Annual Report

(April 1, 1995 - March 31, 1996)

of the

INTER-UNIVERSITY CENTRE FOR ASTRONOMY AND ASTROPHYSICS

An Autonomous Institution of the University Grants Commission

IUCAA

Editor

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

Design, Typesetting and Layout

S.N. Khadilkar
e-mail : **snk@iucaa.ernet.in**

Postal Address - Post Bag 4, Ganeshkhind, Pune 411 007, India
Location - Meghnad Saha Road, Pune University Campus, Ganeshkhind, Pune 411 007, India

Phone
(91) (212) 351414

Fax
(91) (212) 350760

e-mail
root@iucaa.ernet.in

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

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Banaras Hindu University

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Mahatma Gandhi University

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N. Panchapakesan
Department of Physics and Astrophysics
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R.K. Thakur
21, College Road,
Choube Colony
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1. S. Chandrasekhar *
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2. R. Hanbury Brown
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3. A. Hewish
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4. Fred Hoyle
   Bournemouth, UK

5. Yash Pal
   New Delhi

6. A.K. Raychaudhuri
   Calcutta

7. A. Salam
   105 A Lonsdale Road
   Oxford OX2 7ET, UK

8. P.C. Vaidya
   Gujarat University, Ahmedabad

* *deceased (21.08.95)*

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M. S. Sahasrabudhe
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D. R. Shinde
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S. R. Tarphe

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B. Bhawal (till 18.12.95)
C. Boily (till 8.12.95)
R. K. Gulati
S. Koshti (till 27.10.95)
S. Lau (till 25.5.95)
B. Nath
D. Ojha (from 13.6.95 to15.3.96)
M. Seriu (till 1.5.95)
S.K. Sethi
S. Sinha
R. Srianand (from 13.7.95)

Research Scholars

J. S. Bagla
R. Balasubramanian
V. Chickarmane
D. Duari (till 17.5.95)
S. Engineer

T. S. Ghosh (till 27.10.95)
K.R. Jotania (till 22.5.95)
K. Harikrishna (from 1.8.95)
A.A. Mahabal
S. D. Mohanty
D. Munshi
A. Nayeri (from 16.1.96)
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K. Srinivasan
L. Sriramkumar
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A. Aherrao (ADC Project) (till 20.4.95)
J. Apte (ADC Project)
A. Bhave (Office Automation) (till 27.11.95)
V. Mahabal (Office Automation)(from 1.8.95 to 31.3.96)
G. Molakala (ERNET Project) (till 1.8.95)
S. Ponrathnam (ADC Project)
S. K. Pradhan (Indo-US Project)

Visiting Scientist

A.N. Petrov (from 11.8.95)

Visiting Students

R. Sachs (till 6.9.95)
R. Somerville (from 22.8.95 to 24.12.95)
S. Sattler (from 1.3.96)

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Visiting Professors

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

C.V. Vishveshwara
Indian Institute of Astrophysics, Bangalore

Senior Associates

S.M. Alladin
Centre of Advanced Study in Astronomy
Osmania University, Hyderabad

R.E. Amritkar
Department of Physics
University of Pune, Pune

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

A. Banerjee
Department of Physics
Jadavpur University, Calcutta

S. Banerji
Department of Physics
University of Burdwan, Burdwan

B. Chakraborty
Department of Mathematics
Jadavpur University, Calcutta

D.P. Datta
Department of Mathematics
NERIST, Arunachal Pradesh

H.L. Duorah
Department of Physics
Gauhati University, Guwahati

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

A.D. Gangal
Department of Physics
University of Pune, Pune

G.K. Johri
Department of Physics
DAV College, Kanpur

P. Khare
Department of Physics
Utkal University, Bhubaneswar

S. Mukherjee
Department of Physics
North Bengal University, Darjeeling

Udit Narain
Astrophysics Research Group
Department of Physics, Meerut College
Meerut

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

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

S.R. Prabhakaran Nayar
Department of Physics
Kerala University, Thiruvananthapuram

A.K. Ray
Department of Physics
Visva Bharathi University, Shantiniketan

K. Sankara Sastry
Centre of Advanced Study in Astronomy
Osmania University, Hyderabad

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

S.G. Tagare
School of Mathematics and C.I.S.
University of Hyderabad, Hyderabad

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

D.B. Vaidya
Department of Physics
Gujarat College, Ahmedabad

S.D. Verma
Department of Physics
Gujarat University, Ahmedabad

...till June 30, 1995

B. Basu
Department of Applied Mathematics
Calcutta University, Calcutta

B. Ishwar
Department of Mathematics
Bihar University, Muzaffarpur

L. Radhakrishna
Department of Mathematics
Shivaji University, Kolhapur

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

from July 1, 1995...

P.K. Bhuyan
Department of Physics
Dibrugarh University

B.K. Datta
Department of Mathematics
Tripura University

A.K. Goyal
Department of Physics and Astrophysics
Hans Raj College, Delhi

V.H. Kulkarni
Department of Physics
University of Bombay

B. Lokanadham
Centre of Advanced Study in Astronomy
Osmania University, Hyderabad

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

S.N. Paul
Serampore Girls' College, Hooghly

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

P. Vivekananda Rao
Centre of Advanced Study in Astronomy
Osmania University, Hyderabad

Associates

K. Boruah
Department of Physics
Gauhati University, Guwahati

S. Chakrabarty
Department of Physics
University of Kalyani, Kalyani

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

S. Chandra
School of Sciences
Indira Gandhi National Open University
New Delhi

R.K. Chhajlani
Department of Physics
Vikram Univerisity, Ujjain

M.K. Das
Department of Physics and Electronics
Sri Venkateswara College, New Delhi

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

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

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

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

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

C. Mukku
School of Mathematics and C.I.S.
University of Hyderabad, Hyderabad

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

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

S.S. Prasad
Department of Physics
University of Gorakhpur, Gorakhpur

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

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

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

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

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

A.C. Balachandra Swamy
Department of Physics and Electronics
Saradavilas College, Mysore

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

...till June 30, 1995

F. Ahmad
Department of Physics
Kashmir University
Srinagar

S.H. Behere
Department of Physics
Dr. B.A. Marathwada University
Aurangabad

K. Indulekha
Department of Physics
Mahatma Gandhi University, Kottayam

Z.H. Khan
Department of Physics
Jamia Millia Islamia,
New Delhi

U.S. Pandey
Department of Physics
Gorakhpur University
Gorakhpur

A. Qaiyum
Department of Physics
Aligarh Muslim University
Aligarh

A. Sharma
Department of Physics
Kurukshetra University, Kurukshetra

from July 1, 1995...

G. Ambika
Department of Physics
Maharaja's College
Kochi

N. Banerjee
Department of Physics
Jadavpur University
Calcutta

S. Chakraborty
Department of Mathematics
Jadavpur University
Calcutta

R.V. Saraykar
Department of Mathematics
Nagpur University
Nagpur

A.K. Sharma
Department of Physics
Shivaji University
Kolhapur

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

S. Sreedhara Rao
Centre of Advanced Study in Astronomy
Osmania University
Hyderabad

G. Yellaiah
Department of Physics
Kakatiya University
Warangal

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(S.N. Tandon)

Head, Post-Doctoral Research
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Head, Guest Observer Programmes
(A.K. Kembhavi)

Head, Science Popularization and Amateur Astronomy
(N.C. Rana)

Director's Report

This is the eighth Annual Report of IUCAA; the first one was for the year 1988-1989, which included the account of the Centre's development from a concept, to its foundation on December 29, 1988, and then to the initiation of infrastructure. The first report covered 16 pages, in contrast to the present one spanning more than six times as many.

As indicated all through this report, IUCAA's march on its many fronts is continuing vigorously and on behalf of the Centre, I wish to thank the University Grants Commission for its enlightened support. In my personal capacity as Director, I am grateful to all my colleagues for their sincere and dedicated help and cooperation.

This year, however, we lost two well-wishers whose passing away we deeply mourn. The sudden death of Professor G. Ram Reddy on July 2, 1995, while in the UK to receive an award, was a severe blow. As Chairman, UGC from 1991 to 1994, Professor Ram Reddy had headed IUCAA's apex bodies and had provided continuous encouragement and guidance to the Centre.

The second loss came with the news on August 21, 1995 that Professor Subrahmanyan Chandrasekhar is no more. As a distinguished astrophysicist and Nobel Laureate, Professor Chandrasekhar had been a source of inspiration to generations of astrophysicists all over the world. But at IUCAA, we specially cherish his association as an Honorary Fellow of the Centre.

On December 28, 1992 when IUCAA's buildings were dedicated to the users by Professor Ram Reddy, the Dedication Lecture was delivered by Professor Chandrasekhar.

At its meeting on January 8, 1996, the Governing Body took the decision to name the IUCAA Auditorium after Professor Chandrasekhar. The naming ceremony took place on February 6, 1996 in an informal function at the hands of another distinguished astrophysicist Professor Sir Hermann Bondi. The occasion was his talk in IUCAA's lecture series for school students. About 500 of them were present at this function.

The monthly lectures to school students (in English, Hindi or Marathi) as well as the Summer Programme for IX-X Std. students are part of IUCAA's activities in science popularization. These and other programmes are described elsewhere in this report. The task of creating and motivating humanpower for astronomy and astrophysics (A & A) should really begin at the school level.

Going to the other end, the various research programmes at IUCAA both by the residents (core faculty, post-doctoral fellows and research scholars) and visitors (associates and others from university departments and colleges) continue to expand. The relevant information appears under specific headings in this Report.

The usage of IUCAA's facilities by the visitors has grown. During 1995-96, 1210 human-days were spent by associates at IUCAA. For 62 associates on the roll, this works out at about 20 days per associate. We feel that there is scope for further increase and urge all the concerned Vice-Chancellors and College Principals to encourage their faculty and students to use its facilities by treating their visits to IUCAA as on duty. After all, an inter-university centre is like a field station to the universities.

Apart from facilities like the instrumentation laboratory, computer centre, astronomical data centre and the library, the users can (and do) also take advantage of the schools and workshops in specialized fields arranged by IUCAA. IUCAA's Academic Calendar is published annually and distributed to all concerned university departments and colleges.

Another major facility approved by the UGC to be set up under the auspices of IUCAA for its users is a 1.5 metre class telescope. This is expected to be fabricated by the Royal Greenwich Observatory, Cambridge, UK, with involvement from the IUCAA scientists. We would also like to involve members from universities and colleges if they come forward as volunteers. Site testing for the telescope is going on. For reasons of logistics, we are concentrating on good sites within 2-3 hours of driving distance from IUCAA. The telescope should take about three years to make and will considerably boost observational astronomy in the universities.

IUCAA's building programme on the campus is now heading towards completion, with the erection of four Type IV staff quarters and five servant quarters. Landscaping continues to be done in stages, the most recent addition being of the rose garden behind the computer centre.

To supplement its grants from the UGC and project funds from other agencies, IUCAA has set up a Corpus Fund. Our intention is to achieve a target of Rs.1 crore (Rs. 10 million). I strongly urge all readers of this report to donate to the IUCAA Corpus Fund and also to find prospective donors! (Donations to IUCAA qualify for 100% deduction under section 80GGA of the Indian Income Tax Act, 1961).

My report will not be complete without a note of appreciation to Dr. Ramesh Mashelkar, Director General, CSIR, for his excellent Foundation Day Lecture on December 29, 1995, that greatly enthused the packed lecture theatre. The text of the lecture is found in this report.

J.V. Narlikar

Awards and Distinctions

S.V. Dhurandhar

- Data analysis consultant for the Australian gravitational wave detection project - AIGO.

S. Koshti

- Associate of the Indian Academy of Sciences.

J.V. Narlikar

- BBV Foundation (Spain) Distinguished Lecturer at the Instituto D'Astrofisica D Canerias, Spain, May 1995.

T. Padmanabhan

- Member of the Advisory Board for History of Science (Modern Period), of the Indian National Science Academy, New Delhi, for the period 1996-1998.

- Fellow of the Maharashtra Academy of Sciences.

Calendar of Events

April 9 - 21	Sino-Indian School on Astronomy, at Nanjing, China
April 17 - May 26	School Students' Summer Programme, at IUCAA
May 2 - 5	Workshop on Effective Way of Teaching Science for Pune school teachers, at IUCAA
May 8 - 26	Refresher Course in Astronomy and Astrophysics for college and university teachers, at IUCAA
June 5 - July 14	Vacation Students' Programme, at IUCAA
August 21	IUCAA-NCRA Graduate School : First Semester begins
September 18 -22	Workshop on Space Dynamics and Celestial Mechanics, at B.R.A. Bihar University, Muzaffarpur
September 25 - 28	Pre Total Solar Eclipse - Training Programme, at IUCAA
Novmeber 23 - December 7	Indo-US Wokshop on Elliptical Galaxies : Structure and Dynamics, at IUCAA
December 9 - 12	Workshop on Gravitational Waves, at IUCAA
December 13 - 19	International Conference on Gravitation and Cosmology (ICGC-95), at IUCAA
December 20-23	Miniworkshop on Gravitational Collapse and Cosmic Censorship, at IUCAA
December 25	Annual Cricket Match between IUCAA and NCRA
December 29	IUCAA-NCRA Graduate School : First Semester ends
December 29	Seventh IUCAA Foundation Day
January 9 - 12	Workshop on Active Galactic Nuclei, Dense Stellar System and Galactic Environments, at IUCAA
January 15	IUCAA-NCRA Graduate School : Second Semester begins
February 1 - 3	Workshop on Nuclear Astrophysics, at Kalyani University, Kalyani
February 6	IUCAA Auditorium named after Subrahmanyan Chandrasekhar
February 26 - March 1	Workshop on Instrumentation for Small Telescopes and Astronomy Programmes at University Level, at Bhavnagar University, Bhavnagar
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 Gravity and Cosmology

Is minisuperspace quantization valid?:

Quantum Cosmology is based on the hypothesis that quantum mechanical principles can be applied to the universe as a whole. In this framework, the focus is on a "wave function for the universe" which obeys an equation called the Wheeler-DeWitt equation. Loosely speaking, this equation is analogous to the Schrodinger equation in quantum mechanics but is mathematically untractable in its general form. While the standard Schrodinger equation depends on finite number of independent variables, the Wheeler-DeWitt equation depends on infinite number of independent variables. To make any progress, one often ignores all but a finite set of these variables, thereby reducing the Wheeler-DeWitt equation into a tractable form. This procedure is called *minisuperspace quantization*, which refers to the technique of quantizing only a restricted set (in most cases finite) of degrees of freedom of the gravitational field. For example, a quantized description of a Friedmann universe is obtained by only quantizing the scale factor.

However, since this procedure involves the truncation of infinite number of degrees of freedom of the gravitational field it can at best be an approximation. It is not clear whether the degrees of freedom which are ignored, will remain frozen at the given values when the system evolves according to the laws of quantum mechanics. Thus, before taking the predictions of quantum cosmology (based on minisuperspace approximation) seriously, it is crucial to assess the regime of validity of this approximation.

M. Rosenbaum , M.P. Ryan and *S. Sinha* studied this question in an earlier work using the model of a $\lambda\phi^4$ field theory on manifold with topology $R \times S$. In that work, they had given a set of criteria for the validity of the minisuperspace approximation. This analysis was, however, restricted to short time scales. Recently, by refining their perturbation technique they have come up with an improved set of criteria valid over all time scales. This will hopefully serve as a model framework to address the question of whether quantum minisuperspaces give us any useful information about quantum gravity.

Classical limit of primordial quantum fluctuations:

It is generally believed that inflation provides a mechanism for transforming tiny primordial quantum fluctuations of the quantum field driving the inflation, into classical density perturbations. These classical perturbations are amplified by the gravitational instability and eventually could provide the seeds for galaxy formation at a later epoch. In the stochastic inflation scenario, originally proposed by Starobinsky, it is suggested that the modes of the quantum field with wavelength larger than the characteristic curvature scale of the universe will behave classically. The evolution, of course, will be affected by the modes with shorter wavelength in a statistical sense. Mathematically, one can describe the evolution of the long wave modes by a classical Langevin equation driven by a "noise" term arising from the short wavelength modes.

While this procedure allows us to set up the necessary equations to study the evolution of the perturbations, it does not clarify the "mechanism" behind the transition from the quantum to the classical domain. A natural and plausible mechanism for the quantum field to become effectively classical is through a process called decoherence. In this formalism, originally developed (independently) by J. Halliwell and *T. Padmanabhan*, one studies the relevant quantum field not in isolation but as a system interacting with an "environment". This interaction can often suppress the quantum interference effects and lead to an effectively classical behaviour.

Within the context of stochastic inflation, it seems natural to treat the long wavelength modes as the "system" and the short wavelength modes as "environment". Given any interacting field theory, one will be able to determine the nature of the coupling between these two and set up a formalism to study the evolution of the system. *S. Sinha* has started an investigation of this issue using quantum master equation techniques for an interacting scalar field theory, where the short wavelength sector of the field acts as an environment coupled to the long-wavelength sector. Preliminary results indicate that, in the generic case, the noise contribution from the short wavelength modes will be coloured rather than white.

Fluctuations in black hole radiation:

Extensive work on black holes, culminating in Hawking's remarkable discovery of their quantum radiance, has shown that black holes obey a generalized version of the laws of equilibrium thermodynamics. It is, therefore, tempting to ask: Do they also conform to the principles of non-equilibrium thermodynamics and statistical mechanics when they are perturbed from their equilibrium state?

For example, most thermodynamic systems obey some form of relation between the relaxation processes (which try to drive the system towards equilibrium) and the fluctuations around the equlibrium. In general, such relations are called "fluctuation-dissipation" theorems. One could, therefore, ask whether black holes coupled to quantum fields obey a fluctuation-dissipation theorem. If so, one can try to understand black hole evaporation as a noisy process incorporating the effect of fluctuations.

In their attempt to answer such questions, B.L. Hu, A. Raval and *S. Sinha* are continuing their efforts to probe stochastic effects in black holes coupled to quantum fields. Applying the recently developed adaptation of the Influence Functional technique to semiclassical gravity, they have shown that a fluctuation-dissipation relation can be obtained for the case of a scalar field in the black hole spacetime. They have also obtained the auto-correlation function for these fluctuations. Further implications for the backreaction problem are under investigation.

Thermal ambience and fluctuations in classical field theory:

One of the surprising results, in the subject of quantum field theory in curved spacetime, is that particle concept is not generally covariant. For example, the vacuum state of the standard quantum theory in flat spacetime will appear to be a thermal state for any observer who is uniformly accelerated with respect to an inertial frame. It should be stressed that the vacuum state appears as a thermal state to the accelerated observer in a rigorous sense of that term: not only that the mean occupation number is Planckian but even the fluctuations are that of a system in thermal equilibrium. It is generally believed that this result is purely quantum mechanical and arises due to the existence of quantum fluctuations in the vacuum state.

Recently, *K. Srinivasan, L. Sriramkumar* and *T. Padmanabhan* have shown that this phenomenon has an interesting classical analogue. They address the question: how will an accelerated observer view a classical plane wave front? It turns out that such a monochromatic wave will not appear monochromatic to the accelerated observer since the redshift will be time dependent. The power spectrum of the plane wave in the accelerated frame has an interesting form: it exhibits three different terms. The first term is analogous to the quantum zero point energy and the second term is a Planck spectrum parametrised by the acceleration. The third term represents the fluctuations around the thermal state given by $\sqrt{N(N+1)}$ where N is the mean occupancy of the quantum state. The entire result is classical and $\hbar$ does not appear anywhere.

The fact that a plane wave exhibits these properties, especially the fluctuations and the zero point term shows that some of the "purely" quantum mechanical features have interesting classical counterparts - to say the least. *K. Srinivasan, L. Sriramkumar* and *T. Padmanabhan* have extended these results to several other situations like black hole spacetime, de Sitter spacetime, etc. and are in the process of studying the wider implications of the result.

Validity of the tunnelling interpretation for particle production:

One of the nonperturbative results in quantum electrodynamics is related to pair production by a constant electromagnetic field. Schwinger showed that while a constant electric field will produce pairs of charged particles from the vacuum, a constant magnetic field will not. This result was often interpreted as due to the tunnelling of virtual particles through a potential barrier leading to the formation of real particles. The energy for this process has to come from the work done by the external field. Since, electric fields can do work and magnetic fields cannot, it is natural that only the former can lead to pair production. When it was realised in the late seventies, that black hole spacetimes can produce particles, similar tunnelling interpretation was attempted to provide an intuitive understanding of this phenomenon.

In a recent work, *L. Sriramkumar* and *T. Padmanabhan* have closely scrutinised the validity of the tunnelling interpretation which is invoked to explain the phenomenon of particle production in *time independent* external electromagnetic backgrounds. They first show - based on general principles - that a time independent magnetic field, confined to a finite region of space, cannot produce particles. This result, of course, agrees with the conventional wisdom in this subject. But, they find that such a field will, in general, possess a non-zero tunnelling amplitude when described by the conventional approach. According to the tunnelling interpretation, this result would imply that a spatially confined, time independent magnetic field can produce particles. This lack of consistency between these two results calls into question the validity of the tunnelling approach to explain particle production in time independent classical backgrounds. *L. Sriramkumar* and *T. Padmanabhan* believe that this result has important lessons for the study of particle production in gravitation fields.

Classical Gravity

Inhomogeneous cosmology:

The standard paradigm for the universe is based on homogeneous and isotropic Friedmann model. It is, however, important to study models which do not fall in this category. For example, consideration of inhomogeneity is pertinent while discussing generic character of initial conditions, and possibly in the accommodation of the observed large scale structures in the universe. To do this, one needs to seek solutions of the Einstein's equations containing, say, an inhomogeneous and expanding fluid model. This exercise yielded an unexpected and amazing result that there could exist an exact solution of the Einstein's equations without the big-bang singularity and without violating the energy and causality conditions. This solution, discovered by Senovilla, shook the general belief based on the singularity theorems, which are often interpreted as saying that Einstein's theory predicts the big-bang singularity whenever the source satisfies certain physically reasonable conditions. The solution in question brought forth clearly the severe limitations of one of the assumptions used in the proof of the theorems, namely the existence of trapped surfaces from which even photons cannot come out. The violation of this assumption allows non-singular, perfect fluid models without any unphysical behaviour of the fluid.

This non-singular family had models which were cylindrically symmetric, inhomogeneous and anisotropic ("shearing" as well as "accelerating"). It will be interesting to see which of these features are essential for avoiding the singularity. From very general considerations, it can be shown that the collapse is countered by rotation and acceleration of the fluid; so, to avoid the singularity, at least one of them must be non-zero. In the cosmological models, the rotation is zero and hence the acceleration - caused by inhomogeneity - must be present to avoid the singularity. On the other hand, shear - caused by anisotropy - helps the collapse; so it would have been nice if one could avoid the shear term. But it turns out that in a general class of spacetimes (specifically, in spacetimes admitting two hypersurface orthogonal spacelike Killing vectors and separable in space and time variables in coordinates specified by fluid flow lines) acceleration is always generated through shear. Hence, to have non-zero acceleration, one must have shear. Note that this result is true in general without reference to the field equation. Thus, non-singular models must necessarily be both inhomogeneous and anisotropic.

N.K. Dadhich and L.K. Patel have generalised this result by dropping the assumption of separability and demanding the spacetime to admit perfect fluid. That is, they show that a spacetime admitting two hypersurface orthogonal spacelike Killing vectors and representing expanding perfect fluid can have non-zero acceleration only if shear is non-zero. Intuitively, it perhaps shows that shear - arising from the slipping of fluid flow lines - mediates the "bounce". Shear, thus, plays a very important role in the avoidance of the big-bang singularity. It is quite tempting to say that shear (anisotropy) like acceleration (inhomogeneity) is a characteristic feature of non-singular models. It is, however, very hard to prove this in general.

Isothermal universe:

W. Saslaw, S. Maharaj and *N.K. Dadhich* have recently considered a cosmological scenario, which evolves through three distinct phases: in the first phase, one has the Einstein-deSitter expansion which asymptotically tends to stationarity; then arises the condensing phase that leads to development of cosmologically significant pressure, and finally the universe is described by an isothermal fluid sphere, with pressure proportional to density and falling as inverse square of the radius. Such an isothermal cosmological model can be described by a remarkably simple metric. It can be argued that the isothermal universe will be a stable system and it is likely to represent a good approximation to the ultimate distribution of galaxies in an Einstein-deSitter universe.

Apart from the intrinsic interest in such an investigation it may have an application albeit speculative and intriguing, to construct a self-consistent model of the end state of gravitational clustering in an Einstein-deSitter universe. If our actual universe were to evolve into this isothermal state, this would be the ultimate astrophysical prediction.

On generalised vacuum:

The gravitational field of a point particle can be described by a single function of space in both Newtonian and Einstein's theory. This function ("potential") satisfies, however, different set of equations in these theories. As a result, it is permissible to add a constant term to this potential in Newtonian theory, while it is not permissible to do so in Einstein's theory. *N.K. Dadhich*, who has investigated this scenario, had found earlier that Einstein's equations do not allow the use of boundary conditions to specify the asymptotic value of the potential and hence its constant value acquires a physical meaning. More recently, he has been investigating the implications of this result.

N.K. Dadhich argues that one is not quite happy - on formal grounds - with the asymptotic flatness of solutions of the Einstein vacuum equations; this is because such solutions do not, in principle, allow existence of energy distribution elsewhere in the universe. A more realistic scenario should have an empty cavity sitting in a non-empty rest of the universe (ROU). This view could be taken as the essence of Mach's principle. It is clear that non-vacuous ROU can be accommodated only at the cost of asymptotic flatness. Now, the pertinent question is: is it possible to drop asymptotic flatness without disturbing the basic character of the field? It turns out that this is indeed possible. The solution will now have the arbitrary additive constant (which will be fixed by prescribing its value at the boundary of the cavity), which will give rise to a non-zero source term as it can no longer have all Ricci components zero. It is clear that the stresses cannot refer to any active gravitational charge, because a constant potential refers to zero gravitational charge. The only way they could contribute is in "curving" the space.

In a more general context, this prescription corresponds to a source that is called a "geometric string" or "string-dust". Such a source does not add any gravitational charge to the system. Considering this generalised equation for the situation under consideration, we do get exactly what we have asked for. *N.K. Dadhich* and L.K. Patel have shown that a similar generalisation is possible for the Kerr geometry as well.

Gravitational Waves

The detection of gravitational waves from astrophysical sources is probably one of the most keenly awaited events in the history of astrophysics. There are a number of experiments around the globe to detect gravitational radiation. Although the decay of the orbit of the binary pulsar PSR 1913 + 16 (leading to the 1993 Nobel Prize to Hulse and Taylor) is correctly predicted - to an experimental accuracy of better than one percent - by the theory of general relativity, the efforts are driven by the desire to see 'gravitational waves in flesh' and use this new probe to explore the universe. Since the nature of the gravitational waves differs enormously from that of electromagnetic waves, the information carried by gravitational waves will be almost 'orthogonal' to that obtained via the electromagnetic spectrum. The opening of this radically new window to the universe may bring us great surprises. Our experience of the past shows that when a new window was opened, for example, the radio, a plethora of new discoveries followed. Pulsars, quasars, the cosmic microwave background, etc. are some of the phenomena. Therefore, we may be prepared for the unexpected.

Several projects for constructing laser interferometric gravitational wave detectors, namely, the LIGO, VIRGO, GEO, TAMA, etc. are either underway or beginning. In this world wide effort, India is collaborating with Australia (the AIGO project). IUCAA is responsible for the theoretical aspects of the experiment. 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, and coincident observation by a network of detctors;

(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 French under the IFCPAR programme.

i (a) Coalescing binaries:

The paucity of gravitational wave sources and the relative difficulty in detecting such waves, as compared to those in the electromagnetic domain, necessitate the development of optimal data analysis techniques to detect the signal, as well as to extract the maximum possible information from the detected signals. Coalescing binary systems are one of the most promising sources of gravitational waves. This is due to the fact that such sources are easier to model and thus one can design detection strategies particularly tuned to such signals. A lot of attention has been devoted in the literature to 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. *R. Balasubramanian, B. S. Sathyaprakash* and *S.V. Dhurandhar* have used such techniques within a differential geometric approach to provide a geometric insight into the problem. Such a formalism allows one to explore the merits and demerits of a detection scheme independent of the parameters chosen to represent the waveform. The formalism also generalises the problem of choosing an optimal set of templates to detect a known waveform buried in noisy data. They stress the need for finding a set of *convenient* parameters for the waveform and show that even after the inclusion of the second-order post-Newtonian corrections, the waveform can essentially be detected by employing a one-dimensional lattice of templates. This would be very useful both for the purpose of carrying out the simulations as well as for the actual detection process. After setting up such a formalism, Monte Carlo simulations are performed of the detection process for the initial LIGO/VIRGO configuration for the first post-Newtonian corrected coalescing binary waveform. These are compared with the results of the simulations with the currently available estimates of the accuracies in the determination of the parameters and the probability distribution of the maximum likelihood estimators. These results bear out a very important fact, namely, that *the covariance matrix underestimates the actual errors by a large margin* in this situation. The actual errors, as obtained through Monte Carlo simulations, are by a factor of two or so greater in the estimation of parameters even when the signal-to-noise ratio is as high as 10. As only a tiny fraction of the events is expected to be detected with a signal-to-noise ratio higher than this value, the covariance matrix is grossly inadequate to describe the errors in the measurement of the parameters of the waveform. It is also found that the deviations from the covariance matrix are more in the case of the first post-Newtonian waveform than in the case of the Newtonian one. Inclusion of higher-order post-Newtonian corrections introduces new parameters that are correlated with those at the lower post-Newtonian waveform. Such correlations are expected to further increase the discrepancy of the covariance matrix results with those inferred from Monte Carlo simulations. Consequently, numerical simulations that take into account post-Newtonian corrections beyond the first post-Newtonian order are needed in order to get a clearer picture about the accuracy in the determination of parameters.

