Sky-Brightness 21.2 mag. to 20.7 mag. in the V band, Extinction in the V band ~ 0.15 mag in good conditions, and in these months ~ 90% of the nights are spectroscopic and about 60% nights are photometric.

The work towards acquiring the land for the observatory and design of the buildings has started. The telescope is expected to be operational in the year 1999.

(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

IUCAA has carried out extensive programmes for the popularization of science during the past year. The ongoing programmes include the summer programme for school students (where each student spends a week during the school vacation at IUCAA supervised by an IUCAA member), lecture demonstrations for school students (once/twice a month on Saturday morning), sky-viewing for the general public (once a month, Friday night), organizing an inter-school science festival on the National Science Day and liaising with the amateur astronomy groups in Pune and elsewhere in India. We also maintain several relevant pages on the world-wide web, organise 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. In addition, this year we organised an open day for the general public, started a weekly workshop for mirror-grinding and telescope making, and published and distributed widely an information booklet on Comet Hale-Bopp.

(I) National Science Day: 28 February 1997

A Science Festival for high school students in the morning and an Open House for the general public with an exhibition, along with lectures, screening of documentaries on video and sky-watching in the afternoon and evening. This is how the National Science Day was celebrated at IUCAA on February 28, 1997.

The Science Festival for Schools

Over five hundred students and science teachers attended the Science Festival. There were three competitive events for the students: one for artists, one for writing essays, and another, a team event, for scientific proficiency and knowledge. Prizes were given in each category (books for individual students, rolling trophies for their schools). The school with the best overall performance was awarded the N.C. Rana Memorial Trophy, which was introduced this year, in memory of our deceased colleague who was indeed sorely missed on this day.

One representative from each school competed for the drawing prize. They were invited to draw in pencil either how they imagined *A View from a spaceship* would be, or their impressions of *Violent phenomena in the universe*. First and second prizes were awarded to Abhishek Kulkarni (Sardar Dastur Boys High School) and Shahid Shaikh (S.V. Union High School). Another student from each school participated in the science essay competition. They had to write, either in English or in Marathi, about

In the morning of the National science Day, seventy schools were represented in an inter-school competition for a pencil sketch on a given scientific theme.

Seven teams were selected from seventy to compete for the final round of the inter-school Science Quiz contest, where they faced questions in physics, astronomy, mathematics, chemistry and biology.

Academic members of IUCAA presented exciting new results in physics and astrophysics to visitors as part of the open day activities.

Visitors were introduced to developments in astronomical instrumentation in the Instrumentation Laboratory.

either the Scientist who inspires them most, or on whether Science should remain a compulsory subject in high school. They were also given the choice to fantasise about what it would be like *if Gravity did not exist, or if Dinosaurs were alive today.* First and second prizes were awarded to Manasi Kakatkar (Muktangan English School) and Ameya S. Gujar (Loyola High School) in the English essay category and to Hemangi S. Modak (N.M.V. Girls' High School) and Amit V. Thombare (Sheth Jyotiprasad Vidyalaya, Daund) in the Marathi essay category.

Seventy schools participated in the first round of the science quiz contest, each school being represented by a team of four students. In the first round, they were given 40 minutes to attempt to answer 25 multiple-choice questions in physics, astronomy, mathematics, chemistry and biology. Of these, seven teams were selected for the final stage, which was conducted in a full Chandrasekhar Auditorium. The finals were convincingly won by M.E.S. Bal Shikshan Mandir, who also won the N.C. Rana Memorial Trophy for the best overall performance in all the events of the day. Prizes were also awarded to Vidya Bhavan High School and St. Vincent High School for ranking second and third respectively. J.V. Narlikar gave away the prizes.

A principal attraction among the day's activities was an hour-long presentation by the *Andhasraddha Nirmoolan Samiti* (an organisation dedicated to eradicating superstition), who showed simple chemical ways of performing many apparent miracles that some so-called godmen often perform.

The Open Day

IUCAA was open to members of the general public for four hours on the afternoon of the 28th. The open day activities, in addition to a general tour of the Centre buildings, consisted of an exhibition to highlight the interests of the academic members of the Centre, demonstration of the instrumentation and computing facilities, slide shows and lectures, video screenings, and the viewing of the Sun and of the night sky using telescopes.

The exhibition consisted mostly of posters prepared by the academic staff and students presenting different aspects of research in IUCAA. In addition, there were posters representing recent important research in other areas of physics. Also, shown (courtesy of the library staff) were some aspects of C.V. Raman's research, which forms the basis of the National Science Day celebrations. Visitors could address their queries to the authors of the posters, many of whom were present in the exhibition area.

Exhibits set up by the Instrumentation Laboratory included a CCD camera, a Seeing Monitor and a demonstration of networking. Staff of the Computer Centre demonstrated the capabilities of the Internet, and the facilities of the Astronomical Data Centre. Image processing and results of astrophysical simulations were also demonstrated on screen.

Short half-hour lectures on various astronomical topics, accompanied by slides, were given by various academic members and visitors. These were very well attended and discussions with the lecturers often went on for hours outside the lecture hall.

Assisted by volunteers of the local amateur astronomers' association (*Jyotirvidya Parisanstha*), skywatching with telescopes was arranged. During the afternoon, visitors could view sunspots with the help of several telescopes varying in aperture between 7 and 20 cm. After dark, a queue of visitors waited patiently to get the opportunity of viewing nebulae and clusters through several telescopes placed in the Aditi complex of IUCAA.

More than two thousand visitors attended various activities during this period.

(II) Other Programmes

Sky-viewing for the Public

During the year, apart from the regular fourth Friday night sky viewing shows using the IUCAA 8" and 3" telescopes, Arvind Paranjpye organised sky-viewing exercises for various local schools and other organisations like the National Defence Academy, Pune.

