IUCAA

INTER-UNIVERSITY CENTRE FOR ASTRONOMY AND ASTROPHYSICS

(An Autonomous Institution of the University Grants Commission)

Annual Report

(April 1, 1998 - March 31, 1999)

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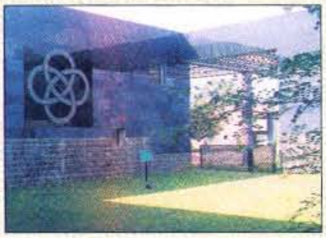


Down the memory lane ...
Ten years of IUCAA (1988-1998)

Anticlockwise, from top right :

- The Golay Bungalow: November 22, 1988 - August 23, 1989
- Shed Aditi commissioned on August 14, 1989
- Devayani, the IUCAA building
- Professor Yash Pal unveiling the foundation stone on December 29, 1988
- The signing of Memorandum of Understanding with the University of Pune, November 1990
- Presentation by IUCAA faculty before the Scientific Advisory Committee, 1991
- G. Ram Reddy welcoming Nobel Laureate Professor S. Chandrasekhar, during the Dedication Ceremony on December 28, 1992
- 6th IAU Asian Pacific Regional Meeting on Astronomy, during August 16-20, 1993
- International Conference on Gravitation and Cosmology, during December 13-19, 1995
- Seminar on Astronomy and Astrophysics, at Pondicherry University, during October 13-14, 1997
- 15th Meeting of the International Society on General Relativity and Gravitation, during December 16-21, 1997
- Michael Berry delivering the 9th IUCAA Foundation Day Lecture, December 29, 1997
- National Science Day, February, 1999








HIGHLIGHTS OF 1998–99

This annual report covers the activities of IUCAA during its tenth year, April, 1998-March, 1999. The endeavours of IUCAA span different fronts, as outlined in the pages of this Report. Here is a quick summary and highlights.

IUCAA has an academic strength of 11 core faculty members, 8 postdoctoral fellows and 10 Ph.D. students. The core research programmes by these academics span a variety of areas in astronomy and astrophysics.

These topics include investigations in quantum gravity, blackhole solutions in GR and string theory, electromagnetic analogues for gravitational fields, structure formation in quasi-steady state cosmology, statistical indicator to discriminate cosmological structures, generic features of gravitational clustering, vacuum polarisation and cosmological constant, investigations on the host galaxies and radio emission from quasars, models of AGN, quasar observation systems, gravitational lensing observation of galaxy correlations function and the local supercluster, galactic dynamics and structure, properties of interstellar dust, different aspects of interstellar and pulsar physics and the development of the necessary instrumentation for the IUCAA Telescope. These research activities are summarised in pages 21-45.

The publications of the IUCAA academics, numbering to about 70 in the current year are listed in pages 69-72. IUCAA members also take part in pedagogical activities like lectures, seminars, popularisation of science etc., the details of which are given in pages 77-78 of this Report.

The extended academic family of IUCAA consists of 76 Associates and Senior Associates, who have been active in several different fields of research. Pages 46-59 of this report highlights their research contributions spanning quantum cosmological models, quantum field theory, exact solutions to Einstein's equations, alternative theories of gravity, cosmology and very early universe, galactic dynamics, interstellar medium and variable stars, X-ray binaries, neutron stars, solar and planetary physics, stellar and galactic photometry and quasar absorption systems. The resulting publications, numbering to about 70 are listed in pages 72-76 of this report.

A total of about 1500 man-days were spent by Associates and Senior associates at IUCAA during this year. In addition, IUCAA was playing host to about 475 visitors through the year.

IUCAA conducts its graduate school jointly with the National Centre for Radio Astrophysics, Pune. Among the research scholars, two have successfully defended their thesis and obtained Ph.D. degree from the Pune University during the year 1998-1999. Summary of their theses appears in pages 60-68.

Apart from these activities, IUCAA conducts several workshops, schools and conferences each year both at IUCAA and at different university campus. During this year, there were 7 such events in IUCAA and 9 were held at other universities under IUCAA sponsorship. One of the major events during the year was the Decennial meeting of IUCAA to celebrate the occasion of IUCAA completing the first 10 years of its existence. This meeting brought together about 125 participants and covered the recent research activities in a wide spectrum of topics in gravitation, cosmology, astrophysics and astronomy. A report on the meeting is given in pages 93-94.

Another main component of IUCAA's activities is its programmes for Science Popularisation. On the national science day this year, several special events were organised including an interschool science festival with over 550 students from 90 schools in the region participating in it.

These activities were ably supported by the scientific and administrative staff (17 and 35 in number) who should get the lion's share of the credit for successful running of the programmes of the center. The scientific staff also looks after the major facilities like library, computer centre and instrumentation lab. You will find a brief update on these facilities on page 98 of this report.