Since the covariance matrix grossly underestimates the errors, a better analytical bound should be sought for. It is so far not clear what is the reason for this discrepancy. An in-depth investigation is required to understand the issue. It is conjectured that the secondary peaks in the ambiguity function are responsible for this behaviour. *S.V. Dhurandhar*, A. Krolak and *S.D. Mohanty* have begun such an investigation. This forms the basis for the Indo-Polish project, which has been submitted to the relevant agency in late 1995.

The need for online gravitational data analysis is spurring researchers to look for faster and more efficient algorithms which produce results quickly with high accuracy. In 1991, *B.S. Sathyaprakash* and *S.V. Dhurandhar* had presented a procedure for detecting coalescing binaries with matched filtering techniques (S-D formalism). This method used a one step search, in that the statistic was compared with a single threshold with very closely spaced filters in the parameter space. Since the event rate for the sources is expected to be low, the threshold is set high to avoid the false announcing of detections which are spurious manifestations of noise alone. However, this method although performing a rigorous search uses lot of computational effort. A hierarchical search, therefore, could be useful in saving computations. *S.D. Mohanty* and *S.V. Dhurandhar* have proposed a rigorous formalism for a *two step* search where the data is searched in two stages. In the first level, a coarse set of templates is used along with a low threshold. In the next level a more finely spaced set of templates is used along with a higher threshold. However, at this level only those templates would be searched which lie in the neighbourhood of the crossings produced in the first stage. The problem however, is involved because there are opposing criteria which decide the optimal strategy. The optimisation has been performed with respect to signal strengths, etc. and it shows that the coarse spacing for the Newtonian template is about ten times larger than the second stage spacing. The computational effort saved is by a factor of about ten.

i (b) Pulsars:

The all-sky, all-frequency search for pulsars has been shown to be computationally a formidable problem. The Earth's motion around itself and the Sun as well as the Moon's motion modulate the signal from a pulsar and introduces incommensurate Doppler shifts corresponding to each direction in the sky. The number of such directions for sensible choice of parameters turns out to be $\sim 10^{13}$ and the number of operations $\sim 10^{23}$ to analyse the data, which is a formidable requirement even for today's high speed computers.

However, it may be possible to get around some of these difficulties by adopting a different approach. D.C. Srivastava, S.S. Prasad, S.R. Valluri and *S.V. Dhurandhar* have opted for a novel approach for estimating the number of degrees of freedom in the function space of signals. The preliminary results, taking into account only the rotational motion of the earth, are encouraging. It also turns out that the precession of the pulsar is a very important aspect in the waveform of the pulsar signal. The precession is the result of the unequal principal moments of inertia of the pulsar and the rotation of the pulsar, in general, can follow very intricate patterns likewise affecting the waveform. A detailed calculation is necessary to cover all possibilities and work on this aspect is being carried out by the same team. The general effect of the precession will be to expand the function space of signals.

i (c) Coincident observation by a network of detectors:

In the next few years, altogether five interferometric gravitational wave detectors are planned at five different locations (2 LIGOs, VIRGO, GEO, AIGO). These will have different sensitivities arising mainly due to different armlengths. Coincident observation by such a network will help in eliminating rare and unmodelled noise sources.

B. Bhawal and *S.V. Dhurandhar* have investigated the problem of setting a threshold for observations against a background of Gaussian noise, when one allows for the time delay windows within which coincidences will be accepted. However, the problem needs to be tackled by the general method of maximum likelihood taking into account all the detectors. *S.D. Mohanty* and *B. Bhawal* are currently studying this problem. One important aspect of the investigation will be the analysis of errors in the estimation of parameters of the signal. These errors will have to be obtained by improved methods than those of the covariance matrix. An accurate determination of errors is important, for example, in determining the direction to the source in the sky which is computed from the times-of-arrival of the signal at each detector of the network. Since the errors in the measured arrival times determine the error in the direction to the source, this issue is of paramount importance.

(ii) Modelling the interferometer:

S.V. Dhurandhar and *B.S. Sathyaprakash*, in collaboration with J.Y. Vinet and P. Hello, have been funded by the Indo-French Centre for the Promotion of Advanced Research (IFCPAR) to model interferometric gravitational wave detectors, that employ very high laser power in their giant cavities. The scope of the present project is to carry out theoretical investigations regarding onset of instabilities arising from the nonlinear coupling of the mirror deformation/displacement with the intracavity power in high power laser cavities. When high power lasers are employed in interferometric cavities that contain mirrors that are freely suspended, one can envisage the following physical effects to be important:

(a) radiation pressure on the freely hanging mirrors which can effectively change the length of the cavity detuning it in the process;

(b) deformations in the mirrors caused by absorption of the intra-cavity light field and the input light field;

(c) generation of photon modes in the substrate of the material of the mirror and consequent efficient absorption of the light field;

(d) thermal lensing introduced in the substrate of the mirror, etc.

This is a coupled nonlinear problem and a two pronged attack has to be launched which consists of analytical and numerical tools.

To this end, an optical code that can accurately determine the intra-cavity light field in the presence of deformations in the surface of the mirrors, nonideal modes of the beam, etc., has been developed. It includes two algorithms:

(1) an algorithm capable of determining the transient temperature field in the laser cavity, in particular on the mirror surfaces, given the input laser power, and

(2) an algorithm to compute the transient deformations of the mirrors and possibly other components, given the transient temperature field.

The code can be used to iteratively study the quality of the intra-cavity light field, and to study the onset of instability in the intra-cavity light power when either the input laser power is high or the finesse of the cavity is large or both. An optical code capable of computing the intra-cavity light field when subject to small perturbations has already been developed.

Before venturing upon the other problems, the problem of the effect of a fluctuating light beam incident on the mirrors has been considered. In this case one can envisage two different kinds of mirror deformations: small scale deformations that occur locally and may disappear in course of time and large scale deformations that tend to expand the mirror surfaces globally and that remain forever. The latter effects are easy to model, given the thermal properties of the material of the substrate of the mirrors and of the mirror coating. What could be potentially a source of major problem is the transient, local deformation. The smallest physical size of such fluctuations to be considered will clearly depend on the time scale in the problem. The relevant scales in the problem have been estimated by assuming that the input laser power fluctuates at a certain fiducial frequency.

Analytical solutions of the heat equation were obtained and it was shown that the boundary conditions are unimportant when the frequency of fluctations is greater than 1 Hz. This simplifies the problem considerably since imposing the boundary conditions at the rim of the mirror is very awkward. Then the time dependent solution of the elastic equations was obtained within the mirror. This described the deformation as a function of time. Then the deformation was coupled to the optical field in the cavity by the usual Fabry-Perot curve and the problem was thus solved self-consistently. This model does not exhibit any instability.

Following the above work, *V. Chickarmane, S.V. Dhurandhar* and J-Y. Vinet are incorporating the effects of radiation pressure into the problem. As a first step in this direction, the transfer function connecting the differential change in length of the cavity to the intra-cavity power was obtained taking into account the time dependence explicitly. Conversely, the effect of the change in power was found on the displacement of the mirror when the mirror is freely hung as a pendulum. The solution to this problem is then sought in a self-consistent manner. Work is in progress for combining the thermal deformation with the radiation pressure and also the effect of the servo-control system. The final solution to the problem is expected to be useful in the design of laser interferometric gravitational wave detectors of the future.

Squeezing the noise:

Squeezed states of light may be used to reduce the photon shot noise in the laser interferometric gravitational wave detector. The photon shot noise at low input laser power far exceeds the noise due to motion of mirrors by radiation pressure fluctuations. By appropriately squeezing the vacuum field at the output port, it is possible to reduce the photon counting noise, thus increasing the sensitivity of the detector. Another technique to increase the sensitivity is to increase the effective laser power by recycling the light coming out of the laser port. *V. Chickarmane* and *S.V. Dhurandhar* have investigated Fabry-Perot cavities and taken into account the effect of losses. This aspect is extremely crucial to the analysis, since the losses affect the results in a salient way. They have also proposed an apparatus for injecting squeezed light into the cavities.

The other important techniques employed

in the laser interferometer are those of internal and external phase modulation. Analysis needs to be performed when the squeezed light is injected into a phase modulated interferometer. *V. Chickarmane* will be working with D. McClelland of the Australian National University, Canberra, Australia, on this aspect as a part of the Indo-Australian collaboration.

Cosmology and Structure Formation

Constraints on big bang cosmology :

From the early days of cosmology when the subject was looked upon more as a speculative exercise than science, things have changed, thanks to the improvement of observing techniques in extragalactic astronomy. One striking example is the performance of the Hubble Space Telescope (HST) in determining the extragalactic distance scale.

The HST observations have favoured an expansion rate for the universe on the larger side. Correspondingly, the cosmological time scales of expansion have got reduced. This has reopened the so-called 'age problem' for standard big bang models. The most popular models (big bang with $\Omega = 1$) predict an age in the range of 8-10 billion years. Compared to ages of stars in globular clusters (12-18 billion years) or nuclear radioactive age determination of our Galaxy (12-20 billion years), this age is too small. To what extent is this a significant constraint?

J.S. Bagla, T. Padmanabhan and *J.V. Narlikar* have examined this question along with other observational results. They have taken into account the cosmic abundance of deuterium, the cluster abundances, the abundance of high redshift objects and gravitational lensing. They find that models without cosmological constant are untenable and that, even models with the cosmological constant are severely constrained. In fact, very little parameter space is left for the standard models if all the constraints are taken seriously.

The quasi-steady state cosmology :

In the light of the above situation, it is worthwhile to explore alternatives to the big bang cosmology. F. Hoyle, G. Burbidge and *J.V. Narlikar* are continuing their work on the quasi-steady state cosmology (QSSC).

R. Sachs, J.V. Narlikar and F. Hoyle have formulated and solved the analytic equations of QSSC to arrive at an exact solution. This solution differs only marginally from the earlier - approximate - solution used by F. Hoyle, G. Burbidge and *J.V. Narlikar* for interpreting the observations. These authors have now used the exact solution to study the redshift-magnitude relation and the counting of radio sources.

In a parallel effort, N.C. Wickramasinghe, *J.V. Narlikar, R. Sachs* and F. Hoyle studied the astrophysical issues relating to the origin, distribution and absorptive effects of slender iron whiskers. They showed that such whiskers naturally condense when iron made in stellar cores is ejected in gaseous form by supernovae. Depending on their length, these whiskers interact with and absorb radiation, being largely effective in the millimetre region. These authors show possible observational evidence for their existence in our galaxy, in intra-cluster medium and in the broad cosmological context. This, therefore, provides a natural rationale for the explanation of the thermalization of the microwave background in the QSSC.

Understanding the nonlinear gravitational clustering:

How did structures like galaxies, clusters, etc. form? It is generally believed that they grew out of primordial fluctuations in the density field due to gravitational instability. A region with slight overdensity (compared to the mean density of the universe) will attract more matter towards it and thereby become more overdense. When the overdensities are small, the growth of structure can be studied using several approximation techniques. But when the structures become nonlinear, the usual procedure is to study them using numerical simulations.

While these simulations are powerful tools in obtaining the consequences of specific models, they cannot - by themselves - provide direct insight into the physical processes which are responsible for the structure formation. It is important that one tries to understand the results of these simulations in terms of the basic physical processes using semi-analytical models.

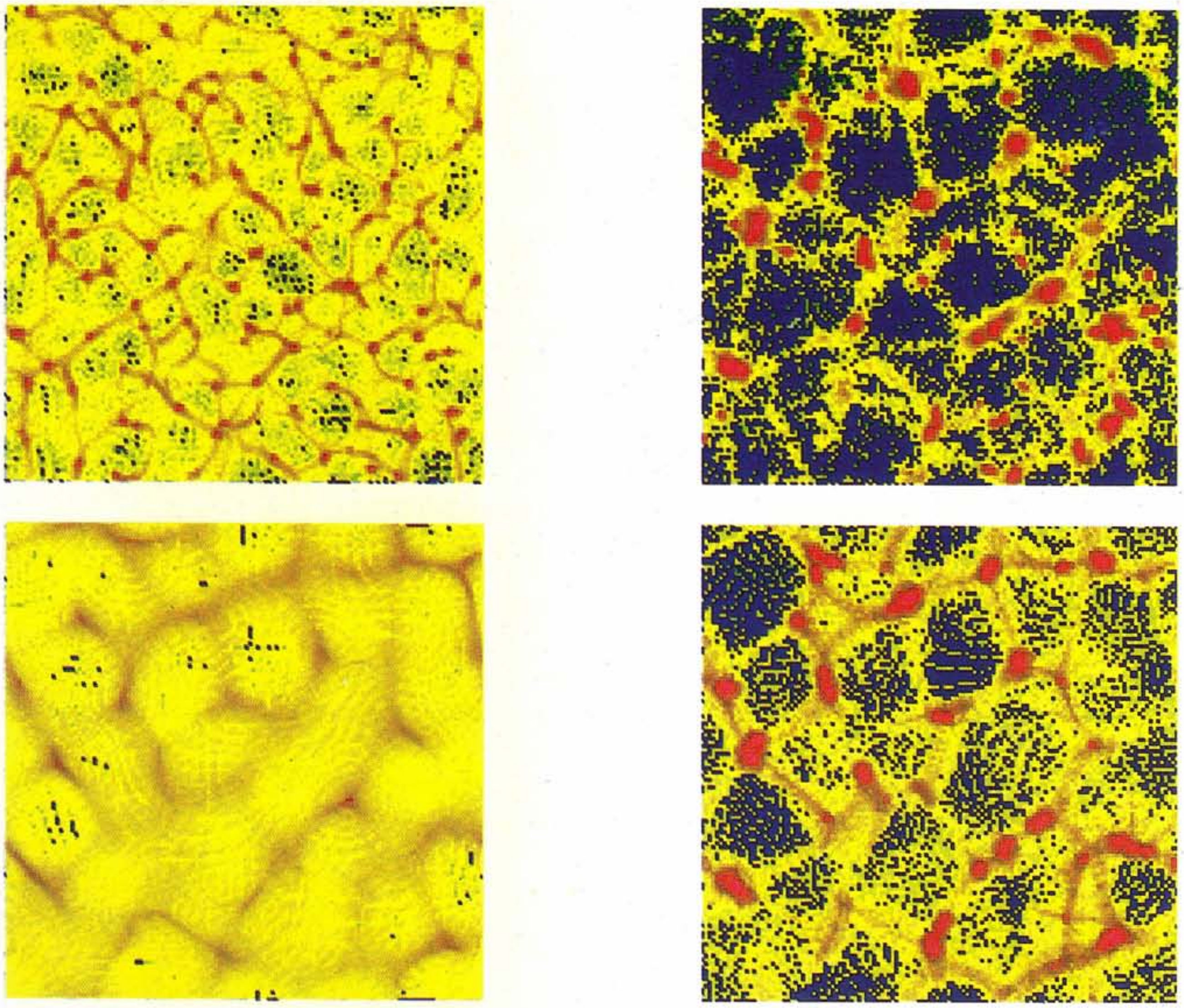
T. Padmanabhan has now succeeded in developing a paradigm which allows such an understanding of the results of numerical simulations for a wide class of models. The key ingredient in this paradigm is an exact equation which relates the two-point correlation function of the mass distribution to the relative velocity of pairs of particles. By studying the characteristics and the scaling behaviour of this partial differential equation, *T. Padmanabhan* could establish a pattern in the flow of power from large scales to small scales in gravitational clustering. Combining this with the behaviour of an isolated spherical overdense region in the universe, it is possible to come up with a simple, semi-analytic model for describing nonlinear clustering in expanding universe. *T. Padmanabhan* has shown that it is indeed possible to understand the nonlinear clustering in terms of three well defined regimes: *(1)* linear regime, *(2)* quasilinear regime, which is dominated by scale-invariant radial infall, and *(3)* nonlinear regime dominated by nonradial motions and mergers. Modelling each of these regimes separately, he could relate the nonlinear two point correlation function to the linear correlation function in hierarchical models. This analysis leads to results which are in good agreement with numerical simulations thereby providing an explanation for numerical results. The ideas presented here will also serve as a powerful analytical tool to investigate nonlinear clustering in different models.

The above analysis reveals an almost universal pattern for a large class of models known as hierarchical models. Hierarchical models have fluctuations at all scales and the local index of the power spectrum varies slowly with scale. To understand the gravitational dynamics in its full glory, one should see how well these ideas work in other models. The other extreme case will correspond to a situation in which all the initial power is confined to a narrow band of length scales. The coupling between the modes will generate power at other scales as the evolution proceeds and one would like to know whether the paradigm developed above works in this case.

J.S. Bagla and *T. Padmanabhan* are carrying out a study of such a class of models, to understand the evolution of power spectrum. In this study, they run the N-body simulations to follow the evolution of a power spectrum which was initially a Gaussian peaked at some scale. A key result of these studies is the equipartition of kinetic energy among various scales in the quasilinear phase. This leads to a power spectrum with slope $n = -1$, starting from the peak of the Gaussian towards larger wavemodes, or smaller length scales. What is more, this result remains true even when there exists smaller scale power with higher amplitude. (This result was tested by introducing small scale power as another Gaussian with a larger amplitude peaked at smaller scale. One expects the small scale peak to generate small nonlinear structures with high binding energy that may resist disruption during the collapse of long wave modes.) In fact, the amplitude and the slope of the net power at small scales *do not depend on presence of small scale power in the initial conditions*. Absence of influence of small scale nonlinear structures on the evolution of power spectrum indicates that we may study evolution of arbitrary power spectra by considering them to be a superposition of suitable combination of modes that evolve independently. Work is in progress to identify these nonlinear units of structure formation.

Lagrangian and Eulerian approximations to gravitational clustering:

Foremost amongst the analytical methods being explored to understand structure formation are techniques based on the Zel'dovich approximation, which has been shown to be remarkably accurate when compared with full N-body calculations. Approximations to gravitational clustering can be either 'Lagrangian' or 'Eulerian'. The great idea of Zel'dovich was to consider perturbations to the trajectories of fluid



This set of figures shows evolution of density fields for two different initial conditions. The left panel shows the density field at some early epoch and the right panel shows the same panels evolved over a period in which the universe expands by a factor eight. The initial conditions were set in such a way that the large scale power in both the cases was same but the top frame had additional small scale power that is apparent from the figure. Density field at the later epoch shows that the dissimilarities between two models are erased by evolution to some extent.

elements, rather than perturbations to the density at each point in space. This formulation of the problem, following fluid elements, is essentially Lagrangian in character, in contrast to the Eulerian approach adopted by Jeans and Lifshitz, in which one looks at quantities defined at fixed spatial positions. P. Coles and *V. Sahni* have shown that Lagrangian approximations such as the Zel'dovich approximations and its extensions provide a remarkably accurate picture of gravitational instability in the non-linear regime. They conclude that, 25 years after it was first suggested, the Zel'dovich approximation is still opening up new avenues towards an understanding of the origin of large-scale structure in the universe, clearly a rich tribute to the innovativeness and physical insight of its originator - Yakov Borisovich Zel'dovich.

V. Sahni and P. Coles have also done an in-depth analysis and review of nonlinear gravitational clustering. This review focussed on important developments in the field of cosmological gravitational clustering during the last decade and contains references to over 500 research articles and reviews. They discuss various analytical approximation methods for following the evolution of cosmological density perturbations into the strong (i.e. nonlinear) clustering regime and critically review various methods for dealing with the non-linear evolution of density inhomogeneities.

New approximations to gravitational instability - Smoothed Potential Approximation:

In recent years, there has been a growing interest in gravitational instability, partly motivated by a consensus that it is the primary driving process for the formation of structure in the universe. Systematic testing and comparison has led to the conclusion that Lagrangian-based schemes, closely related to the Zel'dovich approximation (ZA) are much superior to others. More recent work has focused on understanding why schemes based on ZA work so well outside their original realm of applicability (which was the class of models with truncated initial power spectra called 'pancake models').

There are historical antecedents that suggest smoothing of the initial conditions may be a useful basis for approximations. Evidence began accumulating from numerical simulations that "CDM-like" models produce pancake-like structures. These results were reported with no theoretical explanation.

Later on, the insight developed that if the initial potential were smoothed on the scale of evolved nonlinearity, a structure would appear in the nonlinear state which strongly resembled the one present in the full *N*-body numerical simulations which had used the entire initial spectrum. This happened whether one used *N*-body methods, the Zel'dovich approximation, or the adhesion approximation to evolve the initial state.

It is well known that, in the $\Omega = 1$, matter dominated models, the gravitational potential is constant to linear order in cosmological gravitational clustering. *B.S. Sathyaprakash, V. Sahni* and A. Melott (following the work of Melott and Pauls) have shown that the effect of nonlinear evolution on the potential can be better described by smoothing it on the scale of nonlinearity. They propose a new approximation called the "Smooth Potential Approximation" (SPA), in which particles are accelerated not by their mutual attraction, but by the gradient of the initial potential smoothed on the current scale of nonlinearity. This approximation produces results considerably improved over using a constant potential to move particles, and it is generally better than most schemes so far tested (with the exception of the Conserving Momentum Approximation described below). It is well equipped to describe hierarchical merging scenarios of gravitational clustering with small scale power and in this sense provides an accurate description of gravitational clustering on small scales. It is also reasonably fast and like the Zel'dovich approximation, easy to programme on parallel machines; it can therefore be used with considerable advantage for studying the large scale structure of the universe.

Conserving Momentum Approximation:

S.F. Shandarin and *B.S. Sathyaprakash* have proposed another new approximation to model gravitational instability which they call COnserving Momentum Approximation (COMA). COMA involves two local conservation laws of mass and generalised momentum and is a straightforward extension of the Zel'dovich approximation. This model generally predicts, on large scales, the correct density and velocity distributions. This is remarkable since in COMA, the gravitational force is not computed at every time step and it is much simpler than most and more accurate than all approximations examined till date. COMA demonstrates that the overall appearance of large-scale structure in the universe is explicitly determined by the initial velocity field and it reveals the most significant aspects of gravity regarding the formation of large-scale structure. The approximation naturally unifies the top-down and bottom-up clustering models.

S. Engineer, V. Sahni and *B.S. Sathyaprakash,* together with S.F. Shandarin and A. Melott, have started a detailed investigation of the extent to which the most successful approximations, namely, SPA (described above) and COMA agree with the results of *N*-body in so far as predicting the statistics of the structural units (clusters, filaments and voids) and morphological and topological properties of large scale structure. Their results, as yet tentative, seem to indicate that these approximations (especially COMA) may be an excellent practical tool for cosmological studies which do not require resolution better than 1 Mpc. Such studies would include: large-scale streaming velocities of galaxies and clusters, spatial distribution of rich clusters of galaxies, statistics of voids, percolation properties of large scale structure, weak gravitational lensing by large scale structure, etc.

Percolation as a tool to understand gravitational clustering:

To obtain a full view of structure formation, dynamical methods which describe how structures form must be supplemented by statistical methods describing different aspects of gravitational clustering. The simplest statistic to be applied to galaxy catalogues is the two point correlation function. However, since the correlation function is the Fourier transform of the power spectrum, it ignores information contained in the phases of the various Fourier components. This is a major limitation since it is well known that beyond the linear regime of gravitational instability, coupling between modes becomes important, leading to the build up of phase correlations.

In an effort to remedy this situation, *B.S. Sathyaprakash, V. Sahni* and S.F. Shandarin propose using geometrical and topological indicators of clustering such as the percolation statistic and the genus curve. Indicators such as percolation are sensitive to the overall 'connectedness' of large scale structure and can be used to distinguish between different models of structure formation.

In a comprehensive study, *B.S. Sathyaprakash, V. Sahni* and S.F. Shandarin analyse percolation properties of *N*-body simulations intending to model the universe at different stages of its evolution.

In the universe, one sees 'coherent structures' in the distribution of galaxies on scales of 50-100 Mpc., i.e., on scales at which the correlation function is effectively zero. Such large scale structures appear to have a large spatial extent (such as the "great wall") but occupy a relatively small volume of space (in other words, the "filling factor" of such objects is very small).

It is well known that a random (Poisson) distribution of points percolates at a filling factor (FF) of ~ 0.319. In other words, the fraction of volume occupied by the percolating phase is ~ 32 %. On the other hand, systems evolving under gravitational instability show a much smaller FF at percolation ~ 0.02 - 0.07 %. This is also what one finds from galaxy surveys leading one to believe that the galaxy distribution is strongly non-Gaussian.

B.S. Sathyaprakash, V. Sahni and S.F. Shandarin find that the percolation threshold appears to be sensitive both to the spectral index and the amount of evolution the system has undergone. The smallness of the filling factor in their simulations indicates that clustered matter is likely to be distributed in either sheets or filaments (since both sheets and filaments occupy less space than spheres).

A related issue of considerable importance concerns the *topology* of large scale structure, i.e., whether the distribution of large scale structure is 'meatball-like', 'sponge-like' or some other. High values of the filling factor at percolation (relative to a Gaussian distribution) determine a 'meatball-like' topology, whereas low values indicate a 'bubble or sponge-like' topology. The results of *B.S. Sathyaprakash, V. Sahni* and S.F. Shandarin indicate that overdense regions have a 'bubble or sponge-like' topology and the reverse may be true for underdense regions (voids).

Shapes of clusters and superclusters:

The morphological nature of structures that form under gravitational instability has been of central interest to cosmology for over two decades. As pointed out by Zel'dovich, a remarkable feature of large scale structures in the universe is that they occupy a relatively small fraction of the volume and yet show coherence on scales comparable to the survey size. *B.S. Sathyaprakash, V.Sahni* and S.F. Shandarin have undertaken an exhaustive study of morphology of structures that form under gravitational instability. With the aid of a useful synthesis of percolation theory and shape statistics they have explored the evolution of morphology of isolated density clumps in *real space* and that of the cluster distribution as a whole in scale-invariant cosmological models of gravitational instability. Their results, based on an exhaustive statistical analysis, indicate that at finite density thresholds, one-dimensional filaments are more abundant than two-dimensional sheets (pancakes) at most epochs and for all spectra. Both filamentarity and pancakeness of structures grow with time (in scale-free models, this is equivalent to an increase in resolution) leading to the development of a long coherence length scale in simulations. They intend to investigate the morphology of galaxy distributions in the IRAS catalogue together with K. Fisher.

Large dynamical range, high resolution cosmological simulations:

The importance of having enough dynamical range to carry out a simulation that will address relevant issues in the formation of structure in the universe cannot be overemphasised. Virtually, all observations of large-scale structure indicate that there exist structures (superclusters, voids, and filaments) having length scales >>50 Mpc which are often comparable to the observational extent of the survey. Thus, on the one hand observational samples need to get substantially larger and on the other, large simulations reflecting the enormous dynamical range present in most spectra, such as cold dark matter, need to be performed. However, the largest theoretical simulations of the universe are limited by available computational power and have, therefore, been restricted to boxes not larger than ~ 256 Mpc in length. *V. Sahni* and *B.S. Sathyaprakash* together with S. Habib and S.F. Shandarin are planning to do simulations with a dynamical range large enough to answer many of the outstanding questions in the formation of structure in the universe: such as the coherence length of galaxy clusters, mean sizes of voids, extent of hierarchical clustering in models that have predominantly small-scale power, topology of voids and substructure within them, and so on. Towards this end, they intend to make use of the massively parallel CM-5 supercomputer at the Advanced Computing Laboratory, Los Alamos National Laboratory, U.S.A. The CM-5 is very well-suited for this project; the high speed and large memory available (64 Gflops and 16 GBytes) make it very suitable for the large, data-intensive work needed for modern cosmological simulations. In addition, both the COMA and the SPA are easily parallelisable and, therefore, run very efficiently on this type of machine. The group has already written parallel versions of many of the codes which are needed and intends to run simulations in the autumn of 1996.

Scaling in N-body simulations and counts in cell statistics :

Gravitational clustering in highly nonlinear regime is not so well understood as clustering in quasi nonlinear regime. Scaling ansatzs provide a valuable guide in this context. Assuming scaling of *n*-point correlation functions, one can predict the scaling properties related to counts in cell statistics. *D. Munshi*, in collaboration with F. Bernardeau, R. Schaeffer and A. Melott has studied the scaling properties in highly nonlinear regime for a wide range of power law spectra both in 2D and 3D. By taking all the necessary corrections (like shot noise and finite volume effects) they were able to show that scaling relations work extremely well in highly nonlinear regime for all the power spectra they have studied.

In quasilinear regime they have checked the perturbation theory results against *N*-body simulations. Probability distribution function (pdf) calculated on the basis of three level approximation was found to be in very good agreement with both 2D and 3D *N*-body simulations.

While in quasilinear regime the so called S_N parameters (moments of the one point probability density function) can be calculated using perturbation theory, no such analytical predictions can be made for highly non linear regime. Measurements of S_N parameters in highly non linear regime are also affected strongly by finite volume corrections. Scaling models generically assume that S_N parameters reach a constant value in the non linear regime. Studies using a new method of volume correction based on factorial moments are presently in progress to check these assumptions.