Comet Hale-Bopp

This year the arrival of Comet Hale-Bopp generated immense enthusiasm among the public. We organized several special events for members of the public to use the IUCAA binoculars and telescopes to look at the nucleus of the comet. CCD imaging of the comet was carried out on a few occasions from within the IUCAA campus as well as from the outskirts of Pune, with several such images being displayed on the special home-page on the Web created for the comet. A eight-page booklet about the history of the comet, and details about its orbit and position in the sky was published by Somak Raychaudhury and Arvind Paranjpye and distributed widely all over India. In addition, T-shirts diplaying an image of the comet were sold to the public.

Mirror grinding/polishing at the Science Popularization Laboratory:

From February 1997, a workshop for training enthusiastic amateurs in the grinding and polishing of 7.5 cm mirrors for the use in telescopes is being conducted every Saturday by Arvind Paranjpye. We have had an overwhelming response from the community of local amateur astronomers and telescope makers for this activity.

Inter-School Science Model Competition:

The Rotary Club of Karvenagar organized an inter-school science model competition with the help of some members of IUCAA. IUCAA was represented at the Annual Amateur Astronomer's Meet at New Delhi in January 1997, and was host for the annual meeting of the committee of the Confederation for Indian Amateur Astronomers (CIAA). Several members lectured on popular astronomical topics in local schools and colleges, particularly during the apparition of Comet Hale-Bopp.

Programmes for School Students

As a part of the ongoing science popularization programme, IUCAA has been organizing two programmes for the school students of Pune, in order to motivate students towards a research career in astronomy and astrophysics. The response has been overwhelming.

(I) 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 15, 1996. 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 sun, the solar system, construction of the periscope and kaleidoscope, etc. Instructions were given in Marathi and Hindi as well as in English.

(II) Lecture Demonstrations

This programme was instituted for conveying the excitement of doing science to secondary school students. This is normally held on the second Saturday of every month. The following lecture demonstrations were conducted:

N.K. Dadhich

Some thought experiments and their significance, September 14.

Kuch vaicharik prayog aur unki mahatta, (in Hindi), September 14.

V.K. Kapahi (NCRA)

Exploring the universe through radio waves, (in English and in Hindi), January 25.

J.V. Narlikar

Prithvi palikadil jeevsrusticha shodh, (in Marathi) August 10.

Search for extra-terrestrial life in the universe, August 10.

Mangala Narlikar (Pune)

Four colour problems and other interesting problems in Mathematics, July 13.

Nakasha rangavnyacha ani ganitatil itar manoranjak prashna, (in Marathi) July 13.

T. Padmanabhan

The attraction of gravity, December 14.

R. Ramachandran

The zoo of elementary particles, February 15.

Somak Raychaudhury

Comets: Halley, Hyakutake and Hale-Bopp, October 12.

These lecture demonstrations were conducted in the IUCAA Auditorium, with a capacity of nearly 500. The response from the city schools has been overwhelming; on most occasions, many students had to sit on the floor. On a few occasions, IUCAA was forced to decline admission to late comers because of insufficient sitting space.

Eighth IUCAA Foundation Day Lecture

THE CRISIS IN HIGHER EDUCATION

by
Dr. Suma Chitnis
Director, J.N. Tata Endowment for the Higher Education of the Indians, Mumbai

Dr. Narlikar and friends. Greetings to you on your Foundation Day. I am deeply honoured and very happy to be here today. There are very few institutions of higher education in our country where excellence in research and in teaching are truly practised. IUCAA is one of them. There are very few really outstanding scholars, and IUCAA is headed by one. I feel privileged to be here.

THE CONCERN

For some time now, and particularly since the time I took up the Vice-Chancellorship of the S.N.D.T. University seven years ago, I have been disturbed by the state of higher education in our country. As a sociologist I have been studying issues pertaining to education and development in third world societies for the last thirty years. But despite my long engagement with these issues I was not really aware of what I have seen and experienced of higher education in India over the course of the six years of my Vice-Chancellorship. For these six years, as I attempted to implement at the SNDT University some of the basics of what I believe is needed in higher education, I had the opportunity to observe the system from within, from vantage points not easily accessible to outsiders, to learn how complex the situation in which universities in our country are placed and how deep the cracks in their functioning run. I have experienced in the raw, the pressures that the system has to face, been able to observe at close quarters the consequences of the rapid expansion of higher education, and the implications of adapting a colonial system of university education to the demands of development.

If the perspective from my position as a Vice-Chancellor was thus revealing, the perspective from my current position as a member of the State Planning Board and Chairperson of its Committee on Education is alarming. It is clearly evident that neither the State Governments nor the Central Government is going to be able to pull higher education out of the disarray that it is in. Pressed by other competing demands of development - including the demand for urgent, war scale efforts to achieve long over due targets in literacy and in the universalization of primary school education, they are in no position to spare larger resources for higher education. Precariously placed for survival, and therefore afraid to do anything that will make them unpopular, they are unwilling and unable to take some of the bold steps required to make higher education more efficient, purposive and relevant.....

Faced with this reality, I have come to the conclusion that the responsibility for restoring higher education must be taken by the people. India has a proud history of public initiative on behalf of higher education. The first three universities in the country, set up in 1857, were the result of public initiative. Left to themselves, the British would never have taken a lead in bringing advanced European education to the country. Later, at the turn of the century, when it was recognized that nationalist needs in higher education were not met by the universities set up by the British, socially conscious Indians once gain took an initiative to establish Vishwa Bharati, the Banaras Hindu University, the Aligarh Muslim University, and Jamia Milia. The city of Pune, in particular, has taken initiatives that have made history. For instance the establishment of the Servants of India Society, the Deccan Education Society and the SNDT Women's University. Looking back upon the fifty years of our freedom it seems that in the post-independence period we left too much to the government. I have chosen to speak on the crisis in Higher Education in the hope that what I say will lead to discussion and dialogue on the crisis and help generate the initiatives and action now critically required.