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

CONTENTS

The Council

President
Armaity Desai
Chairperson
University Grants Commission, New Delhi

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

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

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

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

G. D. Sharma
Secretary
University Grants Commission, New Delhi

A. S. Nigavekar (from May 1998)
Vice-Chancellor
University of Pune

V.K. Kapahi (till March 16, 1999)
Director
National Centre for Radio Astrophysics, Pune

N. Babu (till December 31, 1998)
Vice-Chancellor
University of Kerala, Thiruvananthapuram

K. Babu Joseph (from January 1, 1999)
Vice-Chancellor
Cochin University of Science and Technology
Kochi

M. Muniyamma (till December 31, 1998)
Vice-Chancellor
Gulbarga University

D.K. Sinha (from January 1, 1999)
Vice-Chancellor
Visva Bharati, Santiniketan

V. Ramakistayya (till February 1999)
Vice-Chancellor
Osmania University
Hyderabad

D. C. Reddy (from March 1999)
Vice-Chancellor
Osmania University, Hyderabad

J.M. Waghmare (till December 31, 1998)
Vice-Chancellor
Swami Ramanand Teerth Marathwada
University, Nanded

K.M. Pathak (from January 1, 1999)
Vice-Chancellor
Tezpur University

Bimla Buti (till December 31, 1998)
Emeritus Professor
National Physical Laboratory, New Delhi

Suresh Chandra (from January 1, 1999)
Swami Ramanand Teerth Marathwada
University, Nanded

Ved Ratna (till December 31, 1998)
C-536, Saraswati Vihar
New Delhi

Ashok K. Goyal (from January 1, 1999)
Hans Raj College
University of Delhi

K. Sankara Sastry (till December 31, 1998)
Osmania University, Hyderabad

S.H. Devare (from January 1, 1999)
Honorary Professor
University of Pune

Arun Kumar Sen (till December 31, 1998)
Director
Institute of Radio Physics and Electronics, Calcutta

N. Kumar
Director
Raman Research Institute, Bangalore

M.S.V. Valiathan (till June 1998)
Vice-Chancellor
Manipal Academy of Higher Education

V. K. Dalela (from January 1, 1999)
Vice-Chancellor
Pandit Ravishankar Shukla University, Raipur

R.N. Basu
Vice-Chancellor
Calcutta University

A. Bhanumathi
Andhra University, Visakhapatnam

Nirupama Raghavan
Director
Nehru Planetarium, New Delhi

N. Mukunda (from January 1, 1999)
Centre for Theoretical Studies and
Department of Physics,
Indian Institute of Science,
Bangalore

N.K. Dadhich
IUCAA

Member Secretary
J.V. Narlikar
Director, IUCAA

The Governing Board

Chairperson
R.P. Bambah

Members
G.D. Sharma
A.S. Nigavekar (from May 1998)
V.K. Kapahi (till March 16, 1999)
V. Ramakistayya (till February 1999)
D.C. Reddy (from March 1999)
R.N. Basu
N. Kumar
M.S.V. Valiathan (till June 1998)
A. Bhanumathi
Nirupama Raghavan
N.K. Dadhich

Member Secretary
J.V. Narlikar

Honorary Fellows

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

2. R. Hanbury Brown
   Andover, England

3. A. Hewish
   University of Cambridge, UK

4. Fred Hoyle
   Bournemouth, UK

5. Yash Pal
   New Delhi

6. A.K. Raychaudhuri
   Calcutta

7. P.C. Vaidya
   Gujarat University, Ahmedabad

Statutory Committees

The Scientific Advisory Committee

Richard Ellis
Institute of Astronomy,
University of Cambridge, England

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

K. Babu Joseph
Cochin University of Science and Technology
Kochi

Vinod Krishan
Indian Institute of Astrophysics, Bangalore

J. Maharana
Institute of Physics, Bhubaneswar

Franco Pacini
Observatorio Astrofisico di Arcetri, Italy

R. Rajaraman
Jawaharlal Nehru University, New Delhi

Ram Sagar
Uttar Pradesh State Observatory, Nainital

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

J.V. Narlikar (Convener)
IUCAA, Pune

The Users' Committee

from 1.1.1998 to 31.12.2000

J.V. Narlikar
IUCAA (Chairperson)

A.K. Kembhavi
IUCAA (Convener)

N.K. Dadhich
IUCAA

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

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

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

R.S. Tikekar
Sardar Patel University, Vallabh Vidyanagar

G. Ambika
Maharaja's College, Kochi

The Academic Programmes Committee

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

The Standing Committee for Administration

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

The Finance Committee

R.P. Bambah (Chairperson)
G.D. Sharma (Ex-officio Member)
J.V. Narlikar (Ex-officio Member)
O.P. Nigam (Ex-Officio Member)
R.P. Gangurde (Ex-Officio Member)
N.K. Dadhich (Nominee of the Director, IUCAA)
Nirupama Raghavan (Nominee of the Chairperson, Governing Body)
A.S. Nigavekar (Nominee of the UGC)
T. Sahay (Non-Member Secretary)