Anisotropy of the Cosmic Microwave Background:

The ongoing investigations of anisotropy in the Cosmic Microwave Background (CMB) have now matured beyond its "discovery" phase. Future experiments, in particular, the proposed second generation space missions promise to map the anisotropy to significantly higher accuracy and resolution. Consequently, there is a growing need for theoretical exploration of subtler effects in the CMB anisotropy in order to translate observational accuracy into tighter constraints on theoretical models.

Gaussianity of the underlying statistics of the CMB anisotropy could help determine whether the primordial metric fluctuations arose from an inflationary epoch as oppposed to topological defects. This is, however, strictly true only if one can demonstrate that the statistics of the CMB anisotropies are largely unaffected by all nonlinear processes. In the spirit of their earlier work with A.A. Starobinsky on the non-Gaussianity induced in the CMB maps due to gravitational instability of density perturbations from inflation, *D. Munshi* and *T.S. Ghosh* are exploring the magnitude of this effect in other scenarios and from other distinct physical effects. In collaboration with S. Bharadwaj, they have shown that a relic in gravity wave background can induce non-Gaussian signatures in the CMB maps comparable to and in some cases in excess of that from nonlinear gravitational instability of density perturbations. This effect arises from a distinct and almost entirely overlooked physical effect, viz., multiple scattering of CMB photons off the gravity wave background. This result highlights the importance of multiple scattering in any perturbative estimation of non-Gaussianity in the CMB anisotropy maps. The relevance of the gravity wave contribution to CMB anisotropy in the context of inflationary scenarios, as emphasised by *V. Sahni* and *T.S. Ghosh* soon after the discovery of CMB anisotropies by the COBE satellite, is reiterated in this work in an entirely new context.

Observational Cosmology

Peculiar velocities: A better Tully-Fisher relation:

Several recent studies of the distances and motions of galaxies have revealed large systematic departures from the Hubble flow in the local universe. Attributing these departures to gravitational effects, the Great Attractor (GA) model was proposed in the mid-eighties to account for observed large-scale motions. Subsequent studies have failed to detect back-flow into the GA; instead, the results seem to indicate a large-scale parallel streaming flow which includes all galaxies within a radius of cz = 5,000 km/s. The origin of this flow has not yet been explained. However, measured peculiar velocities of galaxies have been used to reconstruct the density field and to find evidence for large concentrations (or underdensities) of mass that might be responsible for our peculiar motion. The existence and nature of the GA are still the subject of debate. The result of Lauer and Postman, viz., the failure to detect convergence to the CMB frame out to 15,000 km/s, adds to the puzzle and underlines the need for more work.

Measuring peculiar velocities beyond the local supercluster requires very precise distance indicators to galaxies. However, the current popular secondary distance indicators (D_n-sigma, Tully-Fisher) claim to measure distances accurate to about 15%. *S. Raychaudhury*, G. Bernstein, and P. Guhathakurta have been measuring peculiar velocities of five clusters between cz = 5,000 and 10,000 km/s (including the Coma cluster), using optical/near-IR photometry and H_α rotation curves of spiral galaxies to measure Tully-Fisher distances. They find that with sufficiently accurate analysis and selection criteria, they are able to measure I-band Tully-Fisher distances to an accuracy of about 5%. The reason behind the Tully-Fisher relation being such a tight one is also a mystery for theoreticians.

Peculiar velocities: The distribution function:

Given sufficiently accurate measures of the peculiar velocities of a random subset of a volume limited sample of galaxies, one can determine its distribution function and check its consistency with cosmological models. *S. Raychaudhury* and W. Saslaw have determined the peculiar velocity distribution function for a representative sample of galaxies which includes a wide range of clustering properties. They have explored in detail the effects of uncertainties in sampling and in distance measures on the estimated distribution function. The observed distribution function is consistent with an earlier prediction of gravitational clustering, over the entire range of peculiar velocities, from field galaxies to rich clusters, on scales up to 50 Mpc. The simplest consistent model can be interpreted to show that most of the inhomogeneous mass of the universe is in galaxies or their haloes.

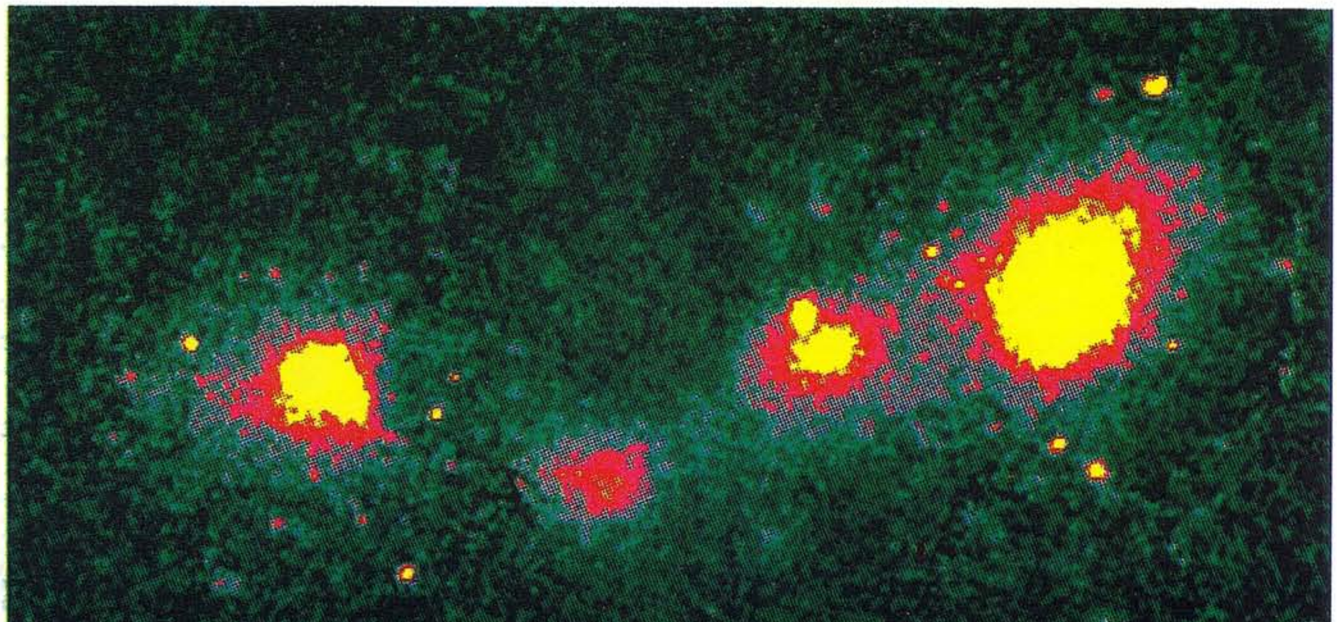
Clusters and Superclusters of galaxies:

The largest bound aggregates of matter in the universe are clusters of galaxies. It is now known that most of the baryonic mass in clusters is in the form of hot gas at a temperature of million degrees. *S. Raychaudhury* has been involved in the study of the distribution of galaxies, dark matter and hot gas in rich clusters and superclusters of galaxies through optical and X-ray observations. Together with B. Forman and C. Jones (Harvard-Smithsonian Center for Astrophysics), he has obtained ROSAT and ASCA images of several clusters of galaxies in the Shapley Supercluster. Some of these clusters, selected from optical catalogues, reveal remarkable substructure when seen in the X-ray (see figure below).

Their main aim is to study X-ray images of clusters belonging to the richest superclusters within $z = 0.1$ and relating X-ray observables (temperature of the hot intergalactic medium, emitted X-ray flux, substructure) to their optical properties (richness, optical luminosity, morphological content, etc.) with a view to studying their mass and internal dynamics. They have also been measuring the abundance of metals in the hot gas in clusters in different regions of the Shapley Supercluster, looking for clues to galaxy formation in different environments.

Mapping the sky:

There is no homogeneous catalogue of bright galaxies in the equatorial strip (-17.5 deg < Declination < + 2.5 deg) of the sky, a region that was missed by the ESO and UGC catalogues. This 'missing strip' has always been a problem for all-sky surveys like optical dipole estimates. *S. Raychaudhury*, together with D. Lynden-Bell and



The core of the Shapley Supercluster, from a mosaic of two long (>20 ksec) observations with the ROSAT PSPC. The cast of characters, from left to right, are the clusters Abell 3562, SC1329-31, SC1327-31 and Abell 3558 (Shapley 8). All of these clusters are around a redshift of 14,000 km/s. Shapley 8 is the central cluster of the Shapley Supercluster, which is the densest Supercluster-size baryonic mass concentration in the nearby ($z<0.1$) Universe.

others, is in the process of producing a catalogue of galaxies in this 'missing strip'. They are also coordinating an effort to produce a galaxy catalogue complete to 17th magnitude in B_J and D > 0.4 arcmin from APM scans of UKST Sky-Survey plates for the whole of the Southern Sky (Galactic latitude | b | > 20°). This involves more than 600 UKST Sky Survey plates.

Extensive photometry has been obtained at CTIO and SAAO for the photometric calibration of this catalogue. This project is expected to be completed by next year, and will produce a catalogue of over 70,000 galaxies, with positions, magnitudes, diameters, position angles and morphological information for all of them.

Quasars and Extragalactic Astronomy

Properties of the Lyman alpha absorbers:

Forest of Ly α absorption lines seen in the spectra of QSOs are believed to be produced by neutral hydrogen clouds in the intergalactic medium. The clouds near the QSOs will be highly ionized due to excess radiation from QSOs (called proximity effect). Using the observed decrement in the number density of Ly α clouds near the quasar redshift one can estimate the intensity of metagalactic background radiation, J_ν. *R. Srianand* and P. Khare collected from the literature a complete sample of intermediate resolution spectra of 69 QSOs and studied various possible uncertainties in estimating J_ν, using the compiled data set. They suggested that, while calculating J_ν using an equivalent width limited samples, one should use effective column density distribution (calculated from the observed equivalent width distribution) rather than using column density distribution estimated from high resolution data (as in earlier studies). Considerations of proximity effect in the spectra of QSOs exhibiting damped Ly α lines gives a background intensity which is 3 times smaller than the value obtained from the whole sample, confirming the presence of dust in the damped Ly α systems. It is shown that the lines close to the QSOs are marginally stronger and broader compared to lines away from the QSOs.

The Ly α lines with absorption redshift larger than emission redshift are shown to be uncorrelated with QSO luminosity, radio loudness or optical spectral index. These lines occur more frequently at high redshifts. Their presence is correlated weakly with the presence of associated metal line systems. The possibilities that the QSO emission redshift is considerably higher and that either the Ly α clouds or the QSOs have peculiar velocities are investigated. They find that a combination of both these phenomenon may be required to account for the presence of these lines. In order to get any reliable estimate of J_ν it is necessary to understand the origin and nature of the associated absorbers. *R. Srianand* is at present looking into the calculation of J_ν using the proximity effect caused by the foreground QSO.

R. Srianand has analysed clustering properties of Ly α lines using the intermediate resolution sample. He has found a weak excess in the pairs of lines with velocity intervals up to $\Delta v = 600$ km s^{-1}. He has shown that the strong lines tend to cluster more compared to weak lines. There is also an indication for the clustering scale in the velocity space to increase with time. The effect seems to be more for high equivalent width lines. He has not found any clear tendency of Ly α lines to cluster around metal line redshifts. If the blending effects inherent to intermediate resolution data used here are not severe, then the results obtained seem to favour the gravitationally induced formation scenarios. This analysis clearly shows that most of the Ly α clouds at higher redshifts are not associated with metal line systems.

R. Srianand has studied the properties of the Mg II absorbers considering their Fe II absorption lines, neutral hydrogen observations (available in the literature) and the photoionization models. He finds a clear increase in the equivalent width ratios of Mg II and Fe II lines with z. The number density of Fe II lines selected absorbers are not showing any evolution with z. He has not found the average Fe II column density to change with z. Based on the available data of Lyman limit sytems (LLS) in the literature, he has not found any dependence of optical depth (τ_{LLS}) on redshift in the range $z = 0.3$-2.0.

He has collected the LLS information for 53 QSO sight lines for which details of Mg II absorption are available. There are 4 Mg II absorption systems which are not LLS at redshifts which are lower than the mean redshift of the sample ($z \leq 1.1$). In the higher z, where one expects to see 2.5 ± 1.4 such absorbers, he has not found any nonLLS Mg II absorbers. Analysis of individual systems implies that some of the absorbers at $z \leq 0.7$ have reached metallicity roughly around solar value, indicating that the chemical enrichment in some of the absorbers are similar to our galaxy, as $z \sim 0.7$ is roughly the formation epoch of Sun in our galaxy. The required ionization parameters for these systems are less than 0.001 in most cases. The results described above together with results obtained for intermediate and high redshift absorbers confirm that the mean ionization state of metal rich absorbing clouds falls with redshift.

R. Srianand and *A.K. Kembhavi* have investigated the recent claim by Webster, *et al* that almost 80 % of quasars are missed in optical surveys due to significant reddening. Using data sample compiled from the literature, and various statistical tests, they have shown that there is no significant correlation between *B-K* colours and other reddening indicators. The distribution of emission line equivalent widths and line ratios of radio loud and radio quiet quasars in the optically selected samples are consistent with their being drawn from the same parent population. The distributions of Balmer line ratios of radio selected and optically selected quasars are identical. They constructed a detailed model for dust in the intervening damped Ly α clouds. Using this model they have showed that, even in the extreme cases, the observed spread in *B-K* colours cannot be explained by the extinction due to intervening dust. The dust-to-gas ratio, required to explain the observed spread in *B-K* colour, and the absence of intrinsic absorption lines predominently in very red quasars clearly rule out reddening due to intrinsic dust. Thus, their analysis shows most of the spread in *B-K* colour is due to effects other than dust extinction. They also notice a weak dependence of *B-K* on core strength and propose that relativistic beaming in flat spectrum radio sources is a source of large *B-K* colours in the Webster, *et al* sample.

He II absorption in intergalactic medium:

The recent detection of absorption by He II (helium atoms with a single electron) at high redshifts by the Hubble Space Telescope has been an important step towards understanding the nature of the background radiation in the ultraviolet at that era. The observations show that there is a considerable amount of singly ionized helium atoms in the intergalactic medium at high redshift. However, the paucity of neutral hydrogen atoms at high redshifts is a well known fact. This means that if the ultraviolet background radiation at high redshift ionizes helium and hydrogen atoms, then it should have such a spectrum so as to leave a lot of singly ionized helium atoms and ionize a lot of hydrogen atoms at the same time. These two observations, therefore, put constraints on the shape of the spectrum of the ultraviolet background radiation at high redshift.

B. Nath and *S. Sethi* have shown that the particular line of sight (to the quasar Q0302-003) that was used for the He II observation is a peculiar one. There is another quasar (Q0301-005) which is in the foreground, with an angular separation of 17 arc minutes from the above mentioned line of sight. This quasar in the foreground is suspected to have ionized the intergalactic clouds (Lyman alpha clouds), which usually populate the intergalactic medium, and which are absent from this line of sight. *B. Nath* and *S. Sethi* have argued that since this is a local effect, observations in this line of sight need not give us clues for the universal background radiation, but only the local radiation in that region. Using typical quasar spectra, they have then estimated the clumpiness of the intergalactic medium in the vicinity of these two quasars.

Broad band (UBVR) imaging of edge-on spiral galaxies:

D.K. Ojha and his collaborators have undertaken the project to investigate the distribution of luminous and dark matter in edge-on spiral galaxies. Such galaxies have several unique properties, including that they provide for a nearby unambiguous separation of the disk's vertical (z) and radial (R) distributions and that they permit an easy separation of distributions layered with respect to the mid plane, such as dust and stellar populations. The measurements of the profile near the plane could possibly trace the star formation rate in these galaxies. Broad band data for the project has been obtained on a number of galaxies using telescopes belonging to the UPSO, Nainital and VBO, Kavalur in India. Image data analysis is in progress at IUCAA. This work is being done in collaboration with V. Mohan and M. Haywood. Detailed examination of a sample of a few spirals would allow them to study these problems more deeply than has been done before.

Ionising the intergalactic medium via decaying neutrinos:

In the big bang model, protons and electrons combine to form neutral atoms at a redshift of ~ 1100 (helium recombines at slightly higher redshifts). These species can get reionized again if the formation of various structures in the universe - like quasars and galaxies - can emit enough ultra-violet radiation. Thus observation of ionization states of hydrogen and helium can be used to study the intensity and spectrum of the background ultra-violet source at high redshifts. However, it is not clear whether conventional sources like quasars and young galaxies can explain the ionization state of hydrogen, which is found to be highly ionized upto a redshift of 5. In recent years, observations of two ionization states of helium - neutral and singly-ionized helium - have revealed certain trends: There is almost no neutral helium in the intergalactic medium; but strong absorption from singly-ionized helium is seen. These observations can point to a unique spectrum of the background ionizing source. In light of the foregoing, more exotic sources of ionization like radiatively decaying neutrinos need to be considered.

S. Sethi has studied the ionization history of the universe in the presence of radiatively decaying neutrinos of masses between 30 eV and a few keVs. He considers a model in which most of the neutrinos decay into invisible particles with a rate $\tau^{-1} >> t_0^{-1}$, t_0 being the present age of the universe, while a small fraction of neutrinos, B, decay radiatively. He follows the evolution of the fraction of neutral hydrogen (H I), neutral helium (He I), and singly ionized helium (He II) in the diffuse intergalactic medium, taking into account the absorption of decay photons by hydrogen and helium in the diffuse intergalactic medium (IGM) and the Lyman α systems. The constraints on radiatively decaying neutrinos from the spectrum of Cosmic Background Radiation (CBR), the supernova 1987A, the cooling of red giants and the diffuse ultra-violet (UV) background are also considered. He derives the region of the parameter space - spanned by the mass of the unstable neutrino m_ν, t, and B - allowed by the Gunn-Peterson (GP) tests for H I, He I, and He II, the proximity effect, and the Lyman α emission at high redshifts. It is shown that the ionization state of the diffuse IGM, as required by the GP tests, can be explained without violating any other astrophysical or cosmological constraint on the model. He also investigated the implications of recently observed resonant neutral helium lines at $z \simeq 2$ on the radiatively decaying neutrino scenario; this observation rules out almost all the parameter space above the neutrino masses ≥ 50 eV.

One can also study, along similar lines, the implications of observed ionization state of IGM on the models of radiatively decaying neutrinos. *S. Sethi* has attempted to obtain bounds on the radiative lifetime of decaying neutrinos from recent observations in the IGM. He shows that the observation of singly ionized helium in the IGM at $z \sim 3.3$ and the observation of neutral helium resonance line in some Lyman limit systems at $z \sim 2$ can be used to obtain extremely stringent lower bounds on the radiative lifetime of decaying neutrinos.

Galactic Astrophysics and Dynamics

Interstellar turbulence:

The structure of turbulence in the ionized interstellar medium is revealed by scintillation and scattering of radio waves from compact sources. There is good support, from both observations and theory, for the idea that the turbulence is magnetohydrodynamic; nonlinear interactions among the slow magnetosonic waves, and Alfv'en waves are probably responsible for creating, and mixing electron density fluctuations down to the small spatial scales probed by diffractive scintillation. Earlier work by *S. Sridhar* and P. Goldreich developed the physics of this turbulence. Ongoing work explores the sources and sites of interstellar turbulence in our galaxy. Most of the observed scattering occurs in regions that are ionized by massive stars; a general, low level of scattering in the diffuse, ionized medium, plus stronger scattering in denser H II regions. Transient magnetic field amplification by turbulence in H II regions, together with turbulence of the slow waves support density fluctuations from being smoothed over by cooling. A simple, statistically homogeneous model appears to reproduce the observed correlation between scattering and dispersion for pulsars. Turbulence behind shocks overwhelms scattering due to the density jump across shock fronts. Radiative shocks compress gas to higher densities, enhancing their ability to scatter radio waves. The outer scale for turbulence behind radiative shocks is of order the cooling length, which could be as small as 10^{-3} parsec. Supernova shocks scatter maximally when they are close to the time of transition between the adiabatic and radiative phases of their evolution. However, the mean free path to encounter the supernova remnant at this phase is large. Radiative shocks last longer than adiabatic ones, and it turns out that the contribution of supernova shocks to the average, galactic scattering is largest when they are near the end of their life. But the scattering is at least an order of magnitude smaller than that observed. Stellar winds in H II regions can enhance the scattering when they are young. Thus, both supernova shocks and stellar winds are sites of rare, but quite strong scattering.

Capture into resonance:

When a resonant island sweeps through a stellar system adiabatically, it could leave behind a radically altered distribution. Nearly all orbits will, generically, pass through resonance; some of them could be captured, dragged along, and released elsewhere in phase space. Building on earlier work in solar system dynamics, *S. Sridhar* and J. Touma arrived at a general formulation of the changes induced in a collisionless stellar system by the passage of a resonant island. They derived equations of evolution for coarse-grained distribution functions; these equations satisfy an $\mathcal{H}$-theorem; thus the microscopic evolution is mixing, and effectively irreversible. This general theory was applied to the problem of vertically heating a slowly growing stellar disc. They constructed a simple model of the growth of a galactic disc in the symmetry plane of an oblate halo, and compared the results with the more realistic orbital computations described briefly below.

Formation of the thick galactic disc by levitation:

Disc galaxies sometimes possess a distribution of stars forming a thick disc. Near the solar circle, the thick disc is a rapidly rotating population that extends to several kiloparsecs (kpc) above the galactic plane. The processes that have heated the thin disc cannot impart the large vertical velocities (> 40 km s^{-1}) needed to support the thick disc. *S. Sridhar* and J. Touma invented a new mechanism for making the thick disc: a 2:2 resonance between vertical and epicyclic oscillations drifts to large vertical energies as the disc grows adiabatically; stars captured into resonance levitate several kpc above the plane. Orbital computations in a slowly growing, model disc + halo potential produced a thick, stellar disc with the following properties near the solar circle: *(i)* the thick disc stars are mostly distributed between 1.5-3.3 kpc, with a hole in the distribution near the galactic plane, *(ii)* the column density is > 1 % of the thin disc, *(iii)* the high altitude stars are on near—resonant orbits that carry them well into the inner galaxy; between 1 kpc and 3 kpc, the lag in rotation velocity increases with height at a rate ~ 20 km $s^{-1}kpc^{-1}$. The process being collisionless, globular clusters can be levitated just as easily as stars; thus the disc globular cluster population can be assembled as naturally as the thick disc. Furthermore, levitation becomes inefficient at large galactic radii; a prediction of their theory vis-à-vis satellite accretion (which produces a flare in the outer parts of the disc) is that the thick disc, as well as the disc globulars should be present only within about 10 kpc of the centre.

Optical and Infra-red Observations of Galaxies

Simulations :

On photographic plates, elliptical galaxies normally look like featureless smooth ellipses, but they are known to contain many faint small and large scale features. These could be in the form of dust patches, dust lanes, arcs and other structures. Such features are found by using different image processing techniques. In the simplest case, one compares images taken at different wavelengths, so that regions of the image which have peculiar colours show up, or one subtracts a smooth average image from the original, revealing irregularities.

Spiral galaxies consist of a bulge, which has properties like those of ellipical galaxies and a disk along with spiral arms. It is of dynamical interest to separate the bulge and disk components. This is done by assuming simple laws for the distribution of intensity in these components, generating a model galaxy and fitting it to observations, after allowing for the spreading of point like images due to the atmosphere. This process involves fitting ellipses to the isophotes of the galaxy, which becomes difficult when the disk of the galaxy is seen edge on.

The decompositon of a galaxy into large scale features and the detection of faint features involves complex image processing, and it is possible to generate artifacts which could be mistaken for real features. On the other hand, not allowing for the presence of real distortions of a smooth structure can lead to errors in the estimation of parameters of the dynamical structures. This is particularly true with CCD (Charged Coupled Device) observations which provide images with a large range of flux in digital format, to which elaborate reduction techniques can be applied.

In order to examine in detail how these issues should be addressed, *Y.. Wadadekar* and *A.K. Kembhavi* have developed programs which simulate galaxies of different kinds and include the effects of noise and seeing. It is possible to insert into these images faint structures of different kinds. Image processing techniques can then be applied to estimate parameters and to compare them with the input, as well as to examine to what extent artifacts are generated and faint features recovered. A whole range of techniques and models are being examined. The results as well as the software developed will be very useful to the astronomical community.

Radio galaxies :

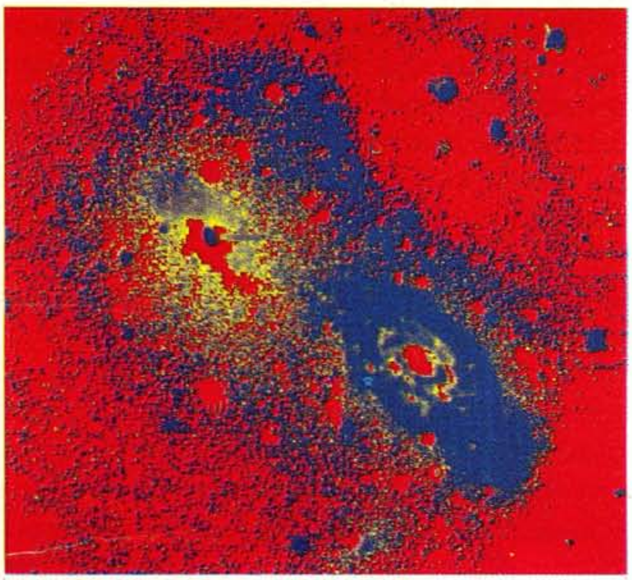
A small fraction of galaxies are powerful radio sources. The radio structures are usually in the form of two nearly symmetric lobes, a compact nucleus and narrow features (jets) which go from the nucleus to the lobes. Radio galaxies very often are associated with elliptical galaxies and show signs of mergers or less violent interactions with other galaxies. They also often show dust lanes and other faint features. In order to understand the origin of radio sources, and how their properties are related to the nature of the host galaxy, it is necessary to examine in detail the optical structure of the galaxy. With this in mind, *A.A. Mahabal* and *A.K. Kembhavi*, in collaboration with P. McCarthy of Carnegie Observatory, have undertaken the observation of a complete sample of radio galaxies from the Molongolo Radio Catalogue. The galaxies are all in the southern sky, and have been observed at optical and near Iinfra-red wavelengths using telescopes of the Carnegie Observatory in Chile. The redshifts range upto 0.3 and some of the galaxies have a small angular size. The surface brightness distribution in these galaxies is being examined in detail, with a view to finding faint features and dust lanes and relating these to the nature of the radio source. Several of the galaxies have been found to have complex structures and multiple nuclei and detailed examination of individual features as well as systematics of the population is in progress. The sample will be observed in different wavebands in the future and it promises to provide much needed insights into the nature of radio galaxies.

Interacting galaxies :

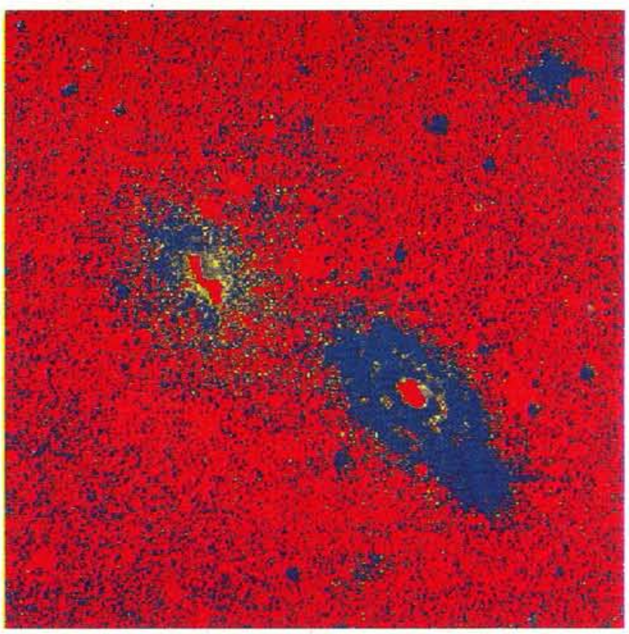
Interaction between galaxies leads to the development of tidal features, exchange of matter, the formation of regions of starbursts and so on. In extreme cases the galaxies can merge, and it is believed that ellipticals can be formed by the merger of spirals. The effects of interaction are not easy to separate from internal features of galaxies, and it is difficult to define observational parameters which could provide some estimation of the interaction strength. The situation can be particularly complex when galaxies are in small or large groups. The simplest interactions can be expected to be those involving two galaxies with the pair being isolated from other influences. *Y. Wadadekar, A.A. Mahabal* and *A.K. Kembhavi*, in collaboration with K. Freeman, have been studying a well defined sample of such isolated pairs in the southern sky. Observations in the visual and near infra-red bands and low resolution spectra have been obtained for the pair IC2200/2200A, as part of a larger program of observations of the entire sample. Image processing using different techniques has shown that one of the two galaxies, which appears to be an elliptical when observed at lower dynamic range, is actually a disk galaxy, with elaborate but faint spiral structure. The other galaxy is an elliptical with a clearly defined dust lane, which connects with a tidal feature in the spiral. The pair is surrounded by a halo. The spectral studies of this pair will provide some information on the velocity structure, and enable the pair to be modelled using different numerical techniques.