During the course of the next forty minutes I propose to describe the crisis in higher education and to identify the sources of some of the critical elements of this crisis. Most of my description will be based on my personal experiences as an administrator.

A VISIBLE CRISIS

The crisis in higher education is visible from many vantage points. The simplest evidence of the crisis comes from newspaper reports. They keep us regularly informed of the mal-functioning of the system. One reads about the leakage of examination papers, errors in the papers set, failure to conduct examinations on time, the sale of question papers and answers prior to examinations, mass copying - often with the collaboration of invigilators and teachers and assisted by parents and violence against invigilators who refuse to join the racket. There are reports about the extensive practice of hiking up marks on payment of a consideration; about the sale of false diplomas and degrees; about strikes, even hunger strikes by students, faculty and other employees whenever attempts to bring discipline to the system are made; about excesses in ragging that offend human dignity and go far beyond the limits of human endurance. The list goes on. Thus, even those who have nothing directly to do with the system are aware that something is seriously wrong with it.

Within the system, each category of participants experiences the crisis in a distinctive way. For instance, faculty will tell you that their salaries are often delayed, that they have hardly any opportunities or facilities for research, that continued scholarship is irrelevant to their advance in their careers since promotion to higher posts is primarily by seniority, that they have no control either over defining the syllabi they teach or over the assessment of their students. College Principals in turn will tell you that most teachers take their professional responsibilities in a spirit unworthy of committed scholars, that they count their professional obligations in terms of the number of hours of teaching done, that they refuse to take anything beyond the set teaching load, that they resent frequent upgrading of syllabi, because it means extra work for them, that they refuse to examine and assess examination papers as they do not consider this task a "part of their job". Finally, students seem to have the most to complain about, starting with the uncertainty of admission to courses and institutions of their choice and of being forced to accept whatever is available, to complaints that academic terms do not commence on schedule, that they are frequently interrupted, that the quality of teaching is poor, that library and laboratory facilities are inadequate, that teachers do not complete the syllabi, that assessment and evaluation are erratic ..... At the apex institutions of higher education, which are generally free from most of these inadequacies there is a steady decline of focused purpose and excellence. At the same time competition is so high that students are pushed into anxieties and tensions which, not infrequently, lead to suicide.

UNMANAGEABLE EXPANSION

All these and a million other anomalies that are visible, are rooted in deeper problems. Perhaps it would be best to start by locating the roots of some of simplest and most visible inadequacies - for instance the uncertainty about securing admissions and the failure of the universities to declare examination results on time. Both inadequacies are, in a sense, a consequence of the fact that universities are pressed to serve students in numbers far in excess of what they are equipped to handle.

The decision to expand and diversify the system of higher education was consciously made at independence. The first three European style universities set up in India in 1857, were supposedly modelled after the University of

London. However, educated Indians were acutely conscious of the fact that university education provided in India was far removed from what was available abroad. Thus, throughout the period of India's struggle for independence, nationalists had cherished the dream of providing in independent India, an university system comparable to the best in the world. They had also dreamt of providing opportunities for higher education to every Indian who aspired to be university educated. The decision to make industrialization and technological advance the corner stone of the country's economic growth and development gave a sharp pragmatic meaning to these dreams. And, upon the achievement of independence higher education in India was extensively expanded and diversified.

However, the demand for education has grown and exploded far beyond the facilities initially planned and designed. This demand has been triggered by many factors. First and foremost, the revolution of rising expectations, and the notion that a university education is a passport to a good job, to a high social status - even to a good deal in the marriage market. Second the failure to provide at middle and high school level courses leading up to suitable employment. There are many occupations, both in the modern industrial technologically advanced sector of the economy as well as the traditional sector, including agriculture, where sound high school or even middle school level education should suffice. But despite a great deal of talk in that direction middle school and high school in our country have never really been successfully structured to be effective terminal points. While these and other factors have been at work, the phenomenal growth in the country's school and college age population has had its own uncontrolled influence on the trajectory of growth.

Today India has the third largest university system in the world. The largest is that of the USA with 14 million students. We have 6 million. During the first decade of independence, between 1951 and 1961 there was 81.48 per cent growth in enrollment in higher education. In 1961-71 it went up further, to 108 percent. By 1971 - 81 it had come down to 29 per cent where it seems to have stabilized. But even this rate of growth is far beyond what the country can handle.

In a sense, the overwhelming majority of those who take admission to university level education are just parked in college. They are not necessarily doing anything productive. Of the total population of university students in the country, 40 percent are in Arts, 20 percent in Commerce and 20 percent in the Science courses. The remaining are in professional courses, such as Engineering, Medicine, Law, etc.

When the degree examination results are declared each year, one notices that less than 50 per cent of the students in non-professional courses pass. Records of prestigious institutes for further education, such as the Institutes of Management, reveal that only a minuscule percentage of graduates from these fields are able to make their way through competition for admission to these institutions where graduates from fields such as engineering also converge. And, most important of all, the graduates that are produced cannot, and are not being absorbed in the economy on an adequate scale. This has led to a massive problem of unemployment and under-employment of university graduates in the country. As far back as 1953, when the University Grants Commission was established, its first Chairman had warned against excessive expansion of higher education and pointed out the need to keep the system to manageable size. What then one may ask is the purpose of expanding these sectors and admitting more and more ? How productive is the education that is being given ? Is it really substantial enough to be spread over the three year period through which a degree course runs?