Members of IUCAA

Academic

J.V. Narlikar (Director)
T. Padmanabhan (Dean, Core Academic Programmes)
A.K. Kembhavi (Dean, Visitor Academic Programmes)
J. Bagchi (from 3.8.98)
N.K. Dadhich
S.V. Dhurandhar
R. Gupta
S. Raychaudhury
V. Sahni
R. Srianand
S. Sridhar
S.N. Tandon

Scientific and Technical

N.U. Bawdekar
S. Bhujbal
V. Chellathurai
P.A. Chordia
H.K. Das
S. Engineer (from 15.3.99)
D.V. Gadre
G.B. Gaikwad
S.U. Ingale
P.A. Malegaonkar
V.B. Mistry
A. Paranjpye
S.K. Pathak (from 25.11.98)
S. Ponrathnam (from 1.4.98)
S. Sankara Narayanan
H.K. Sahu
S.K. Vijaianand (from 30.11.98)

Administrative and Support

T. Sahay (Senior Administrative Officer)
N.V. Abhyankar
V.P. Barve
S.L. Gaikwad
B.R. Gorkha
B.S. Goswami
R.S. Jadhav
B.B. Jagade
S.M. Jogalekar
A.N. Kamnapure (till 30.4.98)
S.N. Khadilkar
M.A. Mahabal
S. Mathew
S.G. Mirkute
E.M. Modak
K.B. Munuswamy
K.C. Nair
R.D. Pardeshi
N.S. Pargaonkar
N.S. Parkhe
R. Parmar
B.R. Rao
M.A. Raskar
M.S. Sahasrabudhe
V.A. Samak
S.S. Samuel
B.V. Sawant
A.R. Shaik (from 18.11.98)
S. Shankar
D.R. Shinde
D.M. Surti
V.R. Surve
A.A. Syed
S.R. Tarphe
S.K. Waghole
K.P. Wavhal (from 4.1.99)

Post-Doctoral Fellows

S.K. Banerjee
S. Bose
V. Faraoni (till 3.9.98)
S. Kar (till 10.7.98)
S. Konar (from 3.8.98)
A. Mangalam
R. Misra
M. Nouri-Zonoz (from 31.8.98)
B.F. Roukema (from 25.9.98)
S. Surya (till 7.8.98)
F. Sutaria (from 12.5.98)
R. Wichmann (till 21.8.98)

Research Scholars

S. Engineer (till 15.3.99)
K. Harikrishna
S.S. Narayanan
A. Nayeri
A. Pai
A.N. Ramaprakash (till 15.5.98)
T. Roy Choudhury (from 4.8.98)
T.D. Saini
N.B. Sambhus
J.V. Sheth (from 3.8.98)
K. Srinivasan
Y.G. Wadadekar

Project Appointments

S.S. Belsare (till 30.11.98)
(Project Officer, Instrumentation Laboratory)
A. Chakraborty (from 13.4.98)
(Project Officer, Instrumentation Laboratory)
T. Deoskar
(Trainee Engineer, Instrumentation Laboratory)
K. James (from 1.2.99)
(ERNET Project)
R.S. Kharoshe (from 1.9.98)
(Trainee Engineer, Instrumentation Laboratory)
S.R. Kulkarni (till 14.7.98)
(Trainee Engineer, Instrumentation Laboratory)
V. Kulkarni (from 18.5.98)
(Science Popularisation)
V. Joshi (till 30.9.98)
(SILFID Project)
A. Lahare (till 12.2.99)
(Computer Centre)
V. Mahabal (till 25.6.98)
(DOE-ERNET Project)
M.N.S. Nair (till 31.5.98)
(Accounts)
A. Pawar (till 26.2.99)
(Administration)

Visiting Scientist / Fellow

Anuradha Bhagwat (till 15.3.99)
(Science Popularisation)

J. Vijapurkar (from 6.7.98)
(Visiting Fellow)

Part-time Consultants

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

Visiting Members of IUCAA

Visiting Professors

Abhay Ashtekar
Centre for Gravitational Physics
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The Pennsylvania State University, USA

C.V. Vishveshwara
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Senior Associates

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University of Rajasthan

A. Banerjee
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Akola

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

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

from July 1, 1998

F. Ahmed
Department of Physics
Kashmir University, Srinagar

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

S. Biswas
Department of Physics
University of Kalyani

Subenoy Chakraborty
Department of Mathematics
Jadavpur University, Calcutta

Soumya Chakravarti
Department of Physics
Visva Bharati, Santiniketan

S. Chaudhuri
Department of Physics
Gushkara Mahavidyalaya, Burdwan

Chanda Jog
Department of Physics
Indian Institute of Science, Bangalore

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

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

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

H.P. Singh
Department of Physics
SriVenkateswara College, Delhi

K. Yugindro Singh
Department of Physics
Manipur University, Imphal

Associates

N. Banerjee
Department of Physics
Jadavpur University, Calcutta

Indira Bardoloi
Department of Physics
Handique Girls' College, Guwahati

S.P. Bhatnagar
Department of Physics
Bhavnagar University

S. Chakrabarty
Department of Physics
University of Kalyani

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

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

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

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

Santokh Singh
Department of Physics and Astrophysics
Deshbandu College, Delhi

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

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

from July 1, 1998...