Chemical Evolution of the Galaxy

It is generally found that certain objects in our galaxy, namely Globular clusters, and the Halo stars, are not only the oldest ones but also the most metal-poor ones, compared to, say, the disc of the galaxy. The disc has spiral distribution of gases, O-B type stars, giant molecular clouds, open clusters and interstellar dust grains. All these objects are found to have near solar metallicity (that is, abundance of all elements heavier than boron) say, within a factor of two or so, whereas the Halo population of stars and the components



This is a B-I colour map of one of the interacting pair of galaxies IC2200 and IC2200A. Blue is "bluer" and red is "redder" in this representation. In IC2200 (at bottom right of image) spiral arm structure is clearly visible. The arms are redder than the rest of the galaxy. A possible tidal feature is faintly visible on the southern side of the galaxy. The big blue blob on the north eastern edge of the galaxy is a saturated star.



This is a B-I colour map of one of the interacting pair of galaxies IC2200 and IC2200A. Blue is "bluer" and red is "redder" in this representation. In IC2200 (at bottom right of the image) the nuclear region is very red. Two spiraling arms are also seen clearly. The tidal feature is also seen on the southern side. In IC2200A the "red" dust feature is visible, distributed symetrically about the centre of the galaxy.

of the Globular clusters show remarkably poor metal abundances at least two to three orders of magnitudes lower than that of the Sun. There is also a remarkable trend in the variation of metallicity and of the systematic rotational speed around the galactic centre as one moves away from the galactic plane in a direction perpendicular to the galactic plane. It is also known that the heavy elements are produced primarily by the stars during their post main sequence stages of evolution, and are thrown away by strong stellar winds as well as catastrophic events such as nova and supernova. The study of the spatial distribution and temporal evolution of the pool of heavy elements (or metals) in and across the plane of the galaxy comprises what is known as the Chemical Evolution of the Galaxy or, of galaxies in the case of other galaxies.

The link between the kinematics and the metallicity variation in different types of population of stars, stellar clusters and interstellar clouds suggests that the study of chemical evolution has to go hand in hand with the dynamical evolution of the galaxy. To that effect, an attempt has been made for developing a numerical code for the dynamical evolution of the galaxy starting from a proto-galactic spherical distribution of gas. The existing formalisms were first reproduced (N. Sambhus and *N.C. Rana*). It was also found that the radius for the inner Lindblad resonance and the observed exponential behaviour of the surface mass density of matter depend critically on fine-tuning of the viscosity parameter for the gas and the initial total angular momentum (N. Sambhus and *N.C. Rana*). A plausible role of the non-linear dynamical effects on the evolution of the galaxies has also been studied (B. Khubchandani and *N.C. Rana*).

Over the past two decades, it has been consistently observed that the hot intra-cluster medium of the rich clusters of galaxies show a near solar abundance of iron, figuring roughly 30 to 40 per cents of the solar value. An attempt has been made to explain such an unexpected overabundance of iron in the hot intra-cluster medium using two different models of chemical evolution with the result that the model developed by *N.C. Rana* and S. Basu was favoured compared to Arimoto's model (M. Chandola and *N. C. Rana*). We have also improved upon the mass-luminosity calibration required for converting the stellar luminosity function into the present day mass function of the stars in the solar neighbourhood due to the actual or observed distribution of the binary and further multiple stellar systems (K. Rajeev, M. Chandola and *N.C. Rana*). Its consequence on the predictions for the stellar remnants such as white dwarfs, neutron stars and black holes, and the so-called failed stars or brown stars (S.R. Pathak and *N.C. Rana*). A comparative study of the age-metallicity relation and the mass-luminosity relation derived from the evolutionary models of the stars suggests that the age-metallicity relation does hardly have any trend (A.R. Kulkarni, M. Chandola and *N.C. Rana*).

The Sun and the Solar System

There has been a lot of confusion in the calculation of the umbral radius of the Moon on the surface of the earth. The prediction depends crucially upon a parameter called *k*, the ratio between the average radius of the Moon and the equatorial radius of the Earth. Fred Espenak and Jay Anderson from NASA and Alan Fiala from USNO are the two main contenders with their predictions for the umbral width during the total solar eclipse of October 24, 1995 over the 76 degree (E) longitude line passing through Rajasthan in India had been 41 km and 43.914 km respectively. This case was taken up by the IUCAA team for direct measurement using arrays of 350 photo-sensitive detectors with on line relay and in situ storing of the solar light flux density levels divided into a logarithmic scale of 255 sublevels (covering from 0.05 lux to 1500 lux) and automatically recorded every 2 milli-seconds for about 256 seconds, the time required for bracketing the event of totality on the IUCAA's chosen sites. The project was a great challenge from both the point of view of planning and execution within a limited budget and time span. Local amateur astronomers, computer hardware and software experts and about 25 enthusiastic students accomplished the job. Each of the 350 detectors had the capacity to record 128 KB of data, each byte reserved for the numerical representation of the solar flux density level.

The umbral boundaries have been successfully recorded by the IUCAA team of 30 volunteers headed by *N. C. Rana*. The following are the actual coordinates of the two limit points: 76 deg 13' 13".2 ± 0".1 (E) in longitude, 27 deg 45' 7".8 ± 0".1 in latitude and 349 m ± 3 m high above the WGS84 ellipsoid (model of the earth) for the northern limit; and 76 deg 01' 55".5 ± 0".1 (E) in longitude, 27 deg 26' 16".6 ± 0".1 in latitude and 402 m ± 3 m high above the WGS84 ellipsoid (model of the earth) for the southern limit. These readings were obtained by using a pair Global Positioning System (GPS) units of the mapping grade and using differential corrections to a suitable reference base point. At the height above the WGS84 ellipsoid, Alan's prediction for the umbral width would be 44.080 km, whereas our findings suggest that the observed width corresponds to 360 m ± 5 m shorter than that predicted by Alan for the southern limit and 480 m ± 5 m shorter than the same for the northern limit. Correcting for the atmospheric bending of sunlight at the observed altitude of 24 deg 32 arc min, and using the ephemeris DE403/LE403 instead of DE200/LE200, a minor correction is obtained, which is within the error of the geo-positioning measurements of the boundary limits. The lunar limb profile errors are still at the level of ± 0".1, which when mapped on the boundaries of the umbral shadows corresponds to ± 4.5 m, again to remain within the error bounds on the geo-positioning measurements of the limit points. Finally, the predicted value as calculated by *N.C. Rana,* et al using the procedure set by IAU, the umbral width shortens further by 148 m, thus implying a true shortage of 630 m ± 10 m only.

These observational discrepancies are resolved by adjusting the solar limb radius during partiality or otherwise (normalised to distance of 1 A.U.), and by adopting a dual value of *k* for the calculation of central eclipses arising due to effective enhancement of the solar limb size projected over a darker background of the sky (intensity falling by a factor of 1,000 to 1 million) as well as due to diffraction of sunlight over the lunar limb. In all theoretical models of solar structure and evolution, in particular of its atmosphere, the assumed radius of the base of the solar photosphere has been 696,000 km, which corresponds to the effective limb radius (the upper limit of the photosphere) of 696,500 km, implying the solar limb diameter at 1 A.U. to be 960".32, instead of the current recommended value of 959".63 by the IAU. It is the former figure that is to be considered for all eclipse calculations. In addition to this, for the central solar eclipses, an effective value of *k* should be modified from the existing USNO's adopted value of 0.2725076 and NASA's adopted value of 0.272281, to an approximate value of 0.2725.

Stellar Astrophysics

In recent years, the understanding of stellar atmospheres, i.e., the layers of the stars that can be observed, has reached to the extent where realistic models are becoming possible due to improvement in the inputs of physics and computational methods. The aim of the stellar group at IUCAA is to apply updated model atmospheres to an extensive library of observed stellar spectra covering wide wavelength range, spectral types and luminosity classes for refining the technique of Artificial Neural Networks (ANNs) and for determination of basic physical properties.

R.K.Gulati, R. Gupta and their collaborators have extensive observational programmes to carry out spectroscopic observations of stars with telescopes in India and abroad.

Stellar parameters:

As a part of this programme, *R.K. Gulati, R. Gupta* and N.K. Rao have gathered the spectra of 80 cool stars in the wavelength range 4850-5500 Å during 4 nights of observations at the 2.34 m VBT at VBO, Kavalur, with Bollen and Chiven spectrograph. The spectra of cool dwarf stars combined with the library of synthetic stellar spectra both at the resolution of 2.4 Å have been used to apply a new method of ANNs for determining atmospheric parameter. Initial results show that the calibration of the MK system for solar-composition cool dwarfs in terms of effective temperature can be derived from this limited wavelength region.

Classification of stellar spectra:

Other observational project was to observe the MK standard stars in order to build an artificial expert system for classification of 11,000 stellar spectra observed earlier by French group. *R.K. Gulati*, along with R. Burnage and E. Maurice, observed the spectra of stars on the photographic plate at the Haute Provence Observatory, Saint Michele, France, by using the Marly spectrograph attached to their 1.2 m telescope attached with Marly spectrograph. The data is being scanned with the Machine Automatique a Mesurer pour l'Astronomie, at Paris Observatory, France. *R. Gupta*, S. Grenier and M. Gerbaldi are also involved in this project.

Library of stellar spectra:

One of the important elements in understanding the stellar populations from integrated spectra of galaxies is a library of stellar spectra exhaustive in spectral types, luminosity classes and metallicities. *R. Gupta* and *R.K. Gulati* have undertaken a key project with F. Valdes and L. Jones on the construction of a detailed stellar library of stellar spectra in the wavelength range 3800-9400 Å at the resolution of ~ 1.5 Å. In the first phase of the project, *R. Gupta* and F. Valdes have taken the spectra of 500 stars using the 0.9 m Coude feed telescope at the Kitt Peak National Observatory (KPNO) attached with the Coude spectrograph and CCD having 3000 pixels along the dispersion axis. The second phase of the observations will be done during April-May 1996.

Peculiar stars:

The λ Boo stars are A type stars which are characterised by deficiency of most elements with respect to the solar composition while carbon, nitrogen and oxygen have approximately solar abundance. These objects have called the attention of astronomers since the patterns of their abundances reflect their evolutionary stage and not the structure of their atmospheres as in the case of other Ap stars. In collaboration with M. Gerbaldi, R. Farraggiana, and R.L. Kurucz, *R.K. Gulati* has analysed the International Ultraviolet Explorer (IUE) archival spectra of a prototype of λ Boo to understand its evolutionary status. Chemical abundance of zinc and chromium for the star has been determined from the ultraviolet spectrum and compared with the local interstellar gas. Composition of these elements in our analysis is found to be within the limits of the interstellar gas, which supports the hypothesis of selective accretion on the λ Boo.

Stellar population studies:

Since its re-discovery in 1983, the thick disc population's mean parameters have been fairly well defined. The key question, its origin, remains unanswered. Is it ancestral to the classical disc population, or does it represent an accretion victim? *D.K. Ojha*, in collaboration with B. Carney, is involved in continuing effort to answer this fundamental question through a study of approximately 1500 long-lived G-dwarfs situated at various directions of our galaxy for which complete proper motion measurements have been made down to V = 18 mag. As part of this project, they have submitted the observing proposal to KPNO in Arizona. The proposal has been accepted for Schmidt and WIYN telescopes at KPNO. First phase of the observations will be taken in April 1996. They will extract both V_{rad} and [M/H] for 1500 G-dwarfs from high-resolution, low-S/N spectra using the Hydra/echelle spectrograph combination on the WIYN telescope. From these data they expect to resolve the question of the thick disc's origin.

Instrumentation

CCD Camera:

Charge Coupled Device (CCD) detectors are the most commonly used detectors in optical astronomy these days. Therefore, in order to provide instruments with sensitive detectors, CCD cameras are being developed in the instrumentation laboratory by *P. Chordia, M.S. Deshpande, D.V. Gadre* and *S.N. Tandon*. A typical camera would consist of : the detector with a suitable device to cool it to a low temperature (~ -80^0 C), the controller to deliver appropriate voltages and clocks to the detector and to amplify and digitize the signals from each pixel of the detector and a computer to interface with the controller and to receive the image-data. A full camera has been developed with a CCD (EEV CCD02-06, 385 x 578 pixel format) and a read noise has been reduced to a level of 12 electrons, i.e., the r.m.s. noise in the measurement on the number of electrons in any pixel is 12. The controller and the computer interface can be easily programmed to operate with any 3 phase CCD, e.g., a device with 1024 x 1024 pixels. This camera is being used with the imaging polarimeter (see below).

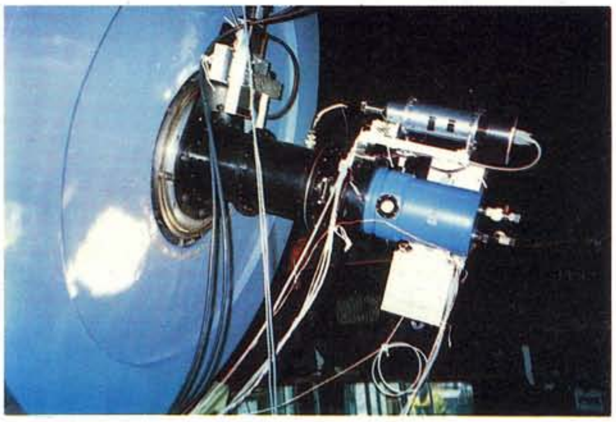
In order to reprogram the present camera for different CCDs, manual operations need to be done on some of the components in the controller. Therefore, a new version of the camera is being developed which would allow reprogramming from the interfacing computer. Additional modifications have been incorporated to reduce the read noise and to use fiber-optic links with the computer to achieve a high level of electrical isolation from the computer and to be able to get a high data rate (on the images from the CCD) and a long distance of operation. Individual cards and most of the new software for this controller have been tested and the full assembly is undergoing tests.

Imaging polarimeter:

For a wide variety of astronomical objects, the light received by us is polarized to some extent. The cause of this polarization could either be related to the intrinsic mechanism of emission, e.g., synchrotron emission or it could be due to reflection and scattering by the intervening medium. In either case, the polarization can be used as a powerful diagnostic tool to understand the nature of the sources and their environment. The polarization is often very small and in many cases it is a small fraction of one per cent. Despite these small values of the signal, the CCD detectors have rendered such measurements possible even for faint objects. An imaging polarimeter has been under development for some time and during this year it has been brought to a state of readiness by *P. Chordia, R. Gupta, A.N. Ramaprakash*, and *S.N. Tandon*. The instrument is capable of measuring linear polarization with sub one per cent sensitivity in a circular field of diameter 30 mm with a resolution of about 0.2 mm, this corresponds to a field of 6 min. of arc at the 1.2 m telescope of Physical Research Laboratory (PRL) at Gurushikhar (where the instrument is expected to see the first light soon) and an angular resolution of two seconds of arc. An offset guidance unit has been included, which can look at a suitable star within a few minutes of arc of the main field and provide guiding for the long exposures necessary to get a high sensitivity. The instrument is undergoing final laboratory calibration after being assembled and integrated with the CCD camera.

Site-testing for the IUCAA telescope:

The UGC has recently approved IUCAA's proposal for setting up a 1.5 m optical-near-infra-red telescope as an IUCAA facility for the university sector. One of the first tasks in this project is the selection of a suitable site. Several instruments have been developed for the purpose and the observations have been started by *H. Das, A. Paranjpye*, and *S.N. Tandon*. The wind and temperature measurements are done by a standard meteorological station working on a battery, while seeing, sky-brightness, extinction, and cloud cover are being observed with a set of instruments



IUCAA's Imaging Polarimeter on the PRL's 1.2m telescope at Gurushikhar, Mount Abu. The polarising optics and the focal reducer are in the black tube right behind the back (blue disk on the left side) of the primary mirror cell, and the CCD camera is in and around the blue cylinder (the liquid N_2 dewar) on the right side.

The detector for the autoguiding unit of the instrument can be seen on top of the CCD camera.

developed using CCDs as detectors. These instruments are briefly described below:

The seeing monitor is based on differential image motion measurement in which the images of polaris made by two 15 cm lenses, which are mounted on a common stand at a separation of 100 cm, are brought near each other on a CCD. This optics allows the two images to be recorded simultaneously. A series of short exposures (~10 ms) is used to estimate the fluctuations in the separation between the two images, and the magnitude of this fluctuation leads to a measure of the seeing; as the two lenses are mounted on the same stand, the effects of wind shake, etc. are minimized. (The software to estimate the separation between the two images on each frame has been developed by an engineering student, R. Ghare, as a part of his course work.)

The sky brightness and extinction are measured by a CCD camera having a 50 mm focal length lens, whereas the cloud cover is recorded by a CCD camera having a wide angle lens of 6 mm focal length which gives a field of about one steradian.

Automated Photoelectric Telescope (APT) for the universities:

As described in earlier reports, IUCAA has developed a prototype Automated Photoelectric Telescope for the universities under its program of generating interest for experimental astronomy in the university sector, where an interested group will be able to make such a telescope for their own observational programs. The prototype APT had some mechanical flaws which had to be corrected by using position encoders placed on both RA and DEC axes. While acquiring an object, the output of these encoders will be used in a feedback loop for correctly positioning the object in the telescope field of view. The hardware/software development for these encoders are currently underway and then the APT will be checked for its improvement in pointing accuracy.

The second APT on the lines of the prototype APT has been mechanically assembled by M.N. Anandaram, a Senior Associate of IUCAA, and his team from the Bangalore University for their own use under the financial support from Department of Science and Technology (DST). The electrical/electronic assemblies are ongoing at the IUCAA Visitors Laboratory. A similar proposal has been recently submitted to DST for funding by the Bhavnagar University. *R. Gupta* and *S.N. Tandon* are involved in these projects.

(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

Onset of chaotic behaviour in quadratically damped systems :

Quadratic damping arises in dynamical systems due to some specific physical reasons. For instance, rapid motion of bodies in fluids with low viscosity creates vortices that can lead to resistance forces proportional to the square of the velocity. A similar kind of damping arises in the equation modelling the dynamics of a Josephson tunnel junction. The onset of chaos in such a junction dc(I) and ac bias (A sin ωt), was carried out using a systematic numerical search procedure.

The phase locked and chaotic domains in the control space (A, ω) are isolated numerically. The degree of chaos in each domain is marked out based on the magnitude of the maximal Lyapunov exponent (LE). The devil's staircase in the phase locked states is found to have gaps due to chaos in between steps.

The LE, which is the order parameter in the transition from order to chaos, is found to obey a linear scaling law. The studies repeated for the Lyapunov dimension also reveal a similar scaling with an index close to one.

M.N. Anandaram

The automated photoelectric telescope :

The mechanical design, construction and assembly work on the 14 inch Automated Photoelectric Telescope (APT) was completed during this year. The stepper motors controlling the RA and Dec friction drives were also powered through stepper controllers and were found satisfactory. The work of fixing position sensors is being completed. The task of completing the P.C. controller card and related software development has been taken up by the project fellow attached to the APT project.

Narayan Banerjee

Studies in curved spacetime :

1. The exact gravitational field of a cosmic string has been investigated. Some exact solutions for both static and nonstatic gravitational fields have been obtained.

2. Magnetohydrodynamic waves through a plasma in a background of curved spacetime has been investigated. An extra term, presumably due to the electric field, had been found out in the expression for Alfven wave velocity. This term gives rise to some additional situations in magnetosonic wave propagation.

3. The causal thermodynamics of non-equilibrium phenomena has been studied in the context of flat Friedman-Robertson-Walker cosmological model both in general relativity and in scalar tensor theories of gravity.

P.K. Bhuyan

Models of electron density in the atmosphere

Radio astronomical measurements at frequencies below about 2 GHz require corrections for ionospheric effects. Ionospheric Faraday rotation may affect polarization observations done with single dish instruments or with radio interferometry. Interferometric observations may need corrections for ionospheric delay errors as well. Diffraction effects, visible in the observations as scintillations in amplitude and phase, also have a relation to the interferometric baseline. To derive correction factors from observed ionospheric parameters, some models are usually used. Work is proceeding on a model of height integrated electron density (also referred to as Total Electron Content) suitable for the Indian low latitude region. This is an extension of the regional model of foF2 (critical frequency of the F-layer).The results of our TEC modelling effort was presented in the INCURSI-96 held at Calcutta in January, 1996.

Kalyanee Boruah

Ultra high energy cosmic rays :

Studies on Ultra High Energy Cosmic Ray interaction in the earth's atmosphere is studied by the method of Monte Carlo Simulation using computer and also experimentally by the method of mini-array (a project funded by BRNS, DAE). Three dimensional Monte Carlo simulation programme is developed and run using the computer facility at IUCAA, by means of multicluster model of high energy nucleon-nucleon interaction using recent data from collider experiments and including the effect of multiparticle production by the mechanism of Higgs particle production via vacuum excitation and bubble formation and its decay to heavy fermion pairs.

S. Chakrabarty

Cosmic strings and quantum gravity :

For the last one year work is being done on two different topics namely (i) Cosmic String Theory, (ii) the use of Ashtekar Variables in Classical and Quantum Cosmology.

In string theory, the studies relate to the trajectories of particles around strings and monopoles. Also some analytic solutions are evaluated for non-stationary monopole configuration.

In Quantum Cosmology, the wave function of the universe for FRW model using Ashtekar variables following the Euclidean path integral technique has been calculated.

B. Chakraborty

Textbook and review article in plasma physics :

1. Preparation of the thoroughly revised text of the third edition of his book Principles of Plasma Mechanics. The book is now in press.

2. Preparation of the text of the paper "Magnetics moment generation in plasma", for submission to Review of Modern Physics as per the acceptance of his proposal to the editor.

D.K. Chakraborty

Modelling elliptical galaxies :

In order to switch over to the field of galactic dynamics, a research project entitled "Dynamical modelling of elliptical galaxies" has been submitted to CSIR. Detailed discussions on this subject with *A.K. Kembhavi* and T. Statler and also an extensive literature survey have been undertaken. A beginning has been made by working out some solutions of the Jeans equation.

M.K. Das

Nonlinear stellar oscillations :

The problem of nonlinear nonradial stellar pulsation has been formulated to study the long term amplitude evolution of the modal amplitudes. The theoretical formulation is now going to be applied to solar *p*-modes. The problem of tidal capture binaries has been studied within the framework of the work done by Gingold and Monghan (1980) and Mardling (1994, 1995) and work is proceeding to extend the formalism to nonlinear domain. The tidal forces are assumed to excite the finite amplitude nonradial oscillation in the star orbiting a central massive star. A part of the mathematical formalism of section (a) will be applicable in such a setting.

B.K. Datta

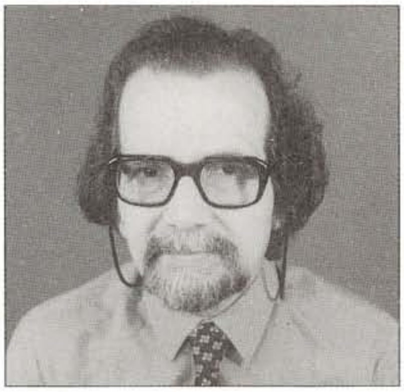
Space-time algebra and Einstein-Cartan theory :

A comprehensive review of space-time algebra as required for the development of physical theories in space time is given. It is demonstrated that the bivectors $\gamma_\alpha \Lambda \gamma_\beta$ play the role of generators of rotations in space-time. The $\sqrt{-1}$ of the Dirac theory can be interpreted geometrically

The Sixth batch of Senior Associates of IUCAA, who were selected for a tenure of three years, beginning July 1, 1995

Senior Associates

P.K. Bhuyan



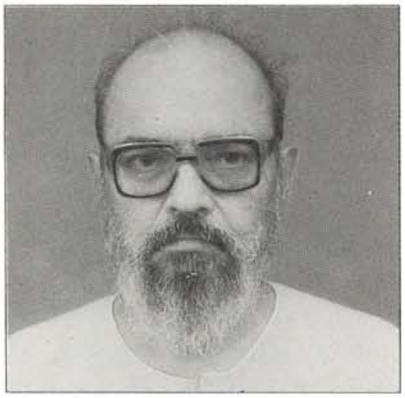
B.K. Datta

V.H. Kulkarni

B. Lokanadham

G.P. Malik

S.N. Paul



R.P. Saxena

P. Vivekananda Rao

as the generator of rotations in the $l_2 \wedge e_1$ -plane with $\hbar/2\ \gamma_2 \wedge \gamma_1$ representing the intrinsic spin in real Dirac algebra. Furthermore, it is pointed out that supersymmetry may be introduced in Einstein-Cartan theory by using space-time algebra.

D.P. Datta

Time in quantum mechanics :

The formalism of the intrinsic time developed recently in the context of quantum cosmology is further extended, so as to be applicable even in quantum mechanics. The nonadiabatic geometric phase in a time dependent quantum evolution is shown to give an independent concept of time, dually related to the external Newtonian time. Interesting duality and scaling relation are derived which reveal a fractal like structure in time. A geometric phase experiment is suggested to probe this quantum mechanical fractality.

S.S. De

A nonsingular origin of the universe and the cosmological constant problem :

The cosmological constant problem has been discussed in the context of a nonsingular model of the universe proposed earlier by the present author. By incorporating the changing gravity approach, it has been shown that the 'zero' cosmological constant is a natural consequence of the present approach of the early cosmological history when the matter has been originated from the anisotropic perturbation of the Minkowski space-time. Work done on the early universe as a thermodynamically open system with matter and entropy creation will appear in the proceedings of the International symposium on Theoretical Physics in honour of S.N. Bose and N.R. Sen held at Calcutta Mathematical Society, Calcutta.

In a different field, a paper entitled "A stochastic ecological model" has been published. This model has wide applications in ecosystems, atmospheric sciences, epidemeology, etc.

A.K. Goyal

Problems in astroparticle physics :

Bounds on neutrino mass and magnetic moment and on other exotic particle properties from astrophysics and cosmology. Effect of interactions on quark-hadron phase transition in the early Universe, in heavy ion collisions and in dense nuclear matter in neutron stars and supernova cores. Burning of two flavour quark matter into strange matter in neutron stars and in supernovae and possible observable signatures. Late information of quark nuggets after quark-hadron phase transition in the early universe, their survival until the present epoch and possible identification with dark matter objects recently observed by gravitational microlensing in the galactic halo.

G.K. Johri

Astrophysics, condensed matter and effect of acoustic cavitation :

An up-to-date and comprehensive review article on Advance of Molecular collisional width and shift of spectral lines in the gas phase has been written utilising the infrastructure facilities of IUCAA and Physics Department of University of North Texas, Denton - TX, U.S.A. and it has been communicated for publication with authors as G.K. Johri, Manoj Johri and James A. Robert. It has been found that although the effect of velocity averaging, temperature and quantum number dependence are not yet understood for all kinds of systems, but their consideration explains discrepancies in between theoretical and experimental results. Laser based infra-red and high resolution infra-red spectrometers are improved techniques and observed data in the ground and in the excited vibrational states, coupled with microwave broadening data can be used to explain bending, stretching and equilibrium geometry. Thus, the anisotropy of the potential can be proved by collisional broadening and line shift data. It has been concluded that the planetary atmospheric radiative transfer study needs data within 1% to correctly understand the astronomical and astrophysical effects.

The Sixth batch of Associates of IUCAA, who were selected for a tenure of three years, beginning July 1, 1995

Associates

G. Ambika

N. Banerjee

S. Chakraborty

R.V. Saraykar

H.P. Singh

S. Sreedhar Rao

G. Yellaiah

The photograph of A.K. Sharma, an Associate of the sixth batch, is not available.

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

- D.P. Datta
- A..K. Goyal
- S.R. Prabhakaran Nayar
- D.B. Vaidya

P.S. Naik

Construction of a photometer :

The design and fabrication of photometer head (optical part of photometer) has been completed and tested for performance with already developed supporting electronic circuits in collaboration with IUCAA Instrumentation Laboratory and its filter slide assembly, analog card, digital display board were tested and found working satisfactorily.

The testing of completed photometer detector on procured C8 Plus Celestron telescope, fabrication of a latitude adjusting plate and observation technique will be undertaken in due course at the Instrumentation Laboratory of IUCAA.

V.M. Nandakumaran

Dynamics of binaries :

Collaborative work with A.K. Kembhavi of IUCAA and M.K. Das of Delhi has started in October1995 on the study of the role of chaos in the evolution of tidal capture binaries in which one of the stars is a compact one. Earlier workers have derived a set of coupled nonlinear differential equations for the orbit and for the amplitudes of the modes of tidal oscillations. These modes are governed by driven harmonic oscillator equations. It is found that inclusion of higher powers of density fluctuations leads to equations for the mode amplitudes which contain quartic nonlinearity. The presence of nonlinearity can give rise to interesting evolutionary behaviour of the binaries. The numerical work is in progress.

Apart from this, work is proceeding in collaboration with a student on the dynamics of a parametrically perturbed logistic map in which the control parameter is varied by a discrete periodic perturbation. The resulting system shows many interesting features.

S.K. Pandey

CCD photometry of galaxies :

The research programme on the detailed photometric studies on early-type galaxies to search for the presence of dust patches/lanes, faint disk, shells and other fine structures embedded in them was continued during the year. Broad band CCD photometry on some more early-type galaxies was obtained from UPSO, Nainital, during November 17-19, 1995 and also from VBT, Kavalur, during March 9-10, 1996 as a part of the collaborative programme with *A.K. Kembhavi* (IUCAA).

Analysis of optical and near IR K-band data on several early-type galaxies obtained from Las Campanas Observatory, Chile, is in progress. Some of the preliminary results were presented at the Scientific Advisory Committee (SAC) of IUCAA at its meeting held during December 7-9, 1995.

He also articipated in the Indo-US workshop on Elliptical Galaxies: Structure and Dynamics, held at IUCAA during November 23 - December 7, 1995. A seminar on Isophotal Distortions and Faint Features in Elliptical Galaxies was delivered during the course of the workhsop.