THE COOLING OFF FUNCTION

We are not the only country which produces graduates in excess of the number that the economy can absorb at a level optimally useful to the individuals concerned as well as to the country. For instance, the U.S.A. also produces graduates far in excess of what the economy needs. Social scientists who have analysed this phenomenon in the U.S.A. say, that by admitting students for higher education universities perform needed "cooling off function" for society. They point out that graduates fresh out of high school have aspirations for jobs of a quality that they cannot really find. So, they go on to university, with the intention of equipping themselves for better futures. By the time they have completed their university education they are more realistic about opportunities and willing to take what is available. Thus by accommodating students who do not find satisfactory employment after high school, universities help to contain and "cool off" the frustration that would otherwise create problems.

To an extent, the situation in India seems to be somewhat the same. One often wonders why bodies like the U.G.C., specifically set up to control and monitor standards in higher education do not halt the run away growth. There are no specific data on the issue, but one is tempted to speculate that this is because the government finds the expansion of higher education useful as a strategy for containing unemployment in the country. It must certainly also find expansion useful as a mechanism for maintaining an image of development and growth.

OTHER VESTED INTEREST

While the government may thus have its own reasons for permitting growth there are many others who have a vested interest in expanding higher education. For instance, in the context of the heavy demand, the provision of facilities for degree level education had become commercially attractive. Despite strict government control over the fees charged, college managements are able to make money through donations charged for admissions and through other routes. Similarly the setting up of colleges and the provision of other facilities for higher education has grown to be an instrument for political leverage. Politicians have discovered that one of the easiest means to gain popularity with their electorates is to start a college for them. Whenever there are moves to curb the growth of higher education, these commercial entrepreneurs and politicians interested in expansion point to the visible demand for facilities. They argue that although India has the third largest university student population in the world, barely 6 per cent of the youth in the relevant age group are at university. The corresponding figure for the U.S.A. is 25 per cent. Since all Plan and other government documents consistently reaffirm the commitment to provide equality of opportunity for higher education their claims stand.

With the climate thus generally favourable to expansion it is interesting to see how the pressures operate to destroy the few restrictions that exist. I will quote from my experience.

The number of students a college may admit is defined by the university to which the college is affiliated. Arrangements for the examinations to be conducted by the university are designed on the basis of numbers thus defined. However, colleges frequently admit students in excess of the assigned number and inform the university only at the point at which the students are required to be presented for examinations. Sometimes this is at the end of the year. But it can be as late as three years from the point of admission. Technically, such admissions are irregular and therefore invalid, and the university has the right to refuse to accept these students for examinations. But the managements of the colleges use political pressure to force the university to comply. Students protest, and go on strike. And eventually, if and when the matter goes to a court of law, the court almost invariably asks the university to examine the students. The argument is that, what happened was no fault of theirs. Against the history of such court judgments this practice has grown to be a recurrent strategy...

During the course of my six year tenure, there were three cases of this nature. Aware of the court judgements, I ruled that the students be accepted for the examinations. But I moved the university authorities to take firm disciplinary action by imposing a stiff fine on the colleges that resorted to this practice. I was able to get this done. But in the process I discovered that my objection to the flouting of university norms was somewhat isolated. Very few in the university system take a serious view of this malpractices or for that matter of many other malpractice that exist. They accept them as a matter of course and do not consider it appropriate to penalize the managements even for their obvious indiscipline. This erosion of discipline, of respect for established norms, and insensitivity to the consequences of irregular expansion is the real problem.

CONSEQUENCES OF INORDINATE EXPANSION

Forced to admit students in numbers far in excess of what they can handle, universities are continuously in default. There is mismanagement of admissions, inability to provide adequate teaching, laboratory and library facilities, and finally inability to declare results on time. Apart from causing inefficiencies in administration, the pressure of numbers has led to a serious decline in standards. As may be expected, adequately qualified teachers are not really available on the scale required nor is it possible to organize instruction in a manner required to ensure quality. The lecture method, together with the annual examination, set up by the British as the cheapest method, and already in use, continues. But it has not been able to deliver what it did in earlier times with smaller classes and better equipped teachers. It is not possible to find examiners to correct the several thousand answer books that pile up in each subject. Progressively both instruction and examinations have deteriorated to a point at which, for the major part the degree is a certificate with very little substance to it.

Initially this decline only affected the humanities, and the social sciences. Since education in these fields was relatively easier to provide and much less expensive, the bulk of the burden of growth was accommodated in courses in these fields. The professional courses, particularly engineering, management and medicine were protected from the onslaught of massification. But by now they too have succumbed. In fact the demand for professional courses is so heavy that sub-standard colleges of engineering and management are mushrooming and thrive. Some of these are started and managed by people with a commitment to education. But for the major part they are either commercial enterprises or politically motivated ventures.

THE MASSIFICATION OF EDUCATION

I have just used the term massification. It is a term that is being increasingly used in discourse on higher education. It refers to expansion motivated by a commitment to equality and made with the intention of extending higher education to the masses. In a sense it underlines the contrast between this modern feature of higher education and the traditional elitism. Historically, higher education has been visibly, unabashedly and self consciously elitist in all societies. Restricted to the priestly classes, the aristrocracy, or at the most to the professional middle classes, it was a privilege either denied or just plain inaccessible to the masses.

Today, both the ideal equality of educational opportunity and the consequent massification of higher education are global phenomenon. However, they have distinctive manifestations in different societies. In India the "massification" of higher education during the course of the five decades since independence has resulted in expansion beyond control, in a deterioration of standards, a breakdown of norms and of discipline and mismatch between what higher education provides and what the country needs.