Kalyani Desikan
M.O.P. Vaishnav College for Women
Chennai

Sukanta Dutta
Department of Physics
SGTB Khalsa College, Delhi

Kanti Jotania
Department of Physics
St. Xavier's College, Ahmedabad

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

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

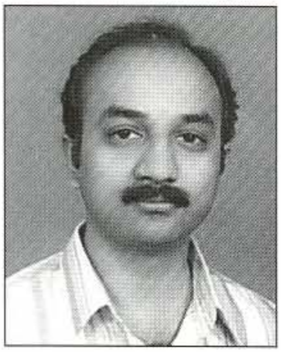
P. K. Srivastava
Department of Physics
DAV (PG) College, Kanpur

The Ninth batch of Senior Associates and Associates of IUCAA, who were selected for a tenure of three years, beginning July 1, 1998

K. Desikan

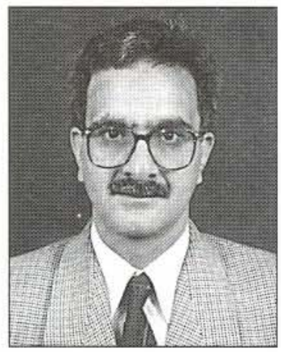
K. R. Jotania

T. C. Phukon



S. Rastogi

P. K. Srivastava



F. Ahmed

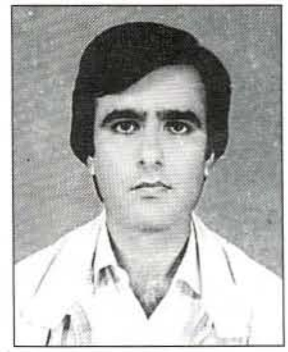
S. Biswas

S. Chaudhuri

C. J. Jog

R. S. Kaushal

K. K. Nandi



P. N. Pandita

K. Y. Singh

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

Soumya Chakravarti
Sukanta Dutta

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

G. Ambika
Narayan Banerjee
Subenoy Chakraborty
D.P. Datta
Ashok K. Goyal
V.H. Kulkarni
G.P. Malik
S.N. Paul
R.P. Saxena
H.P. Singh

Organizational Structure of IUCAA's Academic Programmes

The Director
J.V. Narlikar

Dean, Core Academic Programmes
(T. Padmanabhan)

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

Head, Computer Centre
(A.K. Kembhavi)

Head, Library & Documentation
(T. Padmanabhan)

Head, Publications
(T. Padmanabhan)

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

Head, Instrumentation Laboratory
(S.N. Tandon)

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

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

Head, Recreation Centre
(S.V. Dhurandhar)

Head, Guest Observer Programmes
(Ranjan Gupta)

Head, Workshops & Schools
(Ranjan Gupta)

Head, Science Popularization and Amateur Astronomy
(Somak Raychaudhury)

The Director's Report

The year 1998-99 saw an important landmark for IUCAA, for during this year the Centre completed the first decade of its existence. It was on December 29, 1988 that Professor Yash Pal, the then Chairman of the University Grants Commission, unveiled the foundation stone of IUCAA. We celebrated this event by organizing a Decennial Conference which was well attended nationally and internationally. We had laid special stress on inviting those who had visited the IUCAA during its early days.

A sanskrit shloka says that during the first five years of its life a child should be pampered, in the following ten it should be disciplined while after entering the sixteenth year, the child should be treated as a responsible adult. In the case of institutions these time scales should be ten and fifteen years respectively. Thus, the IUCAA has now completed ten years when as a budding institution it enjoyed indulgence from the community. Now, for the next fifteen years it should be watched and assessed more critically, so that by the time it celebrates its silver jubilee, it will have grown into a mature scientific institution.

While celebrating the decennial, therefore, considerable introspection was also carried out by the IUCAA staff on how we have done so far, to what extent the objectives behind setting up the Centre are being met, and what are the perceptions for the future.

Figures 1-5 show the development and growth of IUCAA's academic programmes and its impact on the university system. The number of universities / postgraduate colleges teaching astronomy and astrophysics has increased to around 30, the number of publications in international standard refereed journals by the university faculty and students has grown, as have instances of participation by them in observational and instrumentation programmes. The number of IUCAA associates has reached 76, against a projected steady state of 100. Although these examples indicate significant improvement, my colleagues and I are well aware that there is much that remains to be done.