Detailed surface photometric analysis for several early-type galaxies observed from UPSO and VBT is completed and results are being compiled for publication. A revised version of the paper entitled Nuclear Dust and outer shells in the Elliptical Galaxy NGC7562: Sahu, et al was submitted to Astronomy and Astrophysics in March 1996.

The paper on A highly flattened stellar disk in the elliptical galaxy NGC4564: D.K. Sahu, S.K. Pandey and *A.K. Kembhavi* was presented at the XVII meeting of ASI held at Guwahati during January 17-20, 1996. This will be published in the Bulletin of ASI.

L.K. Patel

Classical gravity :

The space-time metrics corresponding to radiating fluid spheres and anisotropic fluid spheres complying with the requirements of Einstein's field equations have been obtained and their geometrical and physical features have been examined. Some Bianchi type II, VIII and IX string cosmological models have beer obtained and their relevance has been discussed. Some exact higher dimensional solutions describing the interior fields of relativistic fluid spheres have also been obtained.

S.R. Prabhakaran Nayar

Astronomy teaching and dissemination

The acitivities on astronomy, mainly centred around the development of the activities at the observatory of the University of Kerala. With the newly acquired Celestron C11 telescope and CCD camera, few images of celestial bodies were collected and processed using PC based image processing software. Two M.Phil. students of the Department of Physics could utilise these facilities for their dissertation work. With the technical advice from IUCAA, a SUN workstation was installed at the observatory. Steps are also taken to obtain e-mail facility for developing astronomy work at the observatory. On the popularisation side, the observatory could organise astronomy popularisation programmes during the total solar eclipse of 1995 and during the passage of the comet Hyakutake. They have also participated in the national campaign for atmospheric studies organised by the Department of Science and Technology, during the total solar eclipse of 1995.

As the convener of the section on Astronomy of the Children's Encyclopaedia, prepared by the Kerala State Institute for Children's Literature, a few articles covering almost all the aspects of astronomy were prepared and compiled. For the Doordarshan, a 12 episode programme on astronomy was prepared as a project with the C-DIT, Thiruvananthapuram.

Apart from the astronomy programmes, two projects were carried out in the study of vector plasma motion in the upper atmosphere using HF Doppler radar of the department. Also participated in many national experimental campaign programmes of the DST. In addition, a few observational projects were carried out at the national MST radar at Tirupati to study the dynamics of the atmosphere. The study of temperature profile of the atmosphere using MST radar was selected as the best research work in atmospheric science at the national space science symposium held at Hyderabad. During the period, one student was awarded Ph.D. degree and another has submitted the Ph.D. dissertation under his guidance.

S.S. Prasad

Classical gravity :

A space-time metric is derived from Misra metric (similar to Wanquist metric) by the procedure of 'contraction' discussed in literature by Kinnersley. The metric with perfect fluid source is investigated and two classes of type D gravitational field are obtained. In class I, the space-time is stationary and axisymmetric and the fluid is in rigid rotation with equation of state $\rho + 3 =$ const. This class of solutions incorporates a large number of known vacuum and perfect fluid solutions namely, NUT, NUT metric in de Sitter and Anti de Sitter space, Einstein and Goedel cosmos as special case.

Class II solution is non-static and it also includes a large number of known (FRW, Mc Vittie and Wiltshire) and new solutions.

Presently, some partial work on finding out gravitational wave form emitted from a pulsar, taking into account its precessional motion, has been done.

The different works done in the above period appeared in four preprints of IUCAA.

R. Ramakrishna Reddy

Solar and stellar atmospheres :

The spectrum of PH may occur in the Sun and cool stellar atmospheres. The potential energy curves for the molecule PH and PH^+ are constructed and estimated their dissociation energies. The estimated ground state dissociation energies of PH and PH^+ are 3.10 and 3.20 eV respectively by the curve fitting procedure using Lippincott potential function. The computed values are in good agreement with experimental values [JQSRT, **54** (1995), 1035]. These parameters play a major role in understanding the stellar phenomena, stellar structure and other associated problems. A simple empirical relationship has been established for the estimation of refractive indices for various solar materials directly from their energy gaps. The validity of this equation is tested [Infrared Phys. & Tech., **36** (1995), 825] in various classes of materials such as solar materials, semiconductors, insulators and oxides.

L.M. Saha

Celestial mechanics :

The mathematical formulation of restricted three body problem has been completed taking into account the eccentricity of the orbit. It is proposed to further investigate numerically the stability of various libration points in Sun-Earth-Moon system and Earth-Moon-Artificial Satellite system, using (i) Poincare Surface of Section (ii) Lyapunov's Exponents and (iii) Power Spectral Density methods as dynamical tools.

R. Saraykar

Cylindrical inhomogeneous universes :

R. Saraykar and N.K. Dadhich have tried to prove that a family of solutions of Einstein's field equations describing a inhomogeneous non-singular cylindrical universe filled with perfect fluid is linearized stable. The method uses Holder spaces as function spaces to prove invertibility of certain elliptic operators. The same results can also be derived using Weighted Sobolev spaces.

K. Sankara Sastry

Interacting galaxies :

Hernquist's mass model for spherical galaxies and bulges described by the de Vaucouleur's profile gives analytical expressions for the density profile and the potential. These have been used to derive a simple and exact analytical expression for the gravitational potential energy of a pair of interpenetrating spherical galaxies represented by this model. The interaction potential energy obtained from this work closely agrees with those obtained from Plummer and polytropic models for galaxies of same mass and dynamical radius.

The work has been carried out in collaboration with K.S.V.S. Narasimhan and S.M. Alladin. A paper based on this work is submitted to the Journal of Astrophysics and Astronomy.

H.P. Singh

Astrophysical fluid dynamics :

Visited the Hong Kong University of Science and Technology during August 3 - 10, 1995 to do collaborative research in Astrophysical Fluid Dynamics. Also visited the Inter-University Centre for Astronomy and Astrophysics, Pune as an Associate during October 1 - 18, 1995. Presented a paper in the International Conference on "Windows on the Sun's Interior" held at the TIFR, Bombay during October 19 - 21, 1995. He also went to observe the Total Solar Eclipse on October 24, 1995, from near Neem ka Thana in Rajasthan.

S. Sreedhar Rao

Star System : The SL 9-Jupiter collision spectra, partially reduced earlier (February 1995) at IUCAA, were further analyzed to detect any impact related signatures. A few lines in the region between l 3998 and l 4214 are found to be varying compared to those in the rest of the spectrum. Measurement of radial velocities of various selected lines in the spectra, which has been underway, should provide a clue to the sudden irregularities observed in this region.

Peculiar Stars : A comparative study of the spectral characteristics of the new peculiar class A2IV type stars vis-a-vis Lambda Boo and Am stars is underway to find out any evolutionary implication of these essentially main-sequence stars but exhibiting significant differences in their spectra.

A list of the fainter peculiar stars has been under preparation, towards establishing a standard star grid, for observations as and when the CCD facility is made available. A multi-dimensional classification of the peculiar stars based on an autonomous system to be developed, is envisaged from the above work.

D.B. Vaidya

Porous particles in interplanetary and interstellar space :

Recent studies of interplanetary and interstellar dust provide evidence that cosmic grains are extremely dark (low albedo) and have very low density, suggesting that these grains are porous and might have fluffy structures. Comet Halley probes (Giotto, Vega) have also shown that cometary grains are porous and fluffy. In view of these observations, calculations were made of extinction, scattering and polarization for porous particles, using discrete dipole approximation (DDA). The DDA was applied first to the spheroidal particles, assumed to be made of small scattering elements (dipoles). Then the number of dipoles was systematically reduced to model the porous grains. The aggregates of these grains are suggested to form the fluffy particles. The extinction, scattering phase function and linear polarization as a function of grain size, packing density and refractive index for both porous as well as compact particles were studied. The preliminary results show that the phase function for porous particles deviates considerably from that of the compact solid particles. Results also show that as the porosity increases, the angle of maximum polarization shifts toward 90 degrees. It is also found that in general the geometric albedo is lower for the porous particles. So far, the scattering properties for single sized porous particles have been studied. For comparison with the observed data, calculations with various size distributions are required. These calculations are in progress.

Participated in the IAU colloquium on Physics, Chemistry and Dynamics of Interplanetary Dust, held in Gainesville, U.S.A., during August 14-18, 1995.

Visited Goddard Space Flight Center (GSFC), Greenbelt, Md, USA, during August 21-25, 1995 and Department of Astronomy, University of Maryland, USA, during August 23 - 29, 1995.

P.C. Vinodkumar

QCD Star:

Possibilities of a stable qcd stars beyond the neutron stars are being formulated. With the basic bag model the equation of state for such systems are taken into account by modifying the bag pressure as density dependent. Calculations of its stability parameters are in progress.

This problem was formulated in collaboration with A.K. Ray of Visva Bharati University during their stay at IUCAA.

Lanczos method and confinement potential models:

A class of potentials which are generically related through gauge constraints of a background qcd fields are obtained in our earlier study (Vinodkumar and Khadkikar, Phys. Lett B 1994). These class of potentials are to be solved to find the relationships between their eigenvalues. Since most of them do not have direct analytical solution, we formulated the Lanczos method to solve them with either a single wave vector or with multi-basis vectors. It has been solved analytically using Mathematica up to 4 x 4 dimensions. Details of these calculations are being reported in the INPS 95, BARC, Bombay.

This problem was initiated in collaboration with C. Radhakrishnan Nair during his stay at IUCAA as a refresher course participant.

P. Vivekananda Rao

Algol type binaries :

Analysis of the light curves of the Algol type binaries in various passbands using modern synthetic light curve techniques like Wilson-Devinney enables one 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. Keeping this in view, a few Algol type binaries (data obtained from Japal-Rangpur Observatory and also from other Centres) for which good photoelectric light curves are available, were selected.

Analysis of one such Algol type binary TW Andromedae was done in B & V passbands using the Wilson-Devinney method (Astrophys. J., **166** (1971), 605), keeping $T_{e,h}$ (7200^0 K) and *q* (0.1928) as fixed parameters. From the derived solutions the following improved absolute elements were obtained: $R_h = 2.19 \pm 0.05\ R_O$, $R_c = 3.37 \pm 10\ R_O$, $\text{Log}\ L_h / L_O = 1.0625 \pm 0.1568$, $\text{Log}\ L_c / L_O = 4.973 \pm 0.1172$, $m_h / m_O = 1.677 \pm 0.070$, $m_c / m_O = 0.323 \pm 0.025$. From the position of the primary component of this binary on the evolutionary tracks of stars of Pop I composition computed by Meader and Meynet (Astr. Astrophys. Suppl., **76** (1988), 411) it is noticed that this component is evolving along a 1.7 m_O star. Since the mass of the primary itself is 1.7 m_O, it is concluded that the mass accrued by the primary, if any, had no effect on its evolution.

These results were presented at the Astronomical Society of India meeting held at Guwahati, Assam, during January 17-20, 1996. A full version of this paper has been accepted for publication in the Bulletin of the Astronomical Society of India.

G. Yellaiah

Solar eclipse observations :

Last year during the total solar eclipse (i.e. October 24, 1995) period, a team consisting of ten members (including three research scholars and two M.Sc. students) visited Kalpi and took photographs and other observations of the Sun. The analysis of the data is in progress.

(III) Ph.D. THESIS

Quantum Phenomena in Gravitation and Cosmology - CMB Anisotropy and the Physics of the Early Universe

by *Tarun Souradeep Ghosh*

The theme of this doctoral thesis is to explore some aspects of the inter-relationship between the observed universe and prevalent notions about the physics of the early universe. The work is done within the framework of an expanding universe which progressively cools as it expands. A logical extrapolation to the past brings us to a very hot early universe where our knowledge of high energy physics applies or even needs to be extrapolated. In addition, the existing firm ideas of high energy physics in negligible gravitational fields have to be extended to incorporate effects of large curvature describing the strong gravitational field of the early universe. The vast improvement in the quality and quantity of cosmological observations during the past decade has made it possible to investigate the high energy scenarios indirectly by observing their signatures in the present universe.

The universe that we observe and seek to understand is extremely inhomogeneous on small scales (up to 30 Mpc), but is astonishingly smooth on large scales (> 100 Mpc). Therefore, any reasonable realisation of the universe has to accommodate a spacetime whose metric is perturbed about a homogeneous and isotropic FRW (Friedmann Robertson-Walker) model. Moreover, the perturbations were created with a small amplitude and on scales much larger than length scale set by the expansion rate of the universe. The wavelength of perturbations scales with the expansion of the universe and subsequently moves within the Hubble radius (which increases at a faster rate). As each mode of the metric perturbation enters the Hubble radius, it gets amplified through gravitational instability giving rise to the large scale structures that we see around us (galaxies, clusters and superclusters of galaxies, etc.).

The initial perturbation spectrum on the smooth universe on super-horizon scales is widely believed to have arisen out of quantum fluctuations during an inflationary epoch in the early universe. Besides providing a rationale for the smoothness of the universe on large scale (reflected in the small anisotropy of the Cosmic Microwave Background (CMB) of up to a few parts in a million), inflationary scenarios also provide a causal mechanism for generating the primordial adiabatic density perturbations. Therefore, it is believed that there is a direct link between the inflationary epoch in the early universe at energy scales of $\sim 10^{15}$ GeV, and the present observable universe, connecting physical phenomena over 28 orders of magnitude in the energy scale!

The quantum field theoretic effects on a curved background operate at high energies and play an important role in the physics of the early universe. As discussed above, quantum field theoretical processes during the inflationary epoch in the early universe can be precursors of large scale structures such as superclusters and voids as well as the observed anisotropies in the CMB. Chapter 1 is a brief introduction, spelling out the theme of this thesis. Chapter 2 contains a brief summary of the basic notions of quantum field theory used in this thesis. The study of quantum fields on curved space-times (i.e. matter fields are quantised whereas the background gravitational field is treated classically) emerged as a rich field at the interface of quantum field theory and gravitation, yielding important results such as the quantum evaporation of black holes, particle production in an expanding universe and the scenario for the origin of the primordial density perturbations during inflation.

In Chapters 3 and 4 we illustrate some generic quantum effects that arise in a classical background space-time having non trivial geometry and curvature. We present *original* results from a study of quantum effects in static and non-static conical spaces. It is well known that, space-time outside of a point mass in 2+1 dimensions has a non-trivial topological structure described by a conical spatial geometry. The Einstein's equations in 2+1 D enjoy a unique status owing to the equivalence of the Einstein and Riemann tensors. Gravity outside a source manifests itself as a global topology, conserved quantities being related to topological invariants. This aspect has provided some useful insight into the quantisation of 2+1 D gravity.

In Chapter 3 we show that the conical spatial geometry outside a mass point leads to the presence of a non vanishing one-loop vacuum expectation value of the energy-momentum tensor $< T^{\mu}{}_{\nu} >_{ren}$ (describing the vacuum polarisation), which falls off as r^{-3}, r being the distance from the point mass. This "Casimir-type" stress in general back-reacts on the metric through the semi-classical Einstein equations: $G^{\mu}{}_{\nu} = 8 \pi G <T^{\mu}{}_{\nu}>_{ren}$. The resulting first order corrections to the metric show the metric to be conical but non-flat, the deficit angle now depending upon r. This result has considerable significance since it shows that the semi-classical Einstein theory of gravitation has a Newtonian limit, in contrast to other existing formulations of gravitation in 2+1 dimensions.

In Chapter 4 the above treatment has been extended to a non-static conical space-time in the presence of a cosmological constant - the 2+1 dimensional analogue of the Schwarzschild - de Sitter space-time. In this case, one finds that the presence of a point mass leads to the existence of a steady vacuum flux directed away from the mass so that $<T^{r}{}_{t}> \neq 0$. Since the conformal trace anomaly vanishes in odd dimensions, $< T^{\mu}{}_{\nu} >_{ren}$ so obtained provides the sole contribution to the vacuum polarisation in this space-time. It is also shown that a particle detector of scalar particles in this spacetime experiences a fermionic thermal bath signaling an inversion of statistics. Quantum effects in these spacetimes are closely related to similar effects found in 3+1 dimensional spacetimes in the presence of cosmic strings. In addition, fields residing on a domain wall/bubble wall during a phase transition experience exotic phenomena such as inversion of statistics..

Despite the successes of the hot big-bang model, it is well known that very specific initial conditions have to be invoked to explain the present universe. The idea of introducing an inflationary epoch of rapid accelerated expansion in the early universe to alleviate the naturalness problem of initial conditions was proposed around 1980. Numerous physical phenomena including spontaneous symmetry breaking and phase transitions at high energies, higher derivative and higher dimensional gravity, etc. provide scope for implementing an inflationary scenario. Over the past 15 years since the realisation of the first inflationary models, numerous models have been put forward and, in view of its impressive properties, the inflationary scenario has become a central paradigm of current cosmology. Chapter 5 serves as an introduction to inflation. In this chapter we review the motivation for inflation and outline the mechanism for chaotic inflation. A model independent discussion of scalar field driven inflation is presented. We also present some *original* work on scalar field dynamics in an expanding universe.

Chapter 6 of the thesis is devoted to quantum fluctuations during inflation and the origin of cosmological metric perturbations. A simple unified approach using concepts and techniques introduced in preceding chapters is used to summarise well known results for density perturbation and gravity wave power spectra in inflationary scenarios of the early universe. We use the measured CMB anisotropy to normalise the amplitude of the stochastic gravity wave background from inflation and predict its present spectral energy density. The spectral energy density of the stochastic gravity waves at wavelengths that can be probed by terrestrial (LIGO) and space detectors is shown to be yet another sensitive feature of inflationary models.

In 1992, the DMR (Differential Microwave Radiometer) instrument COBE (Cosmic Background Explorer) satellite announced the first detection of anisotropy in Cosmic Microwave Background on large angular scales. In the context of an inflationary scenario, the detected anisotropy has its origin in the same quantum fluctuations during inflation which gave rise to the observed large scale structure in the universe and a stochastic gravitational wave background, possibly of comparable amplitude. The COBE detection has been followed by a host of detections by other instruments at various angular scales. In Chapters 7 and 8, we present some *original* work on two aspects of the link between the CMB anisotropy, models of structure formation, inflationary scenarios and cosmology.

Both scalar (density perturbations) and tensorial (gravity waves) metric perturbations contribute to the CMB anisotropy on large angular scales. In Chapter 7, the observed anisotropy in the CMB by the COBE-DMR has been used to normalise the spectrum of density perturbations and the stochastic gravity wave background predicted by a broad class of inflationary models. Our work shows that for density perturbation spectra which are tilted with respect to the scale invariant Harrison-Zel'dovich spectrum, a significant component of the COBE measured quadrupole anisotropy in the CMB could be generated by gravity waves, leading, in the standard Cold Dark Matter scenario, to a "gravity wave induced bias", in the variance of the density contrast at $8h^{-1}$ Mpc, over and above the usual bias due to density perturbations. The relative contribution to the CMB anisotropy from gravity waves and density perturbations is found to be extremely sensitive to the underlying model of inflation and can help to distinguish between different models which predict the same spectrum of density perturbations.

It may be possible to determine whether the underlying statistics of the CMBR anisotropy is Gaussian or non-Gaussian from observations in the near future. This issue is discussed in detail in Chapter 8. We show that secondary non-Gaussian features (such as skewness) could be imprinted on the CMBR anisotropy even if the initial perturbation was Gaussian (e.g., as predicted by inflationary scenarios). We present an estimate of the secondary skewness that would arise from weakly non-linear effects during gravitational instability. A calculation of the secondary skewness arising from the second order Sachs-Wolfe relation is also presented. We show that although the secondary skewness from these effects is non-zero, its amplitude is far below the fundamental observational limits set by the cosmic variance.

The details of the calculations of the work presented in this thesis are given in the Appendices A-F. Some of the appendices also provide some background material that may be useful for appreciating the issues involved in this thesis.

The thesis ends with a summary and discussion of the main results.

(IV) PUBLICATIONS

by IUCAA Academic Staff

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

a) Journals

Bagla, J.S. and **T. Padmanabhan** (1995) Nonlinear evolution of density perturbations, J. Astrophys. Astron. **16**, 77.

Balasubramanian, R., B.S. Sathyaprakash and **S.V. Dhurandhar** (1995) Estimation of parameters of gravitational waves from coalescing binaries, Pramana, **45**, 463.

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b) Proceedings

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Narlikar, J.V. (1995) Problems of astro-particle physics in the quasi-steady state cosmology, *in* Proceedings of PASCOS-94, Ed. Kameshwar C. Wali, 335 (World Scientific).

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- (1995) Direct particle formulation of Mach's principle, *in* Einstein Studies, 6, 250, Mach's Principle: From Newton's Bucket to Quantum Gravity.

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Narlikar, J.V., F. Hoyle and G. Burbidge (1995) Quasi-steady state cosmology, *in* Proceedings of the 6th Asian Pacific Regional Meeting on Astronomy, Pune, August 16-20, 1993, Eds. V.K. Kapahi, N.K. Dadhich, G. Swarup and J.V. Narlikar, J. Astrophys. Astron, **16**, 87 (Supplement to J. Astrophys. Astron.).

Hoyle, F., G. Burbidge and **J.V. Narlikar** (1995) The quasi-steady state cosmology, *in* Proceedings of the IAU Symposium No. 168, Eds. M. Kafatos and Y. Kondo, 329.

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c) Books

Authored/Edited

Narlikar, J.V. (1995) From black clouds to black holes [2nd Edition, World Scientific Publishing Company, Singapore].

- Mahabishye bhrama (1995) [Bengali translation of "A journey through the universe" by Ishani Raychoudhury, published by National Book Trust, India, New Delhi].

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- Postkardatun vidnyan, (1995) (in Marathi) [Published by Marathi Vidnyan Parishad, Mumbai].

- Brahmand ki yatra (1995) [Hindi translation of "A journey through the universe" by Krushna Kumar, published by National Book Trust, India, New Delhi].

- Proceedings of the 6th Asian-Pacific Regional Meeting of Astronomy of the International Astronomical Union (1995) (-Ed), with N.K. Dadhich, V.K. Kapahi and G. Swarup [Published as supplement to J. Astrophys. Astron., **16**].

d) Book Reviews

Narlikar, J.V. (1995) Newton Explained to the "Layman", Newton's Principia for the Common Reader by S. Chandrasekhar, Clarendon Press, Oxford (1955), [Indian Express, October 29].

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e) Popular Science/Technical Articles

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- (1995) Load assembly code in 8052-BASIC system, Design Ideas, EDN, October 26.

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f) Popular Articles

Narlikar, J.V. (1995), Morumamancha koot prashna, (in Marathi) (Loksatta,Gudhi Padawa special supplement, April 1).

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- Parikhsa paddhati : kahi vichar, (in Marathi) (Kathashri, Diwali issue, 51).

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- The excitement of doing science, (Silver Jubilee Souvenir 94-95 of Physics Post-Graduate Centre, Fergusson College, 31).

- Brief history of time- India is a nation on holiday, (The Times of India, Bombay, August 19).

- Bharatatil prachin udaharane, (in Marathi) (4th article in the series "Ase he ganit, ase he ganiti", Chhatra Prabodhan, September 2, 2, 15).

- Sankhyancha Mitra : Srinivas Ramanujan, (in Marathi) (6th article in the series "Ase he ganit, ase he ganiti", Chhatra Prabodhan, October 10, 13).

- Going back in time - Science and technology in epics, (The Times of India, Bombay, September 16).

- Chakravyuha, (in Marathi) (5th article in the series "Ase he ganit, ase he ganiti", Chhatra Prabodhan, September 23, 3, 9).

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- Prayog pahave karun, (in Marathi) (Srujan Anand Shikshan Patrika, Prayogsheelata, Prayogsheel Shikshan special issue).

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- Sarvat hushar shetkari, (in Marathi) (11th article in the series "Ase he ganit, ase he ganiti", Chhatra Prabodhan, March 21, 9, 25).

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- Learning and talent, (The Times of India, Bombay, March 16).

- The ice age cometh, (Science Reporter, March, 15).

by Associates/Senior Associates

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

a) Journals

Banerjee, A., D. Panigrahi and S. Chatterjee (1995) Evolution of Kaluza Klein inhomogeneous model with a cosmological constant, J. Math. Phys., **36**, 361.

Banerjee, A., A. Das and D. Panigrahi (1995) Singularity free cylindrically symmetric solutions in Kaluza Klein space-time, Phys. Rev. D **51**, 6815.

Banerjee, A., B. Bhui and S. Chatterjee (1995) Nonadiabatic gravitational collapse in higher dimensional space time and its juction conditions, Astrophys. Space Sci. (Netherlands), **226**, 7.

Chakraborty, D.K. and K.N. Mishra (1995) Some general relativistic effects on the dynamics of fluid disk, rotating around a Schwarzschild black hole, Astrophys. Space Sci., **226**, 75.

Das, M.K., A.K. Chaudhary, V.B. Bhatia and R.K. Tavakol (1995) Statistical response of randomly excited nonlinear radial oscillation in polytrope, J. Astrophys. Astr. **16**, 45.

Das, M.K., A.K. Chaudhury and R.K. Tavakol (1996) Stochastic nonlinear radial oscillation of self-gravitating polytropic gaseous masses, Ap. J., 463, June 1.

Datta, B.K. (1996) Physical theories in spacetime algebra, quantum gravity, eds. Peter G. Bergaamm, Venze de Sabbata and Hans-Jurgon Trader, World Scientific, Singapore, 67.

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Galileo-Newton-Hamilton, Jour. Birla Planetarium, **8**, 2, 30.

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- (1995) On the gravitational properties of the vacuum energy, Class. Quant. Grav., **12**, 2499.

De, S.S. (1995) A nonsingular origin of the universe and the cosmological constant problem, Comm. Theor. Phys., **4**, 115.

Goyal, A.K., S. Dutta, and S.R. Choudhury (1995) Bounds on neutrino magnetic moment from SN1987A, Phys. Lett. B **346**, 312.

Goyal, A.K. and D. Chandra (1996) Formation and survival of electroweak symmetric nuggets in the early universe, IJMPA, **11**, 361.

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Johri, G.K., (1995) On light emitting bubbles, Bull IAPT, May, 145.

Patel, L.K. and N.P. Mehta (1995) An exact model of an anisotropic relativistic sphere, Austrul. J.Phys. **48**, 635.

Patel, L.K. and S.K. Vaidya (1995) An anisotropic analogue of Finch-Skeu solution, Mathematics Today, **13**, 43.

Prabhakaran Nayar, S.R. (1995) Height gradient of F region vertical drift in the evening equatorial ionosphere, Geophys. Res. Lett., **22**, 2645.

Prabhakaran Nayar, S.R. (1996) Deduction of temperature profile from MST radar observation of vertical wind, Geophys. Res. Lett., **23**, 285.

Reddy, R.R., Y.N. Ahammed, A.S. Rao and T.V.R. Rao (1995) Dissociation energies of PH and PH^{+}, J. Quant. Spectro. Radiat. Trans (UK), **54**, 1035.

Reddy, R.R. and Y.N. Ahammed (1995) A study on the Moss relation, Infrared Phys. and Technol. (UK), **36**, 825.

Reddy, R.R., Y. N. Ahammed, M. Ravi Kumar and P.M. Reddy (1995) Mean velocities and lattice energies of some ionic crystals , Acoustics Letters (UK), **18**, 31.

Reddy, R.R., Y.N. Ahammed and M. Ravi Kumar (1995) Variation of Magnetic susceptibility with electronic polarizability in compound semiconductors and alkali halides, J. Phys. Chem., **56**, 825.

Shah, H.S., D.G. Adroja and **D.B. Vaidya** (1995) Determination of imaginary part of refractive index: A different approach, Ind. J. Pure and Appld. Physics, **33**, 670

Singh, H.P., I.W. Roxburgh, and K.L. Chan (1995) Penetration below a convection zone, Astronomy and Astrophysics (Springer), **295**, 703.

Tikekar, R. and **L.K. Patel** (1995) Radiating black hole with interval monopole in Einstein and de Sitter Universe, Mathematics Today **13**, 3.

b) Proceedings

Bhuyan, P.K., and S. Baruah (1996) A regional model of TEC derived from ionosonde measurements for application in radio astronomy, *in* Proceedings of the INCURSI-96 symposium on Frontiers of Radio Science, Calcutta, 11-I4.

Boruah, K., P.K. Boruah, T. Bezboruah, A. Mitra and K.M. Pathak (1995) Simulation of Hadronic Cascades including Vacuum excitation and Higgs production, *in* Proceedings of the 24th International Cosmic Ray Conference, Rome, Italy, **1**, 240.

Boruah, P.K., **K. Boruah**, T. Bezboruah, A. Mitra and K.M. Pathak (1995) Gauhati University mini-array to detect the UHE Cosmic Rays, *in* Proceedings of the 24th International Cosmic Ray Conference, Rome, Italy, **1**, 411.