To a large extent this is a consequence of the fact that the expansion of higher education has been so rapid that it has not been possible to develop suitable manpower to function in the academic and non-academic positions through which universities and colleges operate. Pressed to grow as rapidly as it has done, India could at best follow models from the developed countries, for expansion and diversification. But the higher education systems of these countries were geared to serve the needs of technologically advanced industrialized economies and not to the needs of a developing country making the transition from colonial agricultural economy to industrialization. For that matter there was no parallel situation to use as a model, to draw from. But there are several other factors that are also responsible for this deterioration. For instance, the poor implementation and the politicization of the policy of reservations, which in turn is one of the most distinctive features of India's effort to provide equality of opportunity for education.

THE POLICY OF RESERVATIONS

In principle, the policy of reservations is one of the fairest of human gestures and a bold and courageous effort towards equality of educational opportunity. But in practice it operates in manner that negates some of the basic principles of education and weakens the system. It was specifically instituted to help overcome the traditional ascription of status by caste, by enabling sectors of the population traditionally *ascribed* a low status *qualify* for better positions. By making caste the criteria for admission of students to reserved seats as well as for the appointment of faculty to reserved positions, it has ended up by reinforcing caste.

Further, because the policy is operated by the government bureaucracy, admissions and appointments to reserved positions are ridden with endless rules, regulations and formalities defined by complex formulae. Because it is highly politicized, politically powerful unions watch and monitor these admissions and appointments. These unions can be highly offensive in their dealings with university administrators and unreasonable in their demands. I remember one particular instance which I had to deal with as Vice - Chancellor. I was being pressed by the scheduled caste union to appoint, to the position of Associate Professor, a lecturer who had not even studied the subject for which the Assistant Professorship was assigned. In handling the matter, I felt as though I was dealing with a labour problem rather than with an academic appointment. The concession demanded showed a total disregard for academic standards and requirements. The manner in which the negotiations were forced destroyed the collegial principle which once guided and defined relationships and dealings within the university system.

A POLITICAL FUNCTION

In a sense, by adapting to the requirements generated by the ideal of equality of educational opportunity, the system of higher education is performing a political function. In the performance of this function it has to reverse some of its characters. One of the traditional functions of education was to select a certain kind of elite, and to discard and eliminate those who did not measure up to the standard expected. The culture of this elite dominated in higher education. In opposition to the mass culture, it upheld standards and excellence. In the process of massification this emphasis on standards and on excellence is being questioned, even rejected.

The issue is further complicated by the fact that historically, access to higher education as well as to the more privileged schools has been restricted to those with the means to afford education. Those who have the means are not necessarily endowed with academic excellence. This is global phenomenon. Thus access to higher advantage has historically been a social class related privilege. Over generations the academically unacceptable are bunched with the academically acceptable in the middle and upper classes. They find their way in higher education regardless of their limited calibre. This is now questioned and resented. And in protest the entire culture of excellence is being questioned. This is one of the major elements of the Indian crisis.

DEPENDENCE OF THE GOVERNMENT

Private sector undertakings in the country are not required to implement reservations. Perhaps things would have been less difficult if universities had not grown to be so dependent on and tied up with government. When the country acquired independence, government was responsible for roughly 58 per cent of the expenditure on higher education. By now the government's share has gone up to 88 per cent - even higher according to some estimates. Government funding means government control. It means rules, regulations, the attendant red tape and inefficiencies that exist in any government office or public sector undertaking.

Matters are further complicated by the fact that the responsibility for funding and overseeing higher education is carried jointly by the Central and the State governments. The Central government, through the U.G.C. is responsible for funding the "development" of universities. The State government is responsible for their maintenance, particularly for the salaries of faculty and staff. Most of the development is launched through programmes, funded by the U.G.C., for a five year period through the course of the country's Five Year Plans. State governments are expected to take on the responsibility for funding these development programmes at the end of the five years. The State governments often fail to carry this responsibility. In fact even routine grants are not disbursed by the State government on time. For instance, my experience at S.N.D.T. was that grants towards salaries came ten to fifteen days late each month. The university did not have reserves from which to make interim payments. There was a crisis each month.

Because grants are thus delayed, senior officers of the universities, including the Vice-Chancellor are often compelled to go to the State Department of Education or the Directorate of Education with requests to expedite payment. In the process what belongs to the university by right gets converted into a favour sought. Further, because Ministers and Senior Government Officers are important to universities and colleges as dispensers of grants and permission they get invited to preside over university and college functions. This practice generates an unhealthy ethos.

Another unfortunate consequence of dependence on the government for funds is the practice of inflating budgets for the Five Year Plan proposals that are made. Such inflation is routine in government offices. It is necessitated because mechanical cuts are employed by government authorities who are responsible for scrutinizing budgets. But it is unhealthy for universities to indulge in this practice. It may be pertinent to share my experience of this practice.

I took up the Vice-Chancellorship of the S N D T University in January 1990. One of my first responsibilities was to prepare the budget proposals for the Eighth Five Year Plan. On consulting the university staff I discovered that there was a set formula for the inflation of the budget based upon experience of where the cuts were made. I could not accept the idea of inflating the budget, despite the convincing logic with which my staff persuaded me of the need to do so. I was similarly told that there was a set style for writing the preamble to the budget proposals. I found this style flowery and pompous. I found the statements routinely made in the preamble irrelevant and pretentious.

Much to the consternation of my staff. I decided to write in my own style a short, brisk, completely honest and uninflated budget proposal. While presenting this proposal to the U.G.C. I stated that I disapproved of the practice of inflating budgets and was putting my university at risk by presenting an uninflated budget. I further pointed out that as an academic and a Vice-Chancellor I was responsible for upholding honesty and truth and believed that it is wrong for the U.G.C. to accept inflated budget. There was some shock and considerable amusement at the stand I had taken. The university did get the maximum grant possible. But I think that was only a one time response. It would be foolish to claim that my stand made any dent on the system.