Research, development and other academic activity at the IUCAA are described in detail in the pages that follow. The Scientific Advisory Committee met in early January 1999 and after a four-day marathon of discussions, visits, presentations, etc. gave a very useful feedback. While it was gratifying to see the SAC favourably impressed, my colleagues and I will certainly benefit by its constructive suggestions. Indeed this was the seventh meeting of the SAC, and each meeting has proved very useful to IUCAA in shaping its academic programmes.

One major worry, not only confined to IUCAA, or to astronomy and astrophysics, but to the domestic scientific scene as a whole, is the growing shortage of good research students. With most bright students opting for monetarily glamorous careers after their XII-standard examination, science is losing its sheen, which is the motivation for many of IUCAA's science popularization activities aimed at secondary school students. During this year, the Saturday lecture-demonstration programme was enlarged to include lectures for the XI-XII standard students also. Certainly, the enthusiasm with which these programmes are greeted by students leaves one in an optimistic mood that surely some of these students will be motivated enough to opt for a scientific career.

IUCAA's National Science Day celebrations were a great success. The activity was extended to two days with the first day reserved for schools and the second open to the general public. A major attraction for all visitors, young and not-so-young, was the Science Park inaugurated by the Chairperson, UGC on IUCAA's Foundation Day. It is hoped to add to the dozen or more exhibits in the coming years to bring the total to around 30. These celebrations were followed by a two-day workshop on the problems faced in projecting science through the various media (*see* details in the main body of this report).

It was a pleasure to host a brainstorming session convened by the Chairperson, UGC at IUCAA on December 30, 1998. The topic for discussion was the IUC-Mode, which included a review of how the existing IUCs are working, suggestions about resolving their difficulties and, more importantly, how the mode could be extended to other areas, especially in the humanities and social sciences.

The Decennial Year also saw IUCAA's gardens entering local competitions and winning prizes for the best institutional rose garden, roses of special variety, and also other fruits and flowers. One of the three Newton's apple trees flowered and produced two apples, thus negating the claim that in the Pune climate an apple tree will not survive, let alone blossom and fruit!

It is with a great sense of sorrow that I have to report the sudden and totally unforeseen loss of Professor Vijay Kapahi due to a fast advancing disease. As the Director of the neighbouring National Centre for Radio Astrophysics, he was a member of IUCAA's Council and Governing Board. Besides, he was a friend and supporter of IUCAA in all its programmes. The Indian astronomy community has suffered a great loss through this tragic event.

After completing two terms as Director, I was expecting to make way for someone younger. However, in the interests of the organization, I have been asked to continue for a third term. While this expression of confidence by the President of the Council is very gratifying, I am deeply conscious of the help, guidance and encouragement I have received from so many different quarters to make my job as Director very worthwhile. These include, IUCAA's apex bodies, the Chairperson, Vice-Chairman and the Secretary of the UGC and its secretariat, The Chairperson of the Governing Board, Professor R.P. Bambah, the user community from the universities and last but not the least, all my colleagues at IUCAA. I look forward to continuing indulgence from them in the years to come.

Jayant V. Narlikar

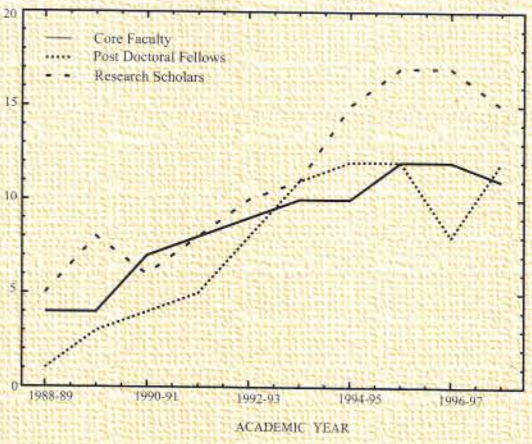


Figure 1: Evolution of the members of core faculty members, post-doctoral fellows and research scholars at IUCAA over the period 1988-97.