(V) PEDAGOGICAL ACTIVITIES

a) IUCAA-NCRA Graduate School

B. Bhawal	Mathematical Methods in Physics
S. Sridhar	Galaxy and Interstellar Medium
T. Padmanabhan	Statistical Mechanics and Quantum Mechanics
	Statistical Mechanics of Gravitating Systems (Topical course)
S. Raychaudhury	Astronomical Techniques
V. Sahni	Extragalactic Astronomy and Cosmology

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

B.B. Nath	Astrophysics I
S. Sinha	Astrophysics II
S.V. Dhurandhar	Astrophsyics II
R. Gupta	*Practicals*

c) Supervision of Projects

S.V. Dhurandhar	T. Majmudar (M.Sc.) *Optimum orientation of the resonant bar antenna for a pulsar source*
	M. Wagh (M.Sc.) *General Relativity and Gravitational Waves*
R. Gulati	M. Dutta (VSP) *SNNS Based Automated Classification of B type stars using International Ultraviolet Explorer (IUE) database*
R. Gupta	Kavita (VSP) *Comparitive study of MK Spectral Class Calibration with respect to effective temperature of dwarf stars*
A.K. Kembhavi	M. Joshi (B.E.) *Image Processing*
	V. Ambekar (M.Sc.) V.V. Nikesh (M.Sc.) *Pulsars*
A.A. Mahabal	A.D. Bachikar S.N. Kurhade N.H. Pathan S.L. Pol (School Students' Summer Programme) *Our solar system*
J V Narlikar	A.N. Lagad P.R. Wagh R.S. Tekade C. Kasamgorchonda R.S. Khilare S.V. Nikam (School Students' Summer Programme) *A spacetime sliderule and the Foucault pendulum*
	P. Ranade (VSP) *Newtonian Cosmology*
A. Paranjpye	M. Jadhav *Photometry of Variable Stars*
	A. Agte *Seeing measurement using differential image motion*

A.N. Ramaprakash

R. Sayyed
R. Agarwal
D. Padmanabhan
G. Pradhan
(School Students' Summer Programme)
Understanding the simple pendulum

R. Badade (B.E.)
P. Chordia (B.E.)
Position control system for IMPOL
(jointly with S.N. Tandon)

A. Gujarathi (B.E.)
M. Agarwal (B.E.)
V. Kambham (B.E.)
Designing and building an incremental encoder readout circuit
(jointly with S.N.Tandon)

N.C. Rana

N. Gandhi
(Jawaharlal Nehru Fellowship Student)
Equations of motion of any point-mass particle in GR

S.M. Jejurikar (T.Y. B.Sc.)
Observation of meteor showers

A.V. Wagh (T.Y. B.Sc.)
Mystery of black holes

A.B. Gadling (T.Y. B.Sc.)
Study of sunspots

A.A. Kolaskar (T.Y. B.Sc.)
Big bang

S.Y. Bhide (M.Sc.)
Compatibility of classical, relativistic structure of electron and its quantum nature

N. Sambhus (M.Sc.)
Evolution of disc galaxies

K. Darak (M.Sc.)
Structure of solar chromosphere

P. Kale (M.Sc.)
Design for photodetector assembly for TSE project

M. Chandola (M.Phil.)
Test of a model of chemical evolution

S. Raychaudhury

R. Kumar (M.Sc.)
A.Ganti (M.Sc.)
Astronomical image processing

V. Sahni

S. Terdalkar (VSP)
Aspects of Newtonian cosmology

N. Kanekar (M.Sc.)
On the age of the universe and gravitational instability in expanding models of the universe

S.N. Tandon

R.P. Ghare (B.E.)
Processing and analysis of the CCD images for (i) Differential image motion seeing monitor, and (ii) All sky camera

A.M.Sagrolikar (B.E.)
A.J. Sane (B.E.)
Guiding platform for small telescopes

D.P. Aundhekar (B.Sc.)
G.D. Gaikwad (B.Sc.)
Night sky photometer
(jointly supervised with A. Paranjpye)

S. Pandit (B.Sc.)
Scintillation measurements with a photometer

A. Apte (M.Sc.)
Differential image motion seeing monitor
(jointly supervised with A. Paranjpye)

T. Deoskar (B.E.)
Writing an improved user interface for the CCD camera host software as well as a CCD image display programme
(Jointly supervised with D. Gadre)

d) Supervision of Thesis

J.V. Narlikar and V. Sahni

Tarun Souradeep Ghosh (1995) qualified for the Ph.D. degree of University of Pune for his thesis on *Quantum Phenomena in Gravitation and Cosmology - CMB Anisotropy and the Physics of the Early Universe.*

N.C. Rana

R. Roy (1995) qualified for the Ph.D. degree of University of Bombay for his thesis *Investigations into the N-body Problem of Gravitation and Energy-Momentum Tensor of Supergravity.*

T. Mathews (1995) for his thesis *Bigbang Nucleosynthesis Revisited* which has been submitted to the Cochin University of Science and Technology.

e) Tutorial Assistantship

J.S. Bagla

Statistical Mechanics and Quantum Mechanics, IUCAA-NCRA Graduate School (for T.Padmanabhan).

(VI) IUCAA COLLOQUIA, SEMINARS, ETC.

a) Colloquia

P. Pal : *Do neutrinos have mass?*, April 24.

S. Shandarin : *Topology of galaxy distribution*, July 24.

N.C. Wickramasinghe : *Iron whiskers in the galaxy and elsewhere*, August 28.

G.C. Asnani : *Some challenging problems in tropical meteorology*, September 4.

K.S. Krishna Swamy : *Infrared emission from comets*, September 11.

N.C. Rana : *The global positioning system : An overview*, September 25.

O. Gingerich : *A report on the progress in stellar evolution to 1953*, October 16.

S. Roy : *Hands-on astrophysics: Discovering the changing nature of variable stars*, November 1.

M. Barma : *Time-dependent properties of interacting stochastic systems*, November 13.

M.N. Kulkarni : *The global positioning system: An overview*, December 4.

A. Khare : *Quantum and statistical mechanics of anyons*, January 8.

B.B. Chaudhuri : *How the computer can read an Indian language book*, January 29.

A.A. Rangwala : *Optical solitons : Genesis and applications*, February 5.

Roberto Gallino : *Aims and difficulties in the galactic chemical evolution of the s-elements*, February 19.

Adriaan Blaauw : *History of the International Astronomical Union (IAU)*, March 1.

V.R. Venugopal : *Hickson's compact groups of galaxies - Facts and fallacies*, March 18.

b) Seminars

S. Mukherjee : *A statistical study of the magnetic field decay in single radio pulsars*, April 4.

S. Engineer : *Evolution of spherical density perturbations*, April 26

T.D. Saini : *Charged particle in curved spacetime*, April 26.

K. Srinivasan : *Some observational aspects of the quasi-steady state model*, April 26.

Y. Wadadekar : *Interaction in elliptial galaxies*, April 26.

Marc Van Loo : *Uniform universal expansion and a variable light speed: The predictions of a bimetric spacetime proposal*, July 14.

S. Kalyana Rama : *Consequences of nontrivial PPN parameters in a graviton-dilaton theory*, July 27.

A. Gopakumar : *Gravitational radiation from compact binaries in quasi-elliptical orbits*, August 1.

R. Sachs : *The quasi-steady state cosmological model - An exact solution*, August 24.

N.C. Wickramasinghe : *Microsoot: A New Model for interstellar dust*, September 5.

A. Krolak : *On estimation of parameters of the gravitational wave signal from a coalescing binary by a network of detectors*, September 22.

W. Rudnicki : *Blackhole interiors cannot be totally vicious*, September 26.

A. Bandyopadhyay : *Quantum interferometry with squeezed radiation*, October 12.

H.C. Spruit : *Magnetically accelerated winds and jets from accretion disks*, October 17.

M. Chiba : *The Origin and Evolution of Galactic Magnetic Fields*, October 18.

A. Petrov : *The field approach and isolated systems in general relativity*, October 19.

P.M. Gondhalekar : *Soft X-Rays in AGNs and quasars: Unification schemes and accretion discs, November 9.*

R. Sommerville : *The small scale velocity dispersion of galaxies: A comparison of cosmological simulations*, November 14.

F. Cooperstock : A *new look at gravitational energy and gravity waves*, November 27.

Bill Saslaw : *The distribution function approach to galaxy clustering*, December 27.

S. Raychaudhury : *Velocity distributions*, December 28.

F. Ahmed : *The basis of the thermodynamic approach to galaxy clustering*, December 28.

S. Kumar : *Magnetic fields in accretion discs*, December 28.

R.S. Tate : *Time-of-arrival in quantum mechanics*, January 2.

A. Khare : *Super symmetric quantum mechanics*, January 10.

F. Verheest : *Waves in dusty space plasmas*, January 22.

M. Samal : *Applications of Cerenkov process in astroparticle physics*, January 23.

A.Z. Capri : *Time and vacuum and the Weyl anomaly*, January 25.

Christian Vanderriest : *Integral field spectroscopy of quasars and galaxies with MOS-ARGUS at CFHT*, January 31.

H. Bondi : *The foundations of the theory of gravitation*, February 6.

P. Saha : *Reconstructing the galactic bulge or How (not?) to compare N-body simulations with discrete kinematic data*, February 12.

M. Parthasarathy : *Post-AGB stars : Chemical composition and evolution*, February 20.

L. Van Waerbeke : *The auto correlation function of the extragalactic background light : A new tool to analyse the gravitational lensing effects*, March 8.

M. Rivas : *The space-time structure of classical relativistic spinning particles*, March 28.

c) Public Lectures

S. Bagchi : *Science through history and making European mind,* May 5.

N.C. Wickramasinghe : *Comets, culture and catastrophies,* September 2.

O. Gingerich : *Circles of the gods : Copernicus, Kepler and the ellipse,* October 15.

H. Bondi : *Energy in the world*, February 7.

d) PEP Talks

B. Bhawal : *Rewinding back to Michelson and playing LIGO*, July 21.

S. Kalyana Rama : *Inconsistent physics in the presence of wormholes*, July 27.

N.C. Wickramasinghe : *Life outside the Earth: Scientific facts and sociological attitudes*, September 1.

K. Harikrishna : *The hitchhiker's guide to the Euler characteristic*, September 15.

J.V. Narlikar : *Luck in astronomy*, November 3.

P.M. Gondhalekar : *Magic, mythology and theology in astronomy*, November 10.

T. Dray : *Rotating observers in relativity*, December 22.

S. Sridhar : *Vortex dynamics*, March 15.

e) Informal Discussion Group Meetings

A. Kembhavi: *Pulsars: Magnetic fields and Statistics*, March 31.

R. Sinha (NCRA): *Morphology of Galaxies*, March 31

N. Dadhich: *Vacuum space-time with the Machian boundary condition*, April 27.

P. Gothoskar (NCRA): *Changing distances to pulsars*, April 27.

R. Gupta: *Temperature calibration of dwarf stars*, May 4.

K. Subramanian (NCRA): *Detecting intergalactic magnetic fields*, May 4.

C. Boily: *Dynamics of star clusters formed in galactic mergers*, June 8.

D. Oberoi (NCRA) *An X-ray jet from the Vela pulsar and other short stories*, June 8.

Y. Gupta (NCRA): *State of the local interstellar medium*, June 22.

B.S. Sathyaprakash: *Second post-Newtonian corrections to gravitational waves from inspiralling binaries*, June 22.

S.V. Dhurandhar: *They do it with mirrors*, July 13.

B. Phookun (NCRA): *Magnetic fields in damped Lyman α systems*, July 13.

A. Pramesh Rao (NCRA): *Radio and X-ray lobes of M87*, July 20.

S. Sinha: *Sonic black holes*, July 20.

V. Chickarmane : *On thermomechanical noise reduction*, August 3.

B.C. Joshi (NCRA) : *Millisecond pulsars in the globular cluster 47 Tuc.*, August 3.

R. Athreya (NCRA) : *Radio polarisation studies of high redshift radio galaxies*, August 17.

R. Srianand : *Clustering properties of Ly α clouds*, August 17.

S.R. Pathak (NCRA) : *A study of Chandrasekhar's mass limit*, August 31.

S.N. Tandon : *Active optics for space coronagraphy*, August 31.

R. Gulati : *UV spectrum of λ Boo star*, September 28.

K. Subramanian (NCRA) : *Report on IAU symposium 173: "Astrophysical applications of gravitational lensing"*, September 28.

C.H. Ishwara Chandra (NCRA) : *FR I - FR II Dichotomy in powerful radio sources*, November 2.

T. Padmanabhan : *Crisis in cosmology: Review of constraints on Ω and H_0*, November 2.

V. Sahni : *Emergence of filamentarity in cosmological gravitational clustering*, November 23.

D.J. Saikia (NCRA) : *Ionization cones and the structure of the central region of AGN*, November 23.

S. Ananthakrishnan (NCRA) : *X-ray jets in the Sun*, December 1.

C.M. Boily : *Star formation in star clusters*, December 1.

S. Jeyakumar (NCRA) : *Compact symmetric objects and their evolution*, December 21.

D.K. Ojha: *Are the thin and thick disk stellar populations of our galaxy ancestral or neighbours by chance?*, December 21.

A. Mahabal : *Elliptical galaxies with core: An urban legend?*, January 4.

R. Malik (NCRA) : *12 km. array*, January 4.

S.D. Mohanty : *The Kuiper belt of comets : Observational evidence*, February 1.

Gopal Krishna (NCRA) : *Report on the Bologna meeting on extragalactic radio sources*, February 1.

B. Phookun (NCRA) : *X-ray emission and the distribution of dark matter*, March 7.

R. Srianand : *Lyman limit imaging of high z galaxies*, March 7.

V. Kapahi (NCRA) : *Confirmation of high deuterium abundance in quasar absorbers*, March 14.

B. Nath : *Ultra high energy cosmic rays from the local supercluster*, March 14.

S. Raychaudhury : *The mass of the Milky Way galaxy from its satellites*, March 26.

M. Vivekanand (NCRA) : *Photon splitting in strongly manifested cosmic objects*, March 26.

(VII) TALKS AT WORKSHOPS OR AT OTHER INSTITUTIONS

a) Seminars, Colloquia and Lectures

J.S. Bagla

Gravitational dynamics in an expanding universe, (Mehta Research Institute, Allahabad, May 18).

Cosmological N-body simulations, (Mehta Research Institute, Allahabad, May 19).

A new indicator of nonlinear clustering, (Raman Memorial Mini Conference, University of Pune, November 18).

Gravitational dynamics in an expanding universe, University of Pune, November 24).

Coupling of modes and evolution of power spectrum, (International Conference on Gravitation and Cosmology, IUCAA, December 14).

Crisis in cosmology : Observational constraints on cosmological parameters, (International Conference on Gravitation and Cosmology, IUCAA, Pune, December 15).

A new indicator of nonlinearity in gravitational clustering, (Institute of Astrophysics, Paris, January 19).

Observational constraints on cosmological parameters, (Moriond Conference on Dark Matter in the Universe, Les Arcs, January 21).

Evolution of a single mode : A paradigm for evolution of arbitrary power spectra, (Max Planck Institute for Astrophysics, Garching, February 2).

Nonlinear evolution of gravitational clustering, (Observatory of Strasbourg, Strasbourg, February 8).

Nonlinear evolution of power spectrum, (Queen Mary and Westfield College, London, February 15).

Velocity contrast : A new indicator of nonlinear gravitational clustering, (Queen Mary and Westfield College, London, February 16).

Evolution of power spectrum in the nonlinear regime, (Institute of Astronomy, University of Cambridge, Cambridge, February 21).

Coupling of modes in the nonlinear regime and evolution of power spectrum, (Royal Observatory of Edinburgh, Edinburgh, February 29).

Nonlinear evolution of power spectrum, (Observatory of Midi-Pyrenees, Toulouse, March 6).

N. Bawdekar

Internet : Access and tools, (3rd CALIBER-96 Conference, Maharaja Sayajirao University of Baroda, Vadodara, February 17).

B. Bhawal

Coincidence detection of broadband signals by networks of the planned laser interferometric gravitational wave detectors, (Les Houches school on "Astrophysical Sources of Gravitational Radiation", September 30 and International Conference on Gravitation and Cosmology'1995, December 15).

Evolution of intra-cavity fields in dual-recycled interferometers, (Workshop on Gravitational Waves, IUCAA, December 11).

Pulsars, (Refresher course in Astronomy and Astrophysics for college and university teachers, IUCAA, May 22).

Hulse-Taylor binary pulsar, (VSP, IUCAA, June 8).

Laser interferometric gravitational wave detectors, (VSP, IUCAA, June 9).

N.K. Dadhich

On non-singular separable and orthogonal perfect fluid spacetimes, (14th Meeting of the

International Society on General Relativity and Gravitation (GR-14), Florence, August 6-12).

On generalisation of Einstein vacuum equation, (Mini Workshop on Gravitational Collapse and Cosmic Censorship, IUCAA, December 23).

S.V. Dhurandhar

Detecting coalescing binary signals and the thermo-optical coupling between laser interferometric cavities, (Observatory du Meudon, June 16).

Detecting coalescing binary signals by Newtonian filters and thermal deformation in laser interferometric cavities, (LAL, Orsay, June 19).

The thermo-optical problem in giant laser interferometric cavities, (UWCC, Cardiff, Wales, June 28).

Possible instabilities in high powered laser interferometric cavities, (Workshop on Gravitational Waves, IUCAA, December 9).

Gravitational waves from pulsars, (ICGC-95, IUCAA, December 18).

The search for gravitational waves, (Commemorative symposium on S. Chandrasekhar: Impact of his work on astronomy and astrophysics, BARC, Bombay, February 28).

R.K. Gulati

Spectrum synthesis of λ Boo, (Workshop on Model Atmospheres and Spectrum Synthesis, Vienna, Austria, July 10).

Applications of artificial neural networks in Astronomy, (Department of Computer Sciences, Punjabi University, Patiala, January 22).

Stellar populations, (Department of Astronomy and Space Sciences, Punjabi University, Patiala).

R. Gupta

Automated telescopes, (Refresher course in A & A for college and university teachers, IUCAA, May 10).

Optical observations in astronomy, (VSP, IUCAA, June 19-20).

Stellar spectral classification of automated techniques, (Institute of Astronomy, Cambridge, UK, January 3).

Neural networks, pattern recognition and signal processing, (Linear Accelerator Laboratory, Virgo group, CNRS, Orsay, France, January 11).

Small telescopes and robotics, (Invited talk, 17th ASI meeting, Guwahati University, Guwahati, January 19).

Automated photoelectric telescopes; Atmospheric effects and astronomical telescopes; Photometry; Photometer; and Astronomical spectroscopy, (IUCAA Workshop on Instrumentation for Small Telescopes and Astronomy Programmes at University Level, K.V. Parekh Science College, Mahuva, February 28-29).

A.M. Kane

The Internet : An introduction, (2 lectures, Computer Society of India, Pune, July 13).

Computer networking, (2 lectures, Workshop on Selection of Computer Hardware / Software, YASHADA, Pune, October 6).

Internet for the banking industry, (2 lectures, Workshop on Computers and Telecommunication Networks for Banks and Financial Institutions, NIBM, Pune, November 30).

A.K. Kembhavi

Dust lanes in elliptical galaxies, (Colloquium, University of Amsterdam, Holland, July 15).

The shapes of galaxies, (Colloquium, TIFR, Bombay, August 23).

Internet, (Pauling Club, NCL, Pune, October 12).

How many binary pulsars are there?, (Invited talk, Workshop on Gravitational Waves, IUCAA, December 10).

CCDs and other electronic detectors, (School of Studies in Electronics, Pt. Ravishankar Shukla University., Raipur, February 27).

A.A. Mahabal

Dust in elliptical galaxies, (Indo-US Workshop on Elliptical Galaxies : Structure and Dynamics, IUCAA, December 4).

Low opacity dust and finding it, (OCIW, Pasadena, USA, March 15).

D. Munshi

Gravitational clustering in the quasilinear regime, (Scuola Internazionale Superiore di studi Avanzati (SISSA), Trieste, Italy, July 26).

A comparison of nonlinear approximations to gravitational clustering, (Max Planck Instute for Astrophysics,, Garching, Germany, August 2).

Scaling relations in gravitational clustering, (Observatory of Paris at Meudon, August 30).

Gravitational clustering : A comparison of different approximations, (Queen Mary and Westfield College, London, England, September 1).

Aspects of scaling in gravitational clustering, (Internationational Conference on Gravitation and Cosmology, IUCAA, December 14).

Large scale structure formation in the universe: Theory vs Observations, (27th conference of IAGRG, Institute of Mathematical Sciences, Madras, February 6).

J.V. Narlikar

The quasi steady state cosmology, (Institute for Advanced Studies in Basic Sciences, Zanjan, Iran, May 7).

The search for extra-terrestrial intelligence, (Institute for Advanced Studies in Basic Sciences, Zanjan, Iran, May 8).

The quasi steady state cosmology, (Sherif University of Technology, Teheran, Iran, May 9).

Recent developments in the quasi steady state cosmology, (Instituto D Astrofisica D Canarias, Tenerife, Spain, May 18).

The quasi steady state cosmology: Achievements and challenges, (Theoretical Astrophysics Centre, Copenhagen, Denmark, May 30).

High energy particle physics in the quasi steady state cosmology, (Universitat Bern, Switzerland, June 6).

Concept of time in science, (His Holiness The Dalai Lama's 60th Birthday Celebrations, New Delhi, July 4).

Medium of instruction, (Ratna Sagar Pvt. Ltd., Delhi, January 17).

Strange effects of gravity, (Summer School Students, MACS, Pune, April 25).

Outstanding problems in cosmology, (2 lectures, VSP, IUCAA, June 12 and 13).

New developments on the Physics-Astronomy frontier - I, (Kothari Memorial Lecture, Physics Department, Banaras Hindu University, October 18).

New developments on the Physics-Astronomy frontier - II, (Applied Mathematics Department, Banaras Hindu University, October 19).

The cosmological challenges, (United Nation's workshop on Basic Space Science: From Small Telescopes to Space Missions at Colombo, January 11).

The Hubble constant, (ASI General Meeting, Guwahati, Assam, January 19).

The new developments on the Physics-Astronomy frontier, (P.C. Mahanta Memorial Lecture, Gauhati University, January 22).

B.B. Nath

Gas ejection from dwarf galaxies and the intracluster medium, (Workshop on Elliptical Galaxies : Structure and Dynamics, IUCAA, November 27).

Intergalactic medium, (IIA, Bangalore, Colloquium, February 13).

Dwarf galaxies in clusters and the intracluster medium, (RRI, Bangalore, Seminar, February 15).

D.K. Ojha

Galactic structure and stellar populations studies : Kinematics of the Galaxy's stellar populations, (IIA, Bangalore, Colloquium, May 9).

Intermediate population II and the merging history of the milky way, (TIFR, Bombay, Seminar, December 12).

Thick disc population of our galaxy, (PRL, Ahmedabad, Seminar, December 13).

Galactic structure and stellar populations studies, (PRL, Ahmedabad, Colloquium, December 14).

T. Padmanabhan

Quantum gravity - still at large, (Theoretical Astrophysics Centre, Copenhagen, May).

Structure formation - models, dynamics and status, (IAU symposium 173 on Gravitational Lensing at Melbourne, Australia, July).

Gravitational dynamics in an expanding universe, (36th Herstmonceux Conference on Gravitational Dynamics at Institute of Astronomy, University of Cambridge, Cambridge, UK, August).

Non-linear gravitational clustering in an expanding universe, (International Conference on Gravitation and Cosmology, IUCAA December 18).

A. Paranjpye

Coordinate system and time in astronomy, (VSP, IUCAA, June 19).

Types of astronomical telescopes and their mounts, (VSP, IUCAA, June 20).

Low cost photometer for monitoring the sky brightness, (Workshop on "Outdoor-Lighting and Night sky brightness", National Astronomical Observatory, Japan, July 15).

Estimation of sky brightness with a low cost photometer, (East Asian Meeting on Astronomy, Ground-Based Astronomy in Asia, Tokyo, Japan, July 20).

Grahan kase pahave (in Marathi), (Surya Grahan Abhyas - Rajyastariya Udbodhan Varga, Pune, October 16).

A.N. Ramprakash

Polarization of light and polarimetry, (Refresher Course in Astronomy and Astrophysics for College and University Teachers, IUCAA, May 11).

Imaging polarimeter (IMPOL), (East Asian Meeting on Astronomy, Ground-Based Astronomy in Asia, Tokyo, Japan, July 19).

S. Raychaudhury

The fundamental plane for disk galaxies, (Indo-US workshop on Elliptical Galaxies: Structure and Dynamics, IUCAA, November)

Peculiar velocities of galaxies, (ICGC-95, Workshop on Observational Cosmology , IUCAA, December 14).

Dark matter in cluster of galaxies, (Invited Talk, Astronomical Society of India, Guwahati, January 17).

Tully-Fisher surveys of the future, (Workshop on Science with the GMRT, NCRA, March 29).

T. Sahay

Project management, (Invited lecture, MBA Support Programme, Pune Management Association, Pune, October 15).

V. Sahni

Aspects of large scale structure of the universe, (S.N. Bose National Centre for Basic Sciences, Calcutta, TPSC Seminar, February 19).

Constraining models of structure formation, (Jadavpur University, Calcutta, Seminar, February 20).

The large scale structure of the universe, (Visva Bharati University, West Bengal, TPSC Colloquium, February 22).

Dynamical and statistical aspects of structure formation in the universe, (Institute of Physics, Bhubaneswar, TPSC Colloquium, February 26).

The inflationary universe: past and present, (Institute of Physics, Bhubaneswar, TPSC Seminar, February 27).

S. Sethi

Ionization structure of IGM at high redshifts, (ASI Meeting, Guwahati, January).

S. Sinha

Stochastic effects in semiclassical cosmology, (Department of Physics, University of Pune, April 7).

Stochastic effects in semiclassical cosmology, (IIA, Bangalore, May 3).

A stochastic approach to semiclassical gravity, (Department of Physics, Tufts University, USA, November 5).

Is minisuperspace quantization valid?, (Department of Physics, University of Maryland, USA, November 10).

A fluctuation-dissipation relation for semiclassical cosmology, (ICGC-95, Workshop on Quantum Gravity , IUCAA, December 13).

Noise in semiclassical gravity, (CTS, IISc., Bangalore, January 18).

R. Srianand

Dusty quasars, (Workshop on Active Galactic Nuclei, Dense Stellar System and Galactic Environments, IUCAA, January 8).

S. Sridhar

Making the thick disc by levitation, (RRI, November 3).

Adiabatic invariants and capture into resonance, (RRI, November 4).

L. Sriramkumar

The issue of backreaction in semiclassical gravity, (TIFR, Bombay, November 22).

S.N. Tandon

Small telescopes, (17th Annual Meeting of the Astronomical Society of India, Guwahati, January).

Detectors and CCDs, (2 talks, IUCAA Workshop on Instrumentation for Small Telescopes and Astronomy Programmes at University Level, Bhavnagar University, Gujarat, February).

b) Lecture Courses

S.V. Dhurandhar

Relativistic mechanics, (Department of Physics, University of Pune, August 7-9), 7 lectures.

R.K. Gulati

Stellar atmospheres and stellar evolution, (Refresher Course in Astronomy and Astrophysics for College and University Teachers, IUCAA), 6 lectures.

A.M. Kane

Data communications, networking and Internet, (Western Regional Convention, Computer Society of India, Aurangabad, March 1), 3 lectures.

A.K. Kembhavi

Millisecond and binary pulsars, starbursts, (Sino-Indian School on Astronomy & Astrophysics on High Energy Astrophysics, Nanjing, China, April 11-21), 3 lectures.

Elliptical galaxies : Structure and dynamics, (Indo-US Workshop on Elliptical Galaxies : Structure and Dynamics, IUCAA, November 23 - December 7), 3 lectures.

J.V. Narlikar

The many different faces of Mathematics, (National Symposium on Desiderata for Mathematics Research, Shivaji University, Kolhapur, March 22 -23), 3 lectures.

T. Padmanabhan

Structure formation in the universe, (Pennsylvania State University, US, May-June), 10 lectures.

N.C. Rana

Solar Astrophysics, (3rd semester students of Department of Space Science, University of Pune, July - November), 26 lectures.

S. Sinha

Quantum dissipative systems, (Saha Institute of Nuclear Physics, March 1, 2, 15), 3 lectures.

R. Srianand

Quasar absorption lines, (NCRA, Pune, February 26 - March 7), 7 lectures.

c) Popular Lectures

A.M. Kane

The Internet and you, (Business India Exhibitions, Networks 95, Bombay, September 6).

The world from your desktop, (Computer Society of India, Pune, September 29).

The world from your desktop, (Cybertech, Nasik, October 14).

A.K. Kembhavi

Cosmic images, (Indira Gandhi National Centre for the Arts, New Delhi, December 20).

Computer superhighways for the universities, (Pt. Ravishankar Shukla University, Raipur, February 27).

White dwarfs, neutron stars, black holes, (Pt. Ravishankar Shukla University, Raipur, February 27).

White dwarfs and the Chandrasekhar limit, (Department of Physics, Bombay University, March 20).

J.V. Narlikar

Are we alone in the universe?, (BBV Auditorium, Madrid, Spain, May 10).

Are we alone in the universe?, (Instituto D Astrofisica D Canarias, Teneriffe, Spain, May 19).

Talent fostering among students, (IUCAA, for Jawahar Navodaya Vidyalaya School Principals, July 18).

Strange and remarkable aspects of the cosmos, (Kendriya Vidyalaya, NDA, Pune, August 19).

From white dwarfs to black and white holes, (NCL Alumni Association, NCL, Pune, September 20).

Dainandin jeevanat vaidnyanik drishtikon (in Marathi), (Jalgaon, September 30).

Vaishwik grahane (in Marathi), (in the Solar Eclipse seminar arranged by, Gram Vidnyan Manch, Pune, Tilak Smarak Mandir, Pune, October 6).

Pruthvishivay itaratra jeevasrushti astitvat ahe ka? (in Marathi), (Latur, October 7).