There are many other ways in which universities are beginning to lose their dignity and strength because of their dependence on government. One of these is the new practice by which admissions to certain courses are made through State government authorities. To admit, teach and evaluate students are the basic functions of any institution of education. By taking over the responsibility for admissions, the government has deprived universities of one of their most basic rights. As Vice-Chancellor I had protested against administration of B.Ed. admissions by State government authorities. In deference to my protest the admissions were left to the universities. But, the fact that I was trying to defend a principle was never understood, not even by my comrade Vice-Chancellors. It is exhausting to thus keep on defending the boundaries of the university's authority and autonomy. Eventually, Vice-Chancellors give up. And gradually there is nothing much left to defend.

THE RESOURCE CRUNCH

Funding is another problem. Universities are continuously short of funds. Even salaries are not adequately covered. I used to face a deficit of about eight lakhs for salaries each month. There are no grants for maintenance of buildings and of facilities. Grants for laboratories, libraries and other such facilities are not only grossly inadequate but erratic. Moreover, resources for higher education are continuously shrinking. In the First Five Year Plan, the expenditure on higher education accounted for 9 per cent of the total budget on education. In the Second Plan it went up to 22 per cent and till the Fifth Plan it ranged between 22 per cent and 25 per cent. It dropped to 18 per cent in the Sixth Plan. 14 per cent in the Seventh Plan and 8 per cent in the Eighth Plan. We do not know what the situation in the Ninth Plan will be. But considering the emphasis that is being placed on Primary School Education the allocations for higher education are not likely to go up.

One of the obvious ways out of this impasse is to create resources by raising fees and by encouraging the establishment of unaided institutions. There are sectors of the population, particularly the urban population, willing to pay much higher fees. But, with a view to protect those who are genuinely unable to pay more, the government imposes firm restrictions on the enhancement of fees at institutions that receive aid. Controls are also exercised over unaided institutions, to the point that many of these institutions are unable to function.

As a Vice-Chancellor, I had explored several other avenues for building resources. One of these, leasing university grounds and premises worked. But subsequently there have been restrictions on the autonomy of universities, in this matter. I had also explored the possibilities of "exporting" education through distance education programmes. This was in response to requests from Dubai and Bahrain. If the university had been allowed to respond to these requests it would have been able to develop excellent instruction materials and substantially improve its distance education programmes. But the university could not move ahead without the permission of the State government and its efforts to secure this permission got hopelessly wrapped in red tape. Papers moved back and forth between the Ministry of Human Resources, the U.G.C. and the Ministry of Foreign Affairs at Delhi, and the State Department of Education and the State Department of Law at Mumbai. The S.N.D.T. University's statutory jurisdiction extends accross the country but the question as to whether it has the authority to conduct courses, even correspondence courses and only for Indian students outside India was never resolved.

Today Canadian, U.K., Australian and American universities freely conduct courses in India. They sell these courses aggressively and charge stiff fees. While the government accepts this, it compels Indian universities to forego opportunities to similarly market their programmes in other countries.

THE NEED TO RESTORE AND REORIENT PERSPECTIVES

For my Ph.D. dissertation, I had studied the teacher role in the college system. One of the most important findings from my study was that although college teachers are referred to as professors, the system is so structured that they do not have any opportunity to profess. They are required merely to be 'lecturers". Similarly, I had observed that they have very little room to address current concerns or to teach creatively and independently. They are straight jacketed by syllabi designed by others, by examinations set and assessed by others and by the expectation that their students respond within the frames set. Confronted by these findings, I had come to believe that teachers would welcome the opportunity for more authority and responsibility and greater freedom. Therefore, as Vice-Chancellor, one of my first efforts was to explore ways and means to increase the authority and the freedom available to teachers, and to provide them with opportunities for independent creative teaching.

I found that this was not impossible. To start with, colleges and college teachers could be given more authority by transferring the first year and second year examinations for the degree courses from the university to the colleges. This would give teachers the opportunity to examine and grade their own students. Accordingly, the change was instituted with the consent of the Academic Council and the Executive Council.

The response to this move was an eye opener. The transfer of examinations to the colleges was seen as a move to push the work load of the university on to the colleges and the teachers. Inter college rivalries surfaced, as teachers and principals pointed out that every college would jack up marks for its own students in order to establish its lead over the others. The academic value of the move hardly figured in the considerations they placed before me. Fortunately, despite some opposition, it was possible to sustain the change. Over a period of time at least some teachers have come to see its merits. But by and large, the outlook does not seem to have changed.

Similarly, with the consent of the Academic Council, the Executive Council and the help of a small group of faculty members, I moved towards providing Seminar courses at the Master's level and towards restructuring the Foundation Course offered to B.A. students in a manner that would provide for more creative teaching. Both the Seminars and the restructured Foundation Course also aimed at providing students with the opportunity to do assignments with library and field research and to respond and relate to current issues. Actually, I had felt the urgency to do something about providing students and faculty this kind of an opportunity when I realized that students and faculty, even from the departments of Political Science, Sociology or Economics remained unaware of and untouched by issues such as the Narmada Andolan and Enron regardless of the fact that morchas and sit-in in connection with such issues were a daily feature just next door to the university campus at Churchgate.

The reaction to this move was extremely uneven. While several students and some teachers reacted with genuine excitement and appreciation, the general response was one of discomfort with what was essentially a far more unstructured method of organizing instruction than they were used to. Among teachers in particular, there was a pathetic anxiety about how examinations could be adapted to the alternate methods of teaching suggested and how uniformity could be retained between the several colleges. In all fairness it must be conceded that those who were appreciative took full advantage of the new freedom, but they were grossly out numbered by the sceptics.