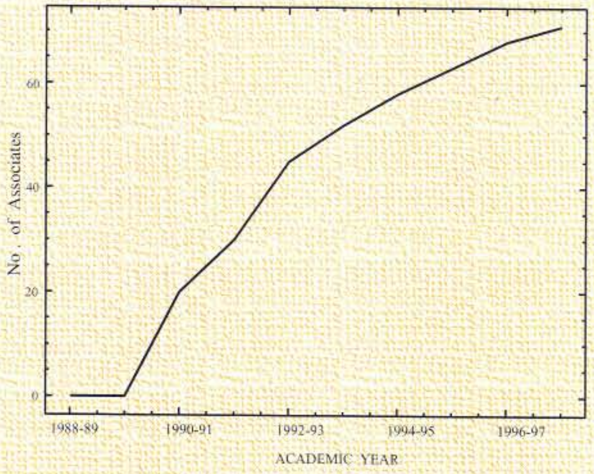
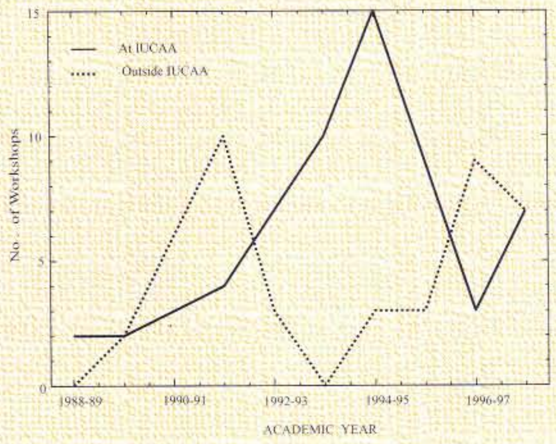


Figure 2: Growth in the number of associates over the period 1988-97.



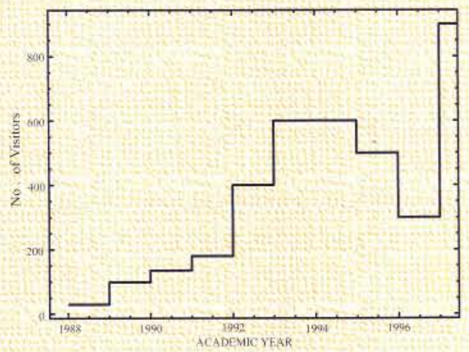


Figure 3: Yearwise distribution of schools and workshops organised by IUCAA during 1988-97 both on and off campus.

Figure 4

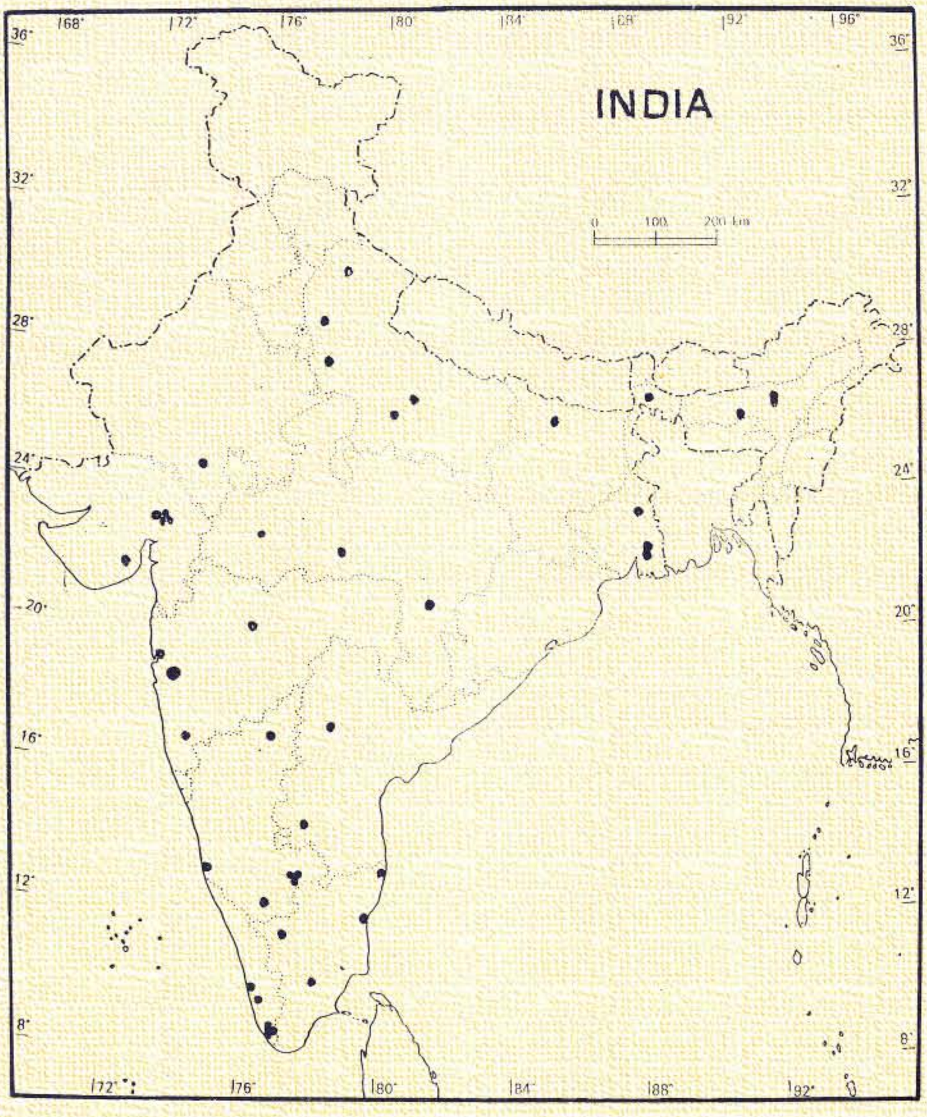


Figure 5: Locations outside Pune where IUCAA's pedagogical activities have taken place during 1988-97.