The key role of science and technology in the present Indian society, National Academy of Direct Taxes, Nagpur, November 9).

Dainandin jeevanat vaidnyanik drishtikon (in Marathi), (SNDT's Smt. Champaben Bhogilal College of Commerce and Economics for Women, (Bombay, November 16).

Communications Technology: Marconi, present and future, (Institute of Electronics and Telecommunication Engineers, Pune, December 5).

The law abiding universe, (Justice B.D. Bal memorial lecture, I.L.S. Law College, Pune, January 6).

Antaratale chamatkar ani tyanche vaidnyanik spashtikaran (in Marathi), (Shivaji University Dnyanvistar Vyakhyanmala lecture, Yashwantrao Chavan Institute of Science, Satara, January 29).

Nave graha, navya grahamala - nirmiti ani shodh (in Marathi), (Vyankatesh Bapu Ketkar Smruti Vyakhyanmala public lecture, Pune, January 31).

Nave graha, navya grahamala - nirmiti ani shodh (in Marathi), (Aarey Dairy Development Commission, Aarey, February 3).

Outstanding problems on the Physics-Astronomy frontier, (P.M. Bhargava Foundation lecture at Hyderabad, February 22).

The many faceted nature of Mathematics, (Mathematics Society, Karnataka University, Belgaum, February 24).

Are we alone in the universe?, (Ravi Parvati Devi College, Belgaum, February 24).

Bhautik shastra ani khagolshastra madhil seemaresha, (in Marathi) (Ramanand Teerth Marathwada University, Nanded, March 2).

Nave graha, navya grahamala - nirmiti ani shodh (in Marathi), (Samata Mitra Mandal va Sneha Savardhan Mandal, Manchar, March 10).

Some questions relating to science-society interaction in the ancient Indian tradition, (during seminar on "Science Tradition and Scientific Tradition, FAMTSIT, Bangalore, March 13).

Did the universe have an origin?, (India International Centre, Delhi, March 19).

A. Paranjpye

Amateur astronomy in India, (Star Watching Meeting, Tokyo, Japan, July 16).

Itihasatil kahi mahatva purna gahane va pidhane (in Marathi), (Swami Vivekanand Vidyamandir, Dapodi, Pune, January 4).

Vishwa- 9-10 chy abhyaskramatle (in Marathi), (Janata Shikshan Sanstha, Pune, January 5).

History of magnitudes and star charts, (Star Party, Jyotirvidya Parisanstha, Khanapur, Pune, January 20).

Roop vikari tare (in Marathi), Jyotirvidya Parisanstha, Pune, March 3).

d) Radio / TV Programmes

A.K. Kembhavi

Time travel : Fact or fantasy?, (All India Radio, Pune, February 28).

J.V. Narlikar

Amhi ase ghadalo (in Marathi), (Youth Programme, All India Radio, Pune, April 18).

Chhanda vachanacha (in Marathi), (Balodyan, All India Radio, Pune, July 30).

In conversation, (Interview by Rajiv Mehrotra, Doordarshan, September 20).

Interview of J. V. Narlikar and Prakash Tupe, (All India Radio, October 14).

Khagras suryagrahan (in Marathi), (Doordarshan, Bombay, October 23).

Growing up : Reflections on childhood in India, (Interview by RAQS Media, Doordarshan, February 18).

Anecdotes from my life, (Interview by National Book Trust, Doordarshan, February 2).

Brahmand, (17 parts serial, Doordarshan, 1995-96).

Total solar eclipse, (Doordarshan, Iradatganj, Allahabad, October 24).

A. Paranjpye

Rahasye gaganachi (in Marathi), (All India Radio, Pune, December 10).

N.C. Rana

A simulation of Total Solar Eclipse, (Video film in English and Hindi) [funded by Vigyan Prasar, New Delhi, 1995].

(VIII) SCIENTIFIC MEETINGS

Sino-Indian School on Astronomy

The first Sino-Indian School on Astronomy, organized jointly by IUCAA and the Purple Mountain Observatory (PMO), Nanjing, was held at the Nanjing Normal University during April 9-21, 1995. This school was the first in a series to be conducted alternately in China and India, and was funded jointly by the Department of Science and Technology, Government of India and the Chinese Academy of Sciences. The theme of the school was High Energy Astrophysics, and the main topics covered included the evolution of massive stars, supernovae, pulsars and star bursts in galaxies. There were 5 lecturers from India and 11 from China and 40 participants from various university departments and institutions from all over China. The main lecture courses consisted of 2 or 3 lectures each and there were a number of seminars delivered by senior researchers as well as graduate students. There was a great deal of discussions generated during and after the lectures, as well as in the evenings, and it was heartening to see that many common astronomical interests exist between the two countries.

From discussions at the school, as well as at the Chinese observatories that the Indian lecturers visited on their way home, it became abundantly clear that there was much scope for the establishment of collaborative programmes between the two countries. In a meeting held at the end of the school, the Scientific Organizing Committee proposed that the next school should be held at IUCAA towards the end of 1996, and that the theme of the school will be observations, in the optical and radio bands, of the phenomena covered in the school in Nanjing. The visit to China was very exciting, memorable and scientifically productive, and it is to be hoped that the collaborations between the two countries will be beneficial to astronomy.

Coordinators : A.K. Kembhavi (IUCAA); Hong-jun Su and Fu-xing Su (PMO, China)

Workshop on Effective Way of Teaching Science

About 150 school teachers from Junior and Senior Secondary schools from Pune with 150 children of the fifth and sixth standard responded to a unique programme on 'Learning Science by Experiments'. About 40 experiments were set up provided with instructions of what to do, and a questionnaire on some fact-finding results. It was noticed that the students' overall performance was far better than their own teachers. The programme was very effectively conducted by Samar Bagchi, former Director of the Birla Museum in Calcutta during May 2-5, 1995 at IUCAA.

Coordinator : N.C. Rana (IUCAA)

3rd Refresher Course in A&A for College and University Teachers

The third Refresher Course in Astronomy and Astrophysics for College and University Teachers was held at IUCAA during May 8 - 26, 1995.

Participants of the 3rd Refresher Course in A&A for College and University Teachers

Thirty four participants joined the programme and there were about 50 lectures following a structured syllabus covering broadly the thrust areas of research in astronomy and astrophysics including the basics. Emphasis was also given for instrumentation and about half a dozen photometers were made by the participants. Due to cloudy skies, the observational programmes suffered. But on the whole, it was a successful venture.

Coordinator : N.C. Rana (IUCAA)

Workshop on Space Dynamics and Celestial Mechanics

A workshop on Space Dynamics and Celestial Mechanics, sponsored by IUCAA, was held at University Department of Mathematics, B.R. Ambedkar Bihar University, Muzaffarpur during September 18-22, 1995. The workshop reviewed the current state-of-the-art in space dynamics and celestial mechanics. There were 35 participants consisting of university/college teachers and research workers from Bihar and the rest of India. The academic programme included 14 lectures by invited speakers. 13 papers were presented by young teachers and research workers. In addition Andre Deprit (U.S.A.) delivered two lectures. The highlight of the meeting was a discussion of symbolic analysis of problems in Celestial Mechanics.

Coordinators : B. Ishwar (B.R. Ambedkar Bihar University, Muzaffarpur) and N.C. Rana (IUCAA)

Indo-US Workshop on Elliptical Galaxies: Structure and Dynamics

This workshop was held at IUCAA during November 23 - December 7, 1995. This was the third in the series of workshops planned under the Indo-US Exchange Programme in Astronomy and Astrophysics. The workshop consisted of a series of talks as well as seminars, by astronomers from the US and India. A variety of observational and theoretical aspects of elliptical galaxies were covered in the talks. There were about 60 participants in all and there was much discussion and exchange of ideas. Plans for collaborative research projects between US and Indian astronomers have been set up and it is hoped that these will be as scientifically fruitful as the projects which emerged from the earlier workshops of the series.

Coordinator : A.K. Kembhavi (IUCAA)

Workshop on Gravitational Waves

This workshop was held during December 9 - 12, 1995 at IUCAA. There were about forty-five participants with a break-up of about thirty from India and fifteen from abroad. The workshop consisted of lectures, seminars and discussion sessions. The discussions sometimes extended over dinner. An introductory talk to student participants was also given after dinner. The speakers were representatives of a wide area from experimentalists working on bar detectors and interferometers to theorists who were interested in intricate waveform calculations and data analysis. The wide coverage was useful for obtaining a perspective of the current status of the field. All the participants found the workshop highly stimulating.

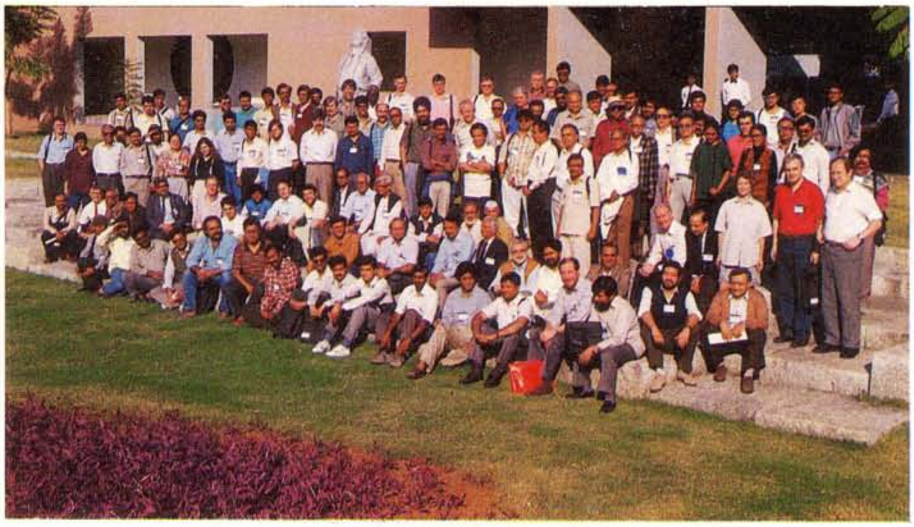
Coordinator : S.V. Dhurandhar (IUCAA)

International Conference on Gravitation and Cosmology (ICGC-95)

This was the 3rd meeting in the series of ICGC meetings hosted in India and was organised at IUCAA during December 13 - 19, 1995. The first one was in Goa in 1987 and the second one was at PRL, Ahmedabad in 1991. The key themes for this meeting were (a) Cosmology and Structure Formation (b) Quantum Gravity (c) Gravitational Radiation and (d) Classical General Relativity.

ICGC-95 had 16 plenary lectures and 4 workshops dealing with the 4 themes mentioned above. The plenary lectures reviewed the current status of different topics in gravitation and cosmology and the workshops were devoted to more specialised and intensive discussions. In addition to these, there was a special workshop on Alternative Cosmologies on one afternoon, which generated lively debate on current status of cosmological models.

The following person gave plenary lectures: L. Blanchet, G.F.R. Ellis, R. Ellis, S. Finn, J. Friedman, J.J. Halliwell, J. Katz, M. Longair, T. Padmanabhan, P.J.E. Peebles, J. Pullin, E. Seidel, D. Shoemaker, C. Torre, M. Varadarajan and J.-Y. Vinet.



Participants of the International Conference on Gravitation and Cosmology

Workshops were coordinated by N. Dadhich, G.F.R. Ellis, J.J. Halliwell, B.R. Iyer, K. Kokkotas, M.A.H. MacCallum, Varun Sahni, T.P. Singh and K.C. Wali.

A special session on Raychaudhuri equation was also coincided with the ICGC-95. This session started with the special remarks by J.V. Narlikar and A.K. Raychaudhuri and was followed by four lectures by D. Brill, C. Clarke, P. Joshi and P. Szekeres, which discussed the applications of Raychaudhuri equation in various areas of gravitation and cosmology.

The conference summary was given by M.A.H. MacCallum. More than 170 participants from India and abroad attended the ICGC-95.

Coordinators : S.V. Dhurandhar and T. Padmanabhan (IUCAA)

Mini Workshop on Gravitational Collapse and Cosmic Censorship

This workshop was held during December 20 - 23, 1995 at IUCAA. The workshop was inaugurated by P.C. Vaidya and the speakers included D. Brill, M. Bruni, C. Clarke, N. Dadhich, T. Dray. I.H. Dwivedi, J. Friedman, S. Hayward, S. Jhingan, P. Joshi, G. Kang, J. Moffat, K. Newman, A. Ori, J. Pullin, K. Rama, E. Seidel, T.P. Singh, P. Szekeres, C.S. Unnikrishnan and C. Vaz. There were in all 50 participants.

Coordinators : N.K. Dadhich (IUCAA); T.P. Singh and P. Joshi (TIFR, Bombay)

Workshop on Active Galactic Nuclei, Dense Stellar System and Galactic Environments

A workshop on Active Galactic Nuclei, Dense Stellar System and Galactic Environments was held at IUCAA during January 9 - 12, 1996. This was organised by Judith Perry, IOA, Cambridge, and Susan Lamb, University of Illinois, Urbana, and S. Raychaudhuri and A.K. Kembhavi of IUCAA. The workshop was conceived as a part of a long-term symbiotic collaboration organised by Judith Perry which involves bringing together a number of active persons in the field to identify problems of common interest and carry on long-term collaboration projects. The idea in having the workshop at IUCAA was to make it possible for Indian astronomers from the universities with interest in the area of the workshop to participate in the highly productive activity. A number of lectures on the theme of the workshop were given and were followed by detailed discussions on the subject matter.

Some of the participants were present in IUCAA for some days before and after the workshop so that informal discussions and setting up of collaborations could take place. The proceedings of the workshop will be published in due course under the Astronomiocal Society of the Pacific Conference Series.

Coordinators : J. Perry (Institute of Astronomy, Cambridge) and A.K. Kembhavi (IUCAA)

Participants of the Workshop on Active Galactic Nuclei, Dense Stellar System and Galactic Environments

Workshop on Instrumentation for Small Telescopes and Astronomy Programmes at University Level

A Workshop on Instrumentation for Small Telescopes and Astronomy Programmes at University Level was held from February 26 to March 1, 1996 at the K.V. Parekh Science College (Bhavnagar University), Mahuva, Gujarat. The workshop was jointly organized by IUCAA, Department of Physics, Bhavnagar University and Mahuva Education Trust. P.C. Vaidya inaugurated the workshop and B.K. Parekh, Chairman, Mahuva Education Trust delivered the presidential address. There were lectures by S.N. Tandon and R. Gupta (IUCAA), T. Chandrasekhar, J.N. Desai, N.M. Ashok (Physical Research Laboratory), R.V. Mehta, S.P. Bhatnagar (Bhavnagar University), A. Ambastha (Udaipur Solar Observatory) and D.B. Vaidya (Gujarat College). There were also experiment and demonstration sessions by V. Ramamurthy (Bhavnagar University) and R. Gupta (IUCAA), and sky-watching sessions. Night sky observation at the residential rural school at Kalsar, where the students and teachers were involved, also formed a part of the workshop. About 40 participants including M.Sc. students, and college and university teachers attended the workshop. A science quiz was organized by C.S. Narayanamurthy (Bhavnagar University) on the National Science Day.

Coordinators : R.V. Mehta (Bhavnagar University), D.B. Vaidya (Gujarat University) and R. Gupta (IUCAA)

(IX) VACATION STUDENTS' PROGRAMME 1995

The Vacation Students' Programme (VSP) was conducted at IUCAA during June 5 - July 14, 1995. Under this programme 15 students from the first year M.Sc. level and third year B.Tech./B.E. level were selected on all India basis of which 11 joined. They spent 6 weeks at IUCAA and completed projects under the supervision of the IUCAA faculty members and post-docs. During the programme, about 20 lectures were delivered by the academic staff of IUCAA and National Centre for Radio Astrophysics (NCRA).

Towards the end of the VSP, all students were asked to give seminars on their projects and later interviewed for a possible future offer of research scholarship at IUCAA, for the Ph.D. programme. Two scholars were pre-selected. B.S. Sathyaprakash was the coordinator of the programme.

Facilities

(I) Computer Centre

The IUCAA Computer Centre has continued to extend improved facilities to users from IUCAA as well as visitors from the universities. There has been all round upgradation in the hardware and software, in line with facilities in other leading centres in the world. During the period of this report, a high performance Silicon Graphics Power Challenge machine which is capable of providing speeds up to several hundred Mflops, when the code is parallelised, has been installed. This machine makes it possible for very long number crunching tasks to be undertaken. The available workstations and PCs in IUCAA are now spread throughout the building which means that large volumes need to flow all over. To ensure speedy transmission of data, the Ethernet network which was laid down 4 years ago is now being changed to an ATM network in steps. The first phase, which has involved fibre optic and UTP cabling and the introduction of Ethernet switches, has already been completed and has substantially increased the throughput of data.

As a part of its activities, IUCAA acts as a node for the ERNET which provides full connectivity to Internet. An increasing number of users from within Pune and the surrounding areas connect to ERNET through IUCAA. Some university departments situated in distant cities also find it convenient to use the IUCAA node.

An increasing number of users from universities and colleges are being introduced to the facilities offered by the Computer Centre. They are being trained in various aspects of computer usage including programming, image processing, text processing and so on. The Computer Centre has also continued to provide advice and support to university departments to improve their computing facilities. University users are being encouraged to start major computing projects based in IUCAA and to use the facilities available by remotely using ERNET.

(II) Astronomical Data Centre

The Astronomical Data Centre (ADC) project, which was funded by the Department of Science & Technology has come to an end on March 31, 1996. During the period of this report, there has been conspicuous increase in number of types of astronomical catalogues available with the ADC. Efforts have also been made to develop software, using network browsers which can be easily installed on a variety of machines. As a result of this development, software which makes it possible to easily access catalogues is available in highly portable form. The software also allows the user to efficiently browse catalogues at remote sites when the required communication facilities are available. The astronomical catalogues in IUCAA, as well as those situated worldwide, can easily be accessed and browsed through using the homepage of ADC on the World Wide Web. The facilities offered by the ADC have been used extensively by astronomers from the university sector as well as research institutions. To familiarise people with the available data, lists of catalogues have been circulated periodically.

(III) Library

The collection of books in the IUCAA Library has continued to grow with the addition of new publications as well as older works. The latter have often been obtained through personal donations of books by many individuals. This has allowed the Library to acquire valuable works which are difficult to obtain or are out of print. The Library now has 12,800 books and subscribes to 160 periodicals. The Library obtains pre-prints and re-prints from a number of sources. The Library has been kept abreast of developments with electronic publishing on the Internet and makes these facilities available to its users. The Library subscribes to the Physics Information Network (PINET) of the American Institute of Physics, and has recently acquired a PC with multimedia capabilities. The Library provides books on loan to libraries in other institutions.

(IV) Instrumentation Laboratory

The laboratory has facilities for assembly and testing of optical instruments, as well as facilities for design and fabrication of the electronics for these. In order to increase the support and facilities for the visitors from the universities, a new laboratory has been created with a dark room, and it has been been equipped with test instruments. This new laboratory is being used by the visiting faculty members from the universities, etc., as well as by the students doing projects as part of their degree course.

The visitor laboratory has also been extensively used for fabricating night sky photometer, B, V and R optical filters by various university/college participants and sometimes by amateurs, and for the purpose of teaching of M.Sc. Astronomy courses, etc. A. Paranjpye, S.N. Tandon and R. Gupta are involved in these projects.

Some instruments for site testing have been developed and these are being used at a prospective site. The imaging polarimeter referred to in the last years report is now ready for use on a telescope. The first CCD camera is ready and it would be used with the imaging polarimeter, and a more versatile version of the CCD camera is under development. More details on these instruments can be seen under the head Instrumentation in the section *Research at IUCAA*.

(V) Recreation Centre

The recreation centre of IUCAA - Chittaranjan - now provides several facilities which are open to staff members of IUCAA and visitors. There are two tennis courts which are maintained on a daily basis. The balls are purchased and made available at a reasonable monthly fee. A cricket kit with net has been purchased and is augmented from time to time as the need arises. An annual cricket match is played between IUCAA and NCRA with enormous competitive spirit. The centre hosts several indoor games and recreational facilities. There is an indoor badminton hall, table tennis table, two carrom boards, a chess board permanently mounted on a table and a gym fitted with modern equipment. It also has a library which at present has about 800 books and novels. Magazines of current interest are purchased regularly. There is also a TV set tuned to various satellite channels and is housed in the lounge. Racquets for tennis, badminton and table-tennis are available to visitors on request. We urge the visitors to use the facilities provided by the centre. The recreation centre is still developing and, thanks to a donation from Larsen and Toubro Ltd., a swimming pool is now under construction and expected to be completed by the end of the summer of 1996. Future plans include a volley ball court, croquet lawn, etc.

Science Popularization Programmes

(I) National Science Day

The National Science Day, on February 28, 1996, was celebrated by IUCAA, with a participation of about 500 school students and teachers. The programme included science test, essay competition, drawing competition, astro-dramas, video show on eclipse and science quiz. Sixty schools from Pune city participated. The title of the essay competition was Difficulties Encountered in Learning Science. Essays were written in Marathi and English, and some of the essays were eye openers to the science curriculum makers. In Marathi essay competition, the first and the second prizes were awarded to Madhura Dilip Sane of H.H.C.P. High School and Vrishali Suresh Kshirsagar of Abhinav Vidyalaya. In English essay competition, the corresponding prizes were awarded to Khushboo Shingare of Vidya Bhavan High School and Anita Sathe of M.E.S. Bal Shikshan Mandir. There were some consolation prizes also.

Theme of the Drawing competition was Any Scientific Exhibit at IUCAA. Some of the drawings were really excellent and the first three prizes were given to Anuja Limaye of P.E.S. Girls' High School, Vinayak Nagpal of Loyola High School and Tejaswini Palande of H.H.C.P. High School respectively. There was one consolation prize too.

The Astro-dramas, 'The Lost Planet' and 'Twinkle, Twinkle Little Star...' were enacted by the Standard V and IX students of Muktangan English School and Junior College. The students were assisted by the teachers and the performance was appreciated by one and all, and the theme was apt to the present day situation. A Video film on the October 24, 1995, total solar eclipse was also shown.

The programme ended with the much awaited Science Quiz, in which 8 teams of 4 students each were selected and participated. The first, the second and the third prizes were won by the teams from St. Vincent's High School and Junior College, Loyola High School and Junior College, and Muktangan English School and Junior College, respectively. The celebrations concluded with the Director giving away the rolling trophy, cup and a plaque to the winning teams.

(II) Popularization of Astronomy

3", 8" and 14" telescopes

This year also IUCAA's two 3", one 8" and one 14" telescopes were being put to use for popularization of Astronomy for public viewing of celestial bodies. This programme is being arranged on every 4th Friday of a month. About 30 people are invited for this viewing. Venus and comet Hyakutake had been this year's attractions. Local amateur astronomers association (Jyotirvidya Parisanstha - JVP) also used IUCAA's 3 inch telescopes for the demonstrations at the camps organized by schools and other clubs.

There has been participation from the JVP in taking photometric observations. The 14" telescope was used for variable star observations. Three variable stars II Peg, UX Ari and HR 1099 were observed by differential photometry. And CCD imaging of the comet Hyakutake was also carried out.

Total Solar Eclipse, 1995

There was on the card a total solar eclipse on October 24, 1995 (in short TSE-95) to be passing over most of the northern and eastern states in India, namely Rajasthan, Uttar Pradesh, Madhya Pradesh, Bihar and West Bengal. The path was approximately 45 Km wide and 1800 Km long with the duration of totality roughly about a minute. There lived at least 25 million people on this belt of totality. IUCAA's popularisation programme has been to remove the die-hard eclipse superstitions to the extent it was possible by giving lectures and radio talks, writing books and articles, and producing audiovisual programmes. During the State's exalting Ganesh festival, one audio-visual programme organised in the city attracted more than 50,000 people, and continued over a period of three weeks. IUCAA had organised a week-long 'Pre Total Solar Eclipse Training Programme' about a month and half in advance of The Day. The amateur astronomers were encouraged to join their hands in the mission of propagating the message of importance of viewing this unique celestial event. Then there were efforts in manufacturing the aluminized mylar sheets indigenously in the country. A firm in Bangalore was identified to produce the aluminized mylar sheets in bulk quantities, and a Pune-based organisation took the responsibility of reaching about 500,000 eclipse goggles to the people. Guess-estimates suggest that at least two million people did watch the total solar eclipse from various locations on the eclipse belt over India. The turn-over from villages were much more than the city-based people for coming out of the house in order to view the eclipse in the sky.

IUCAA's project on TSE-95 for measuring the umbral width of the moon's shadow and therefrom the diameter of the Sun has primarily been executed by the local college and university students, a few hardware and software specialists. Towards the last phase of the project, about 32 amateurs worked for constructing 350 photodetectors with in-situ EPROMs and power supply from ten pencil cells and transplanted at the desired locations in Rajasthan within a time span of only 38 days. A remarkable feat indeed. All the designing of the circuits and the PC boards, assembling 52,000 electronic components, soldering 2,53,000 points on 700 PC boards, testing the performance of the circuits, calibrating the units to absolute flux densities of the sunlight, making 350 sturdy tripods using wooden sticks that support the rolls of cloths, designing altazimuth metallic stands for focussing the units towards the Sun, hiring necessary equipments for power supply, relay work, and drawing 14 Km long cable across the two boundaries of the umbral were executed by these enthusiastic volunteers. This team adopted a self-styled name as 'The Big Bang Group'. IUCAA had spent about Rs. 3,07,000/- towards purchase of hardware, and about Rs. 95,000/- towards conveyance and logistics on sites. This group is enthusiastically awaiting the next such opportunity, provided adequate financial grants are available to that effect.

IUCAA had also specially designed and made 75 eclipse T-shirts, 5,000 eclipse goggles and 200 special Diwali greeting cards, and arranged a special trip to Pragpura in Rajasthan for the interested families in IUCAA for viewing total solar eclipse. A very clear sky throughout the path of the totality over India with a couple of diamond rings, two sets of Bailey's beads and the grand display of shadow bands on this occasion offered the best possible opportunity for both the scientists and the laypersons to their best levels of satisfaction.

Amateur Astronomers' Meeting

As in the previous years, IUCAA extended partial financial support and advice on request for holding the Sixth All India Amateur Astronomers' Meet, conducted under the supervision of the Confederation of Indian Amateur Astronomers. The Meet was organised in Madras during January 25-27, 1996, and hosted by the Tamil Nadu Science and Technology Centre, Tamil Nadu Astronomy Association and Tamil Nadu Science Forum. It was a very successful meeting of about 165 outside participants from various parts of the country in addition to 50 local participants. A wide variety of topics were discussed in the form of seminars, added by the colourful display of Eclipse photographs in prints, in slides, in software packages and in paintings. The next Meet is slated to be held in Delhi hosted by the Nehru Planetarium.

IUCAA also hosted partially and worked fully with mutual understanding of the team members visiting from US Naval Observatory, International Occultation Timing Association, and Science of Space Telescope Institute. They all have been provided with the most accurate coordinates of their observational sites to the level of accuracy better than they wanted for.

Programmes for School Students

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

(I) Summer Programme

Following the trend of the previous years, the summer at IUCAA witnessed about 136 students doing their week-long projects at IUCAA under the guidance of several academic members of our family. The students hailed from about 70 local schools in Pune. Each school had nominated as usual two students of the eighth/ninth/tenth standards, and the load was distributed in six consecutive weeks starting from April 17, 1996. Students performed experiments/observations, made models, went through informal lectures cum discussions, and did their own study in the library. About 56 students made 30 Newtonian telescopes 40 × 50 with sturdy altazimuth stands, and these were donated to the respective schools.

(II) Lecture Demonstrations

For conveying the excitement of doing science to secondary school students, this programme was instituted. This is being held on the second saturday of every month. Under this programme the following lecture demonstrations were conducted:

J.V. Narlikar

Vishwachi rachana, (in Marathi) July 8.

The structure of the universe, (in English) July 8.

A. Paranjpye

Najikchya kalat honarey khagras suryagrahan, (in Marathi) August 12.

N.C. Rana

The forthcoming total solar eclipse, (in English) August 12.

Aftermath of the total solar eclipse, (in English) December 9.

V. Sahni

The expanding universe, (in English) October 14.

S.N. Tandon

Radiation, transport and balance, (in Hindi) January 13.

S.S. Aundhkar (Pune)

Khagras suryagrahana-nantarchey parinam, (in Marathi) December 9.

H. Bondi (Churchill College, Cambridge, UK)

Why is it dark at night?, (in English) February 6.

S. Dake (Pune)

Shaleya prayogashalesathee kami kimtichi shastriya upakaraney, (in Marathi) September 9.

Low cost scientific instruments for school laboratories, (in English) September 9.

All 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, some students had to sit on the floor. On a few occasions, IUCAA was forced to decline admission to latecomers because of insufficient sitting space.

School Students, who participated in the Summer Programme for School Students, with N.C. Rana

Seventh IUCAA Foundation Day Lecture

Making Economic Sense of Science: The Emerging Indian Challenge

by
Dr. R.A. Mashelkar
Director General
Council of Scientific & Industrial Research
New Delhi 110 001

I am indeed honoured and privileged to give the Foundation Day Lecture of IUCAA. I am particularly happy that it gives me a great opportunity to pay my tributes to one of the finest centres of excellence in India that has been built by my friend Jayant Narlikar and his colleagues. I have closely watched the evolution of this great institute. What started in 1988 in 100 square feet space in Golay Bungalow is today a magnificent edifice built on 150,000 square feet with Devayani, Akashganga and Aditi shining away in full glory! IUCAA today has assumed the role of the hub of a wheel with vital and organic linkages with the universities residing on its rim, and what a powerful wheel it is! Already its endeavours in galactic and extragalactic astronomy, theoretical cosmology, gravitation and relativity are bringing glory to Indian science. To me, IUCAA represents India's determination to lead the world in astronomy and astrophysics. I salute this great institute today on its birthday and wish it several glorious decades of leadership.