The changes that were introduced continue. They have stimulated a creative spirit in some teachers and made college exciting for many students. But I am not sure of how significant the long term effects are. Meanwhile, the experiment has clearly revealed that the deterioration that I have been talking about is so extensive and runs so deep that the overwhelming majority of students and teachers expect nothing more than the certificate and examination oriented education that is available. That I believe is the real problem.........

CONCLUSION

I started with the statement that higher education in India is in a state of crisis. I have tried to illustrate this statement with several examples of short comings in the system. Experienced independently of each other, these short comings appear to be so many different problems. But viewed together they fall into place as different facets of the breakdown of a system in deep trouble. Towards the end of the decade of the eighties, the World Bank had commissioned me, and an American colleague of mine, to report on reforms in higher education. We had invited a team of Indian academics and university administrators to think together with us and to examine the outcomes of the several reforms that have been attempted since independence. The findings from our deliberations, published in a volume entitled Reform and Restructuring of Higher Education in India, published by Sage had then revealed that attempts at reform have consistently failed, because solutions were conceived as answers to specific problems whereas what is needed is to understand and to deal with the breakdown of the system. We had pointed out that the ethos of higher education the perspectives and concepts with which students, faculty and administrators function have grown to be warped and distorted with the burden that the system has had to carry since independence. It is increasingly clear that in order to deal with all this, it is necessary to ask bold and searching questions about the statutory character of universities, their relationship with government, their mandate and the functions they are actually called upon to perform. It is necessary to think of alternatives, and to work them out. This involves exercises of pressure on the government, on politicians, on teachers, students and parents. Obviously, this is not a task to be undertaken merely by researchers, educators or administrators. It is certainly not a task for the government, I think we will all agree that it is a task which calls for a concerted and committed effort from those of us who are concerned - and care for higher education in our country.

Narayan Chandra Rana

On August 22, 1996, IUCAA suffered a grievous loss when Narayan Chandra Rana, who was a core faculty member, passed away at the young age of 42. He had been surviving on a pacemaker for over a decade and a half, but in the end such mechanical aids proved inadequate to cope with the vagaries of a progressively weakening and erratic heart.

Perhaps "surviving" is not the right word to describe the dynamic personality of Rana. His small stature and outwardly sedate demeanour hid a highly motivated and restless human being. I discovered this, right from the times when Rana joined me as a Ph.D. student more than sixteen years ago, when we were both at the Tata Institute of Fundamental Research (TIFR), Bombay.

Because of these qualities, the boy from a rustic background in the Midnapur district of West Bengal, became a high achiever at school, had an illustrious career at the Presidency College, Calcutta and came through the stringent selection test for a research scholar at the TIFR with flying colours. Even there, he was the first recipient of the Geeta Udgaonkar Award for the best Ph.D. thesis and later became the INSA Young Scientist Medallist. His research interests covered interstellar grains, primordial nucleosynthesis, and later, the chemical evolution of galaxies and aspects of celestial mechanics.

Characteristically, Rana was non-conformist in his research work also. His critical examination of the standard hot big bang nucleosynthesis had caused considerable controversy back in the early 1980s. There he showed that within the available parameter space it is not possible to fit both the deuterium and helium abundances. After more than a decade, and with the other light nuclear abundances to account for, the problem persists in a greater measure.

His work on chemical evolution of galaxies in the late 1980s was also initiated through his general dissatisfaction with the then existing work in the field. It is a measure of his impact on the field that he was invited to write an article on the subject in the Annual Review of Astronomy and Astrophysics.

In mid-eighties I drew Rana's attention to the famous problem of the precession of the perihelion of Mercury, mentioning that the computing techniques had improved to the extent that a direct calculation of the contribution of other planets to the precession of Mercury's orbit might be possible. Rana acquired Aarseth's N-body code and applied it to the problem and worked out the result which was in agreement with the analytical calculations using perturbation techniques. This work was published in the Monthly Notices of the Royal Astronomical Society. In the years to come Rana kept up his interest in celestial mechanics and was a valuable link between IUCAA and the small community of workers in this field in India.

Rana joined the IUCAA in 1991 and it was here that his many interests began to flower. Put in charge of IUCAA's science popularisation programmes, he took these responsibilities very seriously. His coordination of the National Science Day at IUCAA was very imaginative and would be hard to emulate. He mixed with school children freely and enthused them to participate in the quiz and the various competitions on that day. Likewise, he took up the lion's share of organizing the school students' summer programme and the second-Saturday lecture demonstrations in the Chandrasekhar Auditorium.

He developed rapport with amateur astronomers all over the country and was primarily responsible for catalysing the creation of the Confederation of Indian Amateur Astronomers. His conduct of workshops for making sky-globes, telescopes and even collapsible planetaria drew enthusiastic response. His marathon effort to mobilise an army of amateurs to take part in his experiment of measuring the width of the shadow region at the time of the Total Solar Eclipse of October 24,1995, in order to determine the solar photospheric radius, will be well remembered by the many who participated in the venture or watched it from the sidelines.

But it was as a teacher that Rana excelled in his interaction with the students, in motivating them, in firing their imagination. His bachelor household would always be like a "Gurukul" with visiting or residing disciples. Asked to lecture on a topic, Rana would soon work himself up into the excited state of an ayatollah, far exceeding the allotted time. Inevitably, he would be exhausted afterwards, but this did not stop him from repeating the exercise again and again.

Inevitably also, Rana's strong personality led to conflicts with colleagues and others who were uncomfortable with his exuberant modus operandi. As his heart became weaker, his medical advisers also tried to put brakes on his activities; but to no avail.

Rana will be surely missed at IUCAA but will be fondly remembered for all his contributions. That his impact went well beyond the sphere of IUCAA activities became evident from the fact that we have been inundated by letters from scientists, students, amateur astronomers and laypersons as well as institutions and organizations condoling his untimely demise. On February 28, 1997 (the National Science Day), the National Council for Science and Technology Communications conferred on him its highest award for science popularization. Coming posthumously, this award was a fitting recognition of lifelong dedication to science.