Awards and Distinctions

N. K. Dadhich

The essay, *On electrogravity duality in general relativity*, received an Honorable Mention in the 1998 Gravity Research Foundation Essay Competition.

Nominated on the International Committee on General Relativity and Gravitation as an IUPAP representative for a term of 6 years.

J. V. Narlikar

Visiting Professor's Medal, College de France, Paris

Karveer Bhushan Award from the Bhalji Pendharkar Foundation, Kolhapur, May 4.

Punyabhushan Award from Tridal, Pune, September 12.

N.C. Kelkar Award for literary work, Pune, October 14.

Pune's Pride Award for excellence in academics by the Residency Club, Pune, December 21.

Honorary Fellow, Asiatic Society of Bombay, December 23.

R.D. Birla Award of Indian Physics Association, March 12.

S. Raychaudhury

Elected Councillor, Astronomical Society of India

Elected member, International Astronomical Union

V. Sahni

Elected Fellow of the National Academy of Sciences (India).

Calendar of Events

1998

April 13 - May 22
School Students' Summer Programme
at IUCAA

May 18 - June 5
Introductory Summer School on Astronomy and Astrophysics
at IUCAA

June 1 - July 10
Vacation Students' Programme
at IUCAA

August 17
IUCAA-NCRA Graduate School
First Semester begins

August 18-20
Workshop on Light Scattering by Small Particles and Its Applications in Astrophysics
at Bhavnagar University

October 5-9
Introductory School on Astronomy and Astrophysics
at Sri Venkateswara College, University of Delhi

October 24
Workshop on Total Solar Eclipse 1999
at IUCAA

October 26-31
School on Gravitation and Cosmology
at Cochin University of Science and Technology, Kochi

October 27 - November 4
IUCAA - TIFR School on High Energy Gamma Ray Astrophysics,
at Pachmarhi

November 9-13
Introductory School on Astronomy and Astrophysics
at Indira Gandhi Science Complex-Planetarium, Patna

November 15-24
Workshop on Databases, Data Visualization and Image Processing
at IUCAA

December 3-6
2nd Sino-Indian Workshop on Astrophysics
at IUCAA

December 11
IUCAA-NCRA Graduate School
First Semester ends

December 29
The 10th IUCAA Foundation Day
Inauguration of the IUCAA Science Park

December 30
Brain-Storming on the IUC-Mode
at IUCAA

1999

January 4
IUCAA-NCRA Graduate School
Second Semester begins

January 4-7
Meeting of the Scientific Advisory Committee of IUCAA

January 7-10
Decennial Year Meeting
at IUCAA

January 12-16
Introductory School on Astronomy and Astrophysics
at G.C. College, Silchar, Assam

January 18-19
Orientation Meeting on Exact Solutions in Relativity and Cosmology
at D.D.U. Gorakhpur University
January 25-29
2nd Level 1 Workshop on Astronomical Photometry
at IUCAA

February 9-11
Workshop on Introductory Image Processing and Astronomical Applications
at Tezpur University

February 27-28
National Science Day
at IUCAA

March 1-2
Science and the Media - A seminar
at IUCAA

March 6-10
Workshop on Astrophysics for Physicists
at Visva Bharati, Santiniketan

Academic Programmes

The following description relates to research work carried out at IUCAA by the core academic staff, post-doctoral fellows and research scholars. The next section describes the research work carried out by associates of IUCAA using the Centre's facilities.

(I) RESEARCH BY RESIDENT MEMBERS

The research described below is grouped area-wise. The name of the concerned IUCAA member appears in italics.

Quantum Theory and Gravity

Quantum gravity from pure thought?

The question of bringing together the principles of quantum theory and gravity deserves to be called "the problem" of theoretical physics today. The history of failures in this attempt illustrates the conceptual complexity of the problem. Given the above situation, is it possible to describe the key features which must be present in any future, successful, theory of quantum gravity? *T. Padmanabhan* has succeeded to a certain extent in providing some useful pointers.

The fact that there will exist violent spacetime fluctuations at small scales suggests that the macroscopic, continuum, description of spacetime can only be approximate and valid when quantum fluctuations are averaged over large scales. The description of continuum spacetime in terms of classical, Einstein's equation is similar to the description of a solid by elastic constants or the description of a gaseous system by an equation of state. While the knowledge of microscopic quantum theory of atoms and molecules will allow us, in principle, to construct the description in terms of elastic constants, the reverse process is unlikely to be unique. What one could hope is to take clues from well designed thought experiments, thereby identifying some key generic features of the microscopic theory.