Science is a many splendoured endeavour. I have myself been involved in looking at science that makes economic sense. The issue of making economic sense of science is an old one. But this old problem assumes a new dimension today in the new context, particularly for India. As we know, there has been a sea-change in the economic, political and technological environment the world over. The wave of change sweeping the country and the world has thrown up myriad opportunities and at the same time it has posed enormous challenges. In this new world, there will be extraordinary opportunities for those, who are prepared to welcome these winds of change. One such opportunity will be to create wealth through India's intellectual power.

I am going to speak about the essence of the paradigm of wealth creation through knowledge. Indeed, there is a new definition of wealth today. Wealth is no more measured in terms of fixed assets such as buildings, land, bank account, etc. It is measured in terms of those knowledge based systems, which add value. In today's world, goods, services, data, people, etc. cross the physical borders of different nations freely. However, adding value through knowledge gives nations a competitive advantage. Many countries realise the value of the intellectual prowess of its people. For instance, witness the interesting recent developments in Japan, which is considering a legislation, where intellectual property can be considered as a security against loan.

Where does India stand in this context? Jack Welch, the Chief Executive Officer of General Electric Company from USA was here last year. He said that India is a developing country but it was one of the most developed countries as far as its intellectual infrastructure was concerned. In that sense then, we should be a rich country. But we are not. Why is this so? It is because, among other things, the wealth creation potential of knowledge is something that we have not fully understood. We have still not learnt to build the bridge between discovery and market place. Ability to build this bridge is a prerequisite for

Indian science to make economic sense. I wish to speak to you today about a heady dream of not only making India the intellectual capital of the world but also an economic power to reckon with. If this is the vision of India in the 21st Century, then what would be a road map to reach this vision? I will focus on this vital issue today.

Science-Business Links : Need for Change

Science can make economic sense only when we awaken the scientist in an entrepreneur and also the entrepreneur in a scientist. Nations that occupy leading positions have successfully done this but in India we have not done it so successfully. Further our science-business links have been traditionally very poor.

How do we build a strong bridge between discovery and market place? The battles in the market place are fought, of course, by our industry. What has been their attitude to establish a link between science and business? I am afraid, their attitude has not been very positive. Our industry had enjoyed the presence of a seller's market for many decades. The heat of the competition in the market place was not felt by them. With opening up, the picture is changing. It is becoming clear to the industry that only those will survive and succeed, who understand the market dynamics and consumer needs, who have a sustained commitment to world class R&D, who are able to develop and market superior products ahead of their competitors and who understand the key role of the intellectual property in trade and commerce. But it will be some time before this realisation will materially transform the scenario in India. What are the ground realities today and how quickly can we pass through this transition? Let me address this issue first.

The fundamental problem that we have today is that the institutions and the business units in industry have different cultures. The fact that science has to make an economic sense has not dawned on our institutions. On the other hand, the fact that competitive advantage in business can only be reached by using cutting edge science and engineering alone has not been realised by our industry. There are basic incompatibilities between our institutions and industry. The institutions have a long term horizon on R&D, whereas the business units have a short term horizon. As regards the financial structure, R&D units are considered as cost centres whereas the business units would want them to be profit making centres. As regards the products emerging from R&D laboratories, these invariably come out as some sort of packages containing knowledge and information, whereas the business units would want to convert these into goods and services, which are saleable. There is even a difference in the basic orientation between the institutions and the industry. The institutions work on the basis of scientific novelties and perceived needs, whereas the business units work on the basis of attractiveness in the market and potential for profit. There is a need for both the R&D institutions as well as industry to change their mind sets.

What changes of mind sets will be required if the science-business link in India has to be strengthened? Firstly, our Indian industry will have to champion R&D with a vigour. Apart from its willingness to invest in R&D, the industry should be willing to take risks and should have patience to wait for returns. Publicly funded R&D institutions should be used as idea generators and providers of new concepts by our industry. Industry should not simply look at the institutions as super markets where off the shelf technologies are sold. Indian industry should be prepared to assume the role of partners, who have the technical, financial and marketing strengths to take ideas to the market place. In the true spirit of partnership, the industry should willingly integrate national R&D resources into their business strategy. All this would be possible only when we can change the climate for an interaction between our institutions and the industry with an improved communication and understanding, faith in mutual growth and development of healthy working relationships.

Technology Denial to India

Let us deal with one myth quickly before we move on. As we know, opening up of the economy and integration of the Indian economy with the global economy is a process that has already gained momentum over the last five years. There is a mistaken notion that opening up will result in our having unlimited inflow of technology and therefore we do not have to now worry about developing technological strength by sweating it out! After all technologies will be available on platter. All that we have to do is to acquire them and adapt them. Nothing can be further from truth. I will like to give concrete examples to illustrate as to why such thinking is wrong.

In the first instance, the technology game has become very complex. Technology will be available to Indian companies only if it fits in with the global scheme of a supplier. If Mark-III technology is available, then we might negotiate for Mark-II and in most cases we may get Mark-I. This is because India will be looked at, not as a bottomless pit of demand, but as a competitor in the global market. I remember that when I was associated with Indian Petrochemicals Corporation Ltd. a few years ago, we tried to get the alfa olefins technology from some European, US and Japanese companies. We did not succeed. Was alfa olefin strategic? It was not. After all alfa olefin was going to be used for making sulfonates, which were mere detergents to be sold in the consumer markets. There was nothing strategic about this material, but we still did not manage to get the technology. The reason was simple. With India's competitive advantage, it was felt that we will be competitors in the world market and technology was denied to us.

The technology game is already becoming very complex. The days of straight forward technology licensing are over. Technology-cum-product swap, technology-cum-stake holding, etc. are the new equations. Marketing territory restrictions are being put up. Even technology is being broken into pieces and each part is being made available separately. Straight forward technical services contracts are also becoming difficult to negotiate.

Many sectors of our economy will face unprecedented challenges. Being familiar with the chemical industry, I can quite clearly see the difficulties that we will be encountering in this area. Products will have to meet stringent green specifications. For instance, if one is exporting leather treated with PCP, then the PCP content will be prescribed by the importing country at a few parts per million level and we will have to meet these specifications for our leather to be acceptable. This requires a technological solution. Look at the difficulties the export of Indian fabrics faced recently. The ban on the use of carcinogenic dyes implies that we have to look for alternative green dyes and also new technologies of dyeing. Globally, process and product audits are being enforced. In other words, green technologies will have to be used to provide the right ecofriendly manufacturing options, otherwise our products will not be accepted in the world market.

New non-tariff barriers are beginning to come in. Restrictions due to dual use technology are already familiar to us. Demand on removal of all subsidies, unified IPR regime, etc. are other forms of non-tariff barriers. The same health and safety standards for our labour will be demanded so that the obvious advantage of the cheaper labour that we had always talked about in the context of India will be lost. The only way we can fight these battles is through the means of continuous innovation and technology development.

Before I end this topic, let me correct another impression and that is about availability of technology through joint ventures. Why not form joint ventures and, then of course, technology will be available to us from our foreign partners. This is not quite right again. It needs to be emphasised that equality in equity based joint ventures will have to be earned and not demanded. This equality can be earned only when we have a strong technological muscle ourselves. When our Indian pharmaceutical company Ranbaxy wanted the famous Eli-Lilly from USA to be partners, they were not very successful in persuading them, since Eli-Lilly was lukewarm. However, the moment Ranbaxy demonstrated their technological prowess by developing Cefaclor a leading antibiotic, and capturing a share of world market, Eli-Lilly developed a sense of respect for them and became partners with Ranbaxy. We must realise that eventually strength respects strength.

What I am really trying to emphasise is that there is no substitute for creating a technology movement in the country. Unfortunately this movement has not taken place so far. One element of this technology movement is the science-business link that I spoke about earlier. There is no substitute for our industry itself investing heavily in in-house R&D and synergising with our national institutions.

CSIR's Will to Change

I have spoken at length about the need for the industry to change, but what about the national laboratories? Isn't there a need for change for them also? Of course, there has to be a dramatic change in the way these laboratories function too. I want to seek your indulgence to speak briefly about my own organisation, Council of Scientific and Industrial Research (CSIR). With a chain of 40 national laboratories, employing 10,000 highly qualified scientific and technical personnel, CSIR is trying to open up a new chapter in the partnership with industry by linking its research to market place. We are articulating a new dream and a vision for CSIR 2001. This represents a major vote for change by the members of the CSIR family. CSIR has the dream to become a model of organisation for scientific and industrial research, which implies that it will do industrial research with cutting edge science rather than doing scientific and industrial research with no connection between the two. CSIR wants to be a path-setter in the shifting paradigm of self-financing R&D. It has the vision to become a global R&D platform providing competitive R&D and high quality science based technical services world over.

CSIR realises that this grand vision cannot be achieved unless a close partnership between science and business is forged. CSIR's business strategy would therefore seek to link and relate its R&D to market place by studying and analysing technology and market trends and forecasts. This will help identify niche opportunity areas, partners, customers, competitors and markets. CSIR will be evolving a balanced portfolio of projects. Some projects will be industrially led, cost shared and market driven. Some others will be self propelled and create new processes, products, applications and markets. CSIR will thus be market driven as well as drive the markets. CSIR will be exploring and establishing synergistic alliances, consortia and networks. The idea is to do value addition and maximise the returns.

All of this would necessitate continuous interfacing of CSIR's knowledge with the market place. This is an activity that could be best done through effective business development and marketing systems. CSIR realises that marketing of R&D knowledgebase is different from marketing of physical products and goods or even services. It is best done by persons who are closest to and involved with the generation of the knowledgebase as they are emotionally attached and well versed with diverse nuances and variations of it. Thus the entrepreneur in a CSIR scientist would be awakened, so that he could venture out in the knowledge market space. The strategy to further enhance the marketing of CISR knowledgebase would be to develop, through appropriate training, skills of scientists for diverse aspects of business development and marketing activities. Select CSIR laboratories will be allowed to set up separate companies for business development and marketing. With a step jump in ambition, CSIR will even twin with R&D institutions and organisations to realise synergy of business opportunities. These new models of science and business partnerships that CSIR is trying to experiment with will hopefully represent the microcosm of change that we are all looking for in India.

Transnational Bridges Between Discovery and Market Place

I said earlier that we must build a bridge between discovery and market place to make economic sense of Indian science. There is a new realisation that such bridges cross national boundaries today. Indeed, more often than not, the chain of concept to commercialisation necessarily transcends national boundaries today. There is a great opportunity to make economic sense of Indian science by forging strategic relationships with international partners. Indeed, many major multinational corporations in USA and Europe, whose R&D budgets are larger than even India's R&D budget, are willing to become partners of India's R&D laboratories. We should not take a narrow and timid view of such opportunities that are unfolding but go out aggressively to forge such partnerships and create a win-win situation on our own terms.

In order to understand the intricacies of this game, we must understand the dynamics of the global knowledge market place today. Many companies across the world today consider it to be rather unwise to attempt for self-sufficiency in technology development, particularly in an era, where the R&D costs are increasing rapidly. The concept that technology could be acquired rather than re-invented is gaining momentum. As a part of the global innovation strategy, several companies world over are scouting for new ideas and patents. These companies believe that the surest way of becoming technically strong is through net working with premier organisations across the world. In an era of global connectivity through modern information technology, the concept of virtual laboratory is gaining ground.

External technology acquisition is assuming importance within leading corporations. R&D departments are increasingly being charged with the job of managing and restructuring the corporation's technology portfolio. Their success is being measured in terms of what they have brought to that portfolio.

Science is coming to the centre stage in what is essentially an economic activity in different ways now. Basic scientific skills are gaining importance and the new paradigm is skill based competition. Indeed, as product life cycles keep on becoming shorter, skill-life cycles become longer. The product then is merely an intermediary between company's skills and the market it serves. Rather than being the focus of corporate activity, products are actually transient mechanisms by which the market derives value from a company's skill-base and the company derives value from the market. The high technology companies are therefore asking as to what skills, capabilities and technologies should they build up, rather than asking a stereotype question, as to which markets should they enter, and with which products. The competitive advantage lies in the power and effectiveness of the allied network, which a business team is able to assemble and manage in a short time, rather than in the in-house capability. This strategic shift is shaping up new global partnerships.

I want to emphasise that several factors will help accelerate these new partnerships through globalisation of industrial R&D, but the most important factor that will help the process of creation of seamless laboratories around the world will be the evolution of a global information networks. Indeed, these networks will allow the real-time management and operation of laboratories in any part of the world. Thus, companies will be seeking to gain a competitive advantage by using the global knowledge resource and working with a global time clock.

Realisation of the power of this major paradigm shift means enormous opportunities for Indian R&D institutes. We have to aggressively spot these opportunities. I recall with great satisfaction my speaking to my colleagues in National Chemical Laboratory (NCL) when I took over as the Director of this laboratory on June 1, 1989. I said that we should have the dream of converting the National Chemical Laboratory into an International Chemical Laboratory. What I meant was that we should partner on equal terms with some of the biggest giants in the world. The idea was that they will put the capital on the table and we will match it by our intellectual capital. The hidden agenda was that we will benchmark ourselves with the very best in the world in the process and create a cadre of world class professionals in our own laboratory. We are proud that we began the process of global R&D partnerships in NCL in 1989, well before July 1991, when India as a nation formally decided to integrate its economy with the global economy. NCL entered the global market in 1990 by signing an agreement for sale of its catalyst technology with a multinational company from Netherlands. This was the first time such a reverse transfer of technology was taking place in a high tecn material. NCL had also won a consultancy contract in China in 1990 by competing with reputed US consulting companies. This initial success led to number of other companies joining hands with NCL. Names like General Electric, Du Pont, FMC, Ciba Geigy, Oxychem, Exxon, who are all known giants in the international arena, from USA and Europe have become NCL's partners. This phenomenon has, of course, spread much wider today.

Let me first cite some examples from the CSIR family itself. CDRI in Lucknow has developed an anti-fertility drug, centchroman, and it is now collaborating with a US-based firm on attractive terms to explore its uses for other exclusive applications. IIP in Dehradun has developed a process for the oxidation of cyclohexane to adipic acid along with an Indian company, Adarsh Chemicals. They have signed an agreement for joint development with ABB Lummus Crest Inc. and Praxair Inc. USA. NAL in Bangalore has partnerships in fatigue research with Boeing, a major leader in aircraft business. NAL won a global tender for feasibility studies and computer models on aircraft and helicopter wake vortices for the Civil Aviation Authority of the United Kingdom. It is an interesting thought that NAL's work will have a bearing on the frequency of landing of aeroplanes at Heathrow airport in London! Antrix, the marketing arm of the Indian Space Research Organisation (ISRO) has won international contracts for studying low earth orbit satellite systems, antenna for handheld phones, etc. Indian R&D outfits are making major strides elsewhere too. Take supercomputers based on massively parallel processing mode. C-DAC has built up an international reputation with its PARAM supercomputers. It has already sold its computers to institutions in Britain, Canada, etc. It is trying to set up a mechanism so that it could market its products worldwide. It has built strategic alliances with S.G.S. Thomson from Europe, Concurrent System in Japan and Nextore in US, in a variety of high-tech computing endeavours. I am convinced that the dream of Indian science building bridges with foreign market places will be realised sooner rather than later.

A word of caution is in order here. I want to emphasise that we must know where to compete and where to cooperate. Eventually all efforts on industrial research and development in India must be primarily aimed towards making the Indian industry globally competitive. This would imply that the R&D institutes in India will have to draw out a balanced portfolio of business, which includes international collaboration efforts coupled with a major focus on Indian industry.

I also want to alert you by emphasising that the window of opportunity for making economic sense of Indian science through global partnerships will be limited. We will have to worry about competition, which is emerging in Asia itself. Philippines, Taiwan and China are making serious bids to enter the global software industry. In biotechnology, Taiwan and Singapore are much ahead of us. We also should not underestimate China in the long run as far as process technology is concerned. Sooner rather than later, some of these countries will cover up their deficiencies like language problems, modern management practice, etc. and surge ahead of us. To seek a lead initially may be easy but to maintain it is going to be tough. If we focus, innovate and keep our ambitions of leadership through technology high, then I see no reason as to why India cannot emerge as a global R&D platform.

Intellectual Property Management : A Crucial Issue

The potential of knowledge as a creator of wealth is gaining currency all around the world, but only knowledge that is protected or protectable can have the potential of wealth creation. The inclusion of IPR in the GATT agreement is an indication of this realisation. We will have to pay urgent attention to enhancing our levels of innovation and creativity substantially. A major change in the offing is due to India's accession to World Trade Organisation (WTO). Generation of intellectual property, its capture, documentation, protection, evaluation and its exploitation assumes a crucial importance in the new context. Indeed, there will have to be a sea-change in our ability to manage our intellectual property - be it patents, copy rights, designs, and so on. The greatest challenge will be posed by patents. I wish to focus on this crucial issue here.

Patenting : The New Challenge

The basic criterion for the grant of a patent is that the innovation must have elements of novelty, non-obviousness and utility. A fundamental issue pertains to the quality of the research itself that we need to do. How much of the research that we do today meets even some of these basic criteria? Many of the Indian R&D institutions and industrial firms have so far focussed on imitative research or reverse engineering. How do we change our mind sets so that we move on to doing truly innovative research or in other words doing forward engineering rather than reverse engineering? This is the first big challenge.

Indian contribution to the pool of international patents today is negligible. This will have to be increased very substantially. The volume of technical information is growing by leaps and bounds. Chemical Abstracts alone publishes over 10,000 abstracts each week, over 15 million to date, with disclosures of over 13 million compounds; currently about 25% relate to patents, 60% of which are Japanese specifications. There are thousands of scientific journals documenting contributions from researchers all over the world. In addition to these, there are over 32 million patents published world-wide growing at the rate of more than half a million new applications per year. Our research and development efforts have not taken cognisance of this vast amount of intellectual wealth. Our R&D planning must use this wealth systematically and intelligently.

Skills in filing, reading and exploiting patents will be most crucial in the years to come. Our ability to read or write patents is very poor. In that sense, patent literacy in India is lacking to a great extent. A patent literacy mission will have to be launched with a sense of urgency. Neither can we properly protect our inventions nor can we understand the implications off the patents granted to our competitors. Thus we may have a good invention, but we cannot effectively protect it by patents filed abroad as many of the patents written by our professionals could be easily circumvented. It follows readily that creating top class professionals in patent writing will be an urgent requirement. How do we create, within our system, a cadre of top class professionals, who will fight these battles? These are the burning questions.

We must realise that patent attorneys are one of the highest paid professionals in the West. As an example, organisations such as the Certified Institute of Patents Agents in UK produce high quality patent professionals. An aspirant desirous of making patenting as his profession has to pass a highly competitive examination, which consists of papers in science, engineering, drafting, infringement and a host of related areas. We have no such systems in India. We will have to urgently establish these systems.

Manpower planning for IPR protection will need emergency measures. A number of steps will have to be taken. IPR must be made a compulsory subject matter in the law courses in the universities in India. Our graduates coming out of engineering and technology streams have no idea about IPR, and yet it is these young people, who will have to generate and exploit the intellectual property. We will have to introduce key elements of IPR in their courses. A number of patent training institutes will have to be set up. China has set up 5000 patent training institutes, whereas we have none in India at the moment! It is a matter of deep concern that with a 100 year old system on patents, in India 4000 patents were filed last year, whereas with just a 10 year old system, China had 70,000 patents!

Judicious management of patent information will require well-structured functioning of information creating centres, information documenters and retrievers, information users, IPR specialists and information technology experts. The appropriate and selective use of information aided by state-of-the-art tools of information technology is absolutely essential in the management of this process. However, patent information scientists will have to be trained to make the best use of information technology and local and international data bases effectively and provide service to potential users in all sectors of a business.

Because of a comfortable protection in the past, we have not been concerned about the possible competition that we will be facing in the new world of competitive research. I will illustrate the difficulties that we will face with an experience of my polymer science colleagues in NCL on patenting in a highly competitive area. Exxon and Hoechst today hold nearly 50% of over 400 global patents on metallocenes, catalysts which will have tremendous impact in future on polyolefin polymers made so far by the conventional Ziegler-Natta catalysts. Exxon even sues new companies entering this field for violation of their patents to pre-empt any future competitions in this area. The polymer science group at NCL is faced with an interesting difficulty. It has a novel innovation in metallocenes but it is finding it difficult to break the fortress of these 400 strong patents! This is just an indication of the demands that will be placed on our research in the future. We really need to gear ourselves up fast to face these challenges. Otherwise we will keep on doing good science, but it will never be able to make economic sense!

Biodiversity, Biotechnology and Economic Wealth : Some Vexing Issues

Making economic sense of science related to life forms, be it plant, animal or human, requires a very special consideration. I want to highlight these.

It must be realised that patents are given for "inventions" and not for "discoveries". In the area of biotechnology, the complexity arises from the fact that it is increasingly becoming difficult to determine where "discovery" ends and "invention" begins, because the starting point of any biotechnological invention is pre-existing biological matter provided by nature. The doctrine of grant of patents for the inventions, where there is a human intervention have come into vogue in the judicial decisions of USA to distinguish between a "product of nature" and a "product of man". The issue continues to be clouded. It is important that we in India agree on a clear and unambiguous stand on patenting of life forms, so that what is patentable and what is not patentable can be clearly defined. We will have to give a serious consideration to the moral and ethical issues before defining our stand.

We mentioned about the lack of patent literacy. We need not only "patent literacy" but also "literacy about patents". There is an urgent need to educate the masses, since there are several misconceptions that are prevailing in India today. There is a common misunderstanding that the intellectual property protection will cover all the existing known materials. Thus one often hears about fears in India that Neem will be stolen, Tulsi will be stolen, and so on. This is not correct. The proposed sui generis system will apply only to those "new" varieties developed by plant breeders that satisfy the four criteria of novelty, distinctness, uniformity and stability. For such protection, after the establishment of the sui generis system, appropriate applications will have to be made to the prescribed authority. The legal rights on these application would accrue only after the acceptance of the applications by this authority. The first step is for India to establish appropriate authorities and procedures, which will fully protect the Indian interests.

Once these crucial issues are clarified, the way ahead to benefit from India's biodiversity becomes clear. For instance, India is endowed with rich natural resources like medicinal plants. India has also an established ayurvedic and herbal systems of medicine. It is possible under the new patent regime to protect the active ingredients responsible for the effectiveness of these systems, if they were not known so far. If new compounds or extracts are isolated from different plants, which have important activities, then it will be possible to obtain protection. Even if the composition of the extract is not identified, it is possible to obtain protection. At a later stage, if specific ingredients of the extract are isolated, identified and characterised and if they are new, then product protection for these new compounds can also be secured. India will have to launch a systematic effort to create wealth out of its biodiversity. My personal view is that we ought to develop strong systems to protect our endogenous sources by upgrading our skills on patenting at level with the rest of the world. Perhaps it is not widely known that out of the 80 patents or so on Neem, 28 patents do belong to Indians! Many interesting examples of creating economic wealth out of the synergy of our intellectual prowess, rich biodiversity and the ethnomedicinal and ethnobotanical knowledge base are emerging. Let me cite a few for you.

Consider a recent innovation by one of the CSIR laboratories, namely Central Drug Research Institute (CDRI). It has developed a memory enhancer and Velvette International Pharma from Madras will be now marketing it. Because of the extensive traditional claims of improvement of learning and memory by Brahmi, standardised Brahmi extract based on Bacoside content, which represent specific chemical constituents and biological activity was developed by CDRI. The standardised Brahmi extract was found to facilitate the learning and augment the memory processes in different animal models. The extract was found to be safe in regulatory pharmacology and toxicology studies. It was important to understand the scientific basis. It was found that Bacosides significantly enhance protein synthesis in those regions of the brain which are implicated as centre of memory formation. The standardised Brahmi extract may prove to be a nerve tonic as claimed in traditional knowledge. Where did CDRI draw its inspiration from? Of course, from our rich knowledge base of the past.

Since time immemorial, Brahmi (Bacopa monniera Linn.) has been used as a nervine tonic. This dates back to the time of Athar-Ved (C 800 B.C.) (Athar-Ved Samhita 3:1). Charak Samhita (C.100 A.D.) in Sloka 10:62 also describes the effectiveness of Brahmi. CDRI scientists used this knowledge base but also used their own intellectual prowess to give a scientific base and provide standardisation to develop and market this unique memory enhancer.

Let me cite an example of the innovation done by Regional Research Laboratory (RRL), Jammu, another CSIR laboratory, on a bioenhancer. Addition of this bioenhancer reduces the extent of the drug required by a patient by about 50%, thus reducing the costs, but more importantly, the toxicity. This bioenhancer has been patented in USA by our laboratory and Cadilla will be marketing it by the end of the year. Where did our scientists draw their inspiration from? Well, again from the ethnomedicinal knowledge bases. We must multiply these examples by thousand folds, so that our rich knowledge base of the present and the past and our rich biodiversity will help our science make economic sense.

I must hasten to add that there are deep issues involved about the role of indigenous communities in conservation and sustainable use of biodiversity and sharing of the benefits flowing from commercial uses of these resources. These need to be discussed. A link between the formal system of innovation (in our laboratories) and informal systems of innovation (in our villages) needs to be established. A rationale for biodiversity based enterprises in India needs to be established. Reliable and accessible biodiversity information systems is the need of the hour too. To retain the wealth of practical ecological knowledge of the village folk will require innovative approaches. I am convinced that a promotional and progressive rather than a negative and restrictive approach will go a long way for the nation as a whole.

While on the issue of our rich biodiversity, I wish to stress that the future economies must expand within ecosystems which have limited regenerative capacities. Contrary to the neoclassical theory of continuous material growth, economic activities can undermine the potential for development through over-exploitation of natural resources, and indirectly compromise future production through the discharge of residuals. The old ideas of quantitative growth must give way to the idea of qualitative growth within the limits of the ecosystems. We will have to reconcile developmental goals with ecological capabilities.

While we pursue the goal of making economic sense out of the science we do, we need to take a relook at the conventional indicators of economic growth measured in terms of Gross National Product, Gross Domestic Product, etc. Should we not think in terms of new indicators such as Gross Natural Product or even Gross Ecological Product?. Such indicators will not only themselves measure growth but be indicative of ecologically-sound structural changes in economy. The acceptance of these indicators will also send strong signals about the respect we have for partnership with Nature. After all, our future is intrinsically linked to this basic realisation.

A Word Before Closing

Let me come back to the issue of knowledge as a wealth creator again. The issue of Intellectual Property Rights and Innovation has been widely debated. In 1983, in her forward to the Nicholson report, Mrs. Margaret Thatcher had stated "individuals generating new ideas, whether in universities, companies, Government research institutions, or even in schools, should take very seriously indeed the protection of those ideas".

The subsequent debate in Britain was on which ideas should be protected and when? Who should exploit them and how? Who should profit? How does one resolve the potential conflict between the openness of scientific research and the competitiveness of the commercial world?

In India, it is only now that we are beginning to address this issue. We should address it by involving those who innovate, those who exploit but also those members of the society, who get affected. I am deeply concerned that we have not even begun this dialogue so far. We need to do this with a sense of urgency.

The Final Word

I want to thank you once again for doing me this great honour. Let me end by saying that I strongly believe that we are at a critical juncture in our life. I view India's future with great optimism and hope. I believe that the twenty first century will belong to Asia and India will have a chance to lead. I believe that India will be counted among the top economic powers of the world by 2020. I also believe that India will be an intellectual capital of the world by then. The only major difference will be that by then, we will not just pride ourselves about our intellectual prowess and intellectual infrastructure, but we will also pride ourselves as a nation which has not only learnt on how to do science that will lead and not follow but also as a nation that leads the rest of the world in making the most innovative economic sense of the science it does.

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"DEVAYANI" PUNE UNIVERSITY CAMPUS
POST BAG NO. 4, GANESHKHIND, PUNE 411 007

BALANCE SHEET AS AT MARCH 31, 1996

FUNDS & LIABILITIES		SCHEDULE NO.	AMOUNT (RS.)
1.	Trust Fund or Corpus - Grant-In-Aid from UGC	10	204,447,991
2.	Other Earmarked Funds	11	8,951,926
3.	Popularisation of Science Reserve		500,000
4.	Project Liabilities	12	572,898
5.	Current Liabilities	13	653,992
6.	Excess of Income over Expenditure	22	6,159,665
	TOTAL		221,286,472

ASSETS & PROPERTIES		SCHEDULE NO.	AMOUNT (RS.)
1.	Fixed Assets	14	206,301,482
2.	Investments / Deposits	15	8,342,209
3.	Project Receivables	16	1,102,753
4.	Current Assets -		
	a) Stocks	17	666,332
	b) Cash & Bank balances	18	220,420
	c) Advances Receivables	19	3,853,531
	d) Deposits	20	625,478
5.	Deferred Revenue Expenditure (to the extent not written off)	21	174,267
	TOTAL		221,286,472

For Inter-University Centre for
Astronomy and Astrophysics

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

As per Report of even date
For Parasnis Keskar & Co.,

Sd/-
S. B. Parasnis
(Partner)

Place : Pune
Date : 29th May 1996