- J.V. Narlikar

THE BOMBAY PUBLIC TRUST ACT, 1950
SCHEDULE IX [VIDE RULE 17(1)]
REGISTRATION NO. F-5366

INTER-UNIVERSITY CENTRE FOR ASTRONOMY AND ASTROPHYSICS
POST BAG NO.4, GANESHKHIND, PUNE 411 007

BALANCE SHEET AS AT MARCH 31, 1997

FUNDS & LIABILITIES	**SCHEDULE NO.**	**AMOUNT (RS.)**
1. Trust Fund / Corpus		1,262,501
2. Grant-In-Aid from UGC	10	241,594,579
3. Other Project Grants	11	13,011,654
4. Popularisation of Science Reserve		500,000
5. Project Liabilities	12	1,309,226
6. Current Liabilities	13	691,263
7. Excess of Income over Expenditure	22	3,475,609
	TOTAL	**261,844,832**
ASSETS & PROPERTIES	**SCHEDULE NO.**	**AMOUNT (RS.)**
1. Fixed Assets	14	227,092,876
2. Investments / Deposits	15	780,000
3. UGC Receivables		21,578,000
4. Project Receivables	16	282,244
5. Current Assets		
a) Stocks	17	653,133
b) Cash & Bank Balances	18	2,554,588
c) Advances Receivables	19	8,371,176
d) Deposits	20	431,978
6. Deferred Revenue	21	100,837
	TOTAL	**261,844,832**

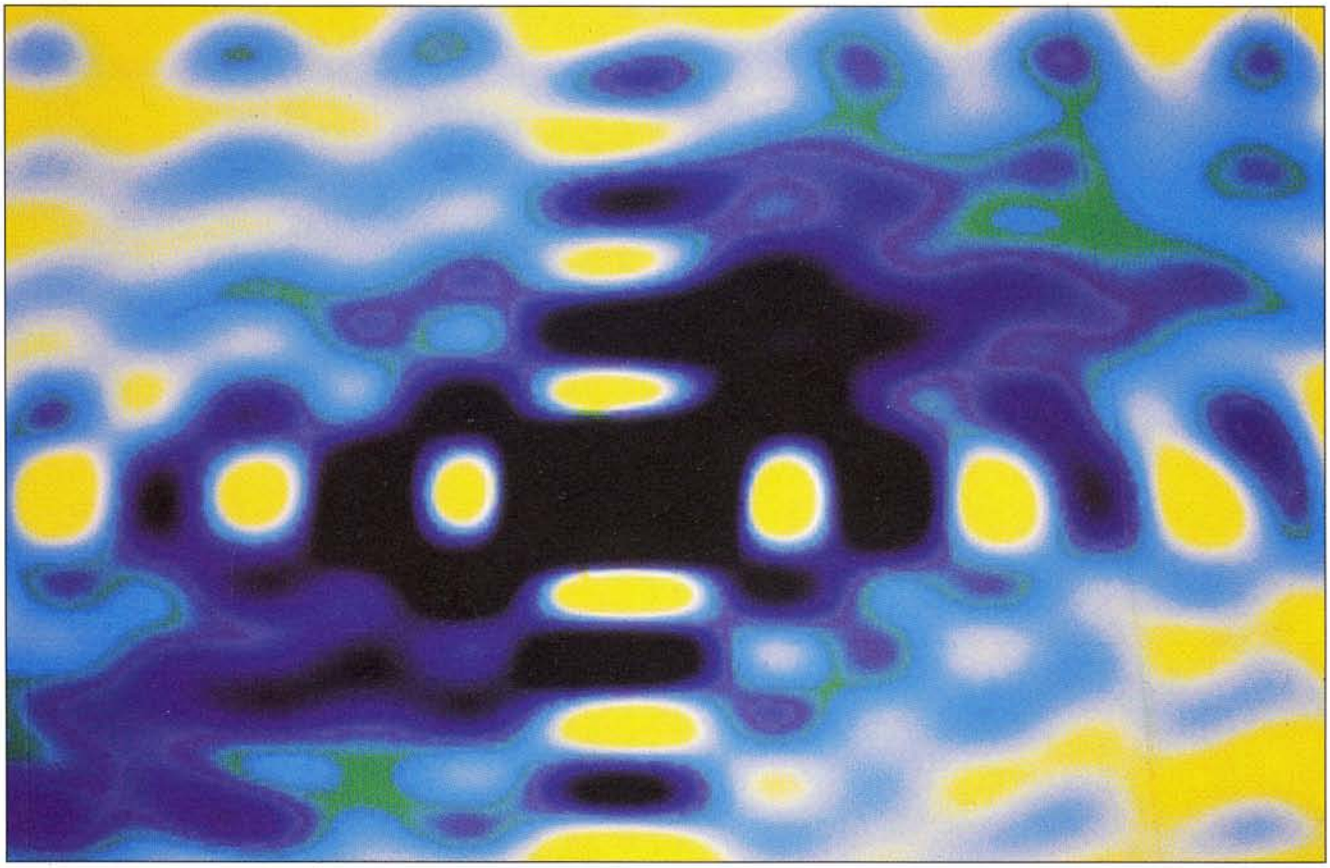
For **Inter-University Centre for Astronomy and Astrophysics**

Sd/-
Prof. J. V. Narlikar
(Director / Trustee)

As per Reports of even date
For **Parasnis Keskar & Co.**

Sd/-
S.B. Parasnis
(Partner)

Place : Pune
Date : 26/06/1997



Galactic Art

An artistic image processing of the picture of a real galaxy
(Ajit Kembhavi and Ashvin Metha)