One might assume that the microscopic description is in terms of certain [as yet unknown] variables q_i and that the conventional spacetime metric is obtained from these variables in some suitable limit. Such a process will necessarily involve coarse-graining over a class of microscopic descriptors of geometry. *Padmanabhan* outlines an argument which suggests that there are *infinite* number of microscopic descriptors which are "integrated out" in proceeding from the fundamental description to spacetime description. The argument proceeds in three steps: (1) Among all systems dominated by gravity, the universe possess a very peculiar feature. If the conventional cosmological models are reasonable, then it follows that *our universe proceeded from quantum mechanical behaviour to classical behaviour in the course of dynamical evolution defined by some intrinsic time variable.* It can be shown that a system with bounded Hamiltonian can never make such a transition if classicality is defined in terms of behaviour of a suitable Wigner function. It follows that the quantum cosmological description of our universe, as a Hamiltonian system, should contain at least one unbounded degree of freedom. It can also be shown that the unbounded mode — which, in the case of FRW universe, corresponds to the expansion factor — will go classical first, as is experienced in the evolution of the universe. (2) Addressing the task of obtaining an unbounded Hamiltonian for an effective theory when the original theory contained a larger set of dynamical variables, it can again be shown that, if one starts with a bounded Hamiltonian for a system with finite number of quantum fields and integrates out a subset of them, the resulting Hamiltonian for the low energy theory cannot be unbounded. (3) Assuming that the original theory is describable in terms of a bounded Hamiltonian for some suitable variables, it follows that an infinite number of fields have to be involved in its description and an infinite subset of them have to be integrated out in order to give the standard low energy gravity. This feature is indeed present in one form or the other in the descriptions of quantum gravity based on strings or Ashtekar variables. The above argument suggests that this is indeed inevitable.

If the description in terms of continuum spacetime is like theory of elasticity, and we do not know the fundamental descriptors of spacetime, is there any way of bridging the gap between the two? It turns out that this is possible by using the properties of macroscopic spacetime near the trapped surfaces. *Padmanabhan* has given detailed arguments last year to show that the event horizon of a Schwarzschild blackhole acts as a magnifying glass, allowing us to probe Planck scale physics. A program for quantum gravity, along these lines, holds promise.

Classical Gravity

Quasilocal energy for rotating charged black hole solutions in general relativity and string theory

Recently, *S. Bose* and T. Z. Naing have explored the (non)-universality of Martinez's conjecture within and beyond general relativity. This conjecture was originally proposed for Kerr black holes and states that the Brown-York quasilocal energy at the outer horizon of such a black hole reduces to twice its irreducible mass. *Bose* and Naing first consider the charged Kerr black hole. For such a spacetime, they calculate the quasilocal energy within a two-surface of constant Boyer-Lindquist radius embedded in a constant stationary-time slice. Keeping with Martinez's conjecture, they find that at the outer horizon of the hole this energy equals the hole's irreducible mass. The energy is positive and monotonically decreases to the Arnowitt-Deser-Misner mass as the boundary-surface radius diverges. Next they perform an analogous calculation for the quasilocal energy for the Kerr-Sen spacetime, which corresponds to rotating charged black hole solutions in a four-dimensional low-energy effective theory derived from heterotic string theory. The behaviour of this energy as a function of the boundary-surface radius is similar to the charged Kerr case. However, they find that it does not approach the expression conjectured by Martinez at the horizon.

Electromagnetics of gravity

Any classical field can be resolved into electric and magnetic parts. Electric part is produced by source (charge) at rest while magnetic part is produced when source is moving. In GR, the source would, along with non-gravitational energy distribution, also include gravitational field energy. The source is, therefore, of two kinds and accordingly it would produce two kinds of electric field. They are termed as active part due to non-gravitational energy and passive due to gravitational field energy. The resolution is done relative to a stationary observer; i.e., with respect to a unit timelike vector. Electric and magnetic parts are given by second rank 3-space tensors orthogonal to the resolving vector. Electric parts are symmetric while magnetic part is trace free. Its symmetric part is equal to the Weyl magnetic part (free field) and antisymmetric part represents energy flux. Thus, all the 20 components of the Riemann curvature are accounted for by 6 each of active and passive electric parts and 8 of magnetic part.

In electrodynamics, a duality relation

between electric and magnetic fields keeps the action and the vacuum field equation invariant. However, there can exist no solution obeying the duality transformation, which when taken entirely leads to zero field. *N.K. Dadhich* asks the question: what happens if one considers the similar duality relation for electric and magnetic parts of the gravitational field ? It turns out that the duality relation which keeps the Einstein action invariant also implies the Einstein vacuum equation. It is a remarkable property that the symmetry of the action leads to the equation of motion for the field. This is similar to the well-known property of GR that equation of motion of the field implies the equation of motion for free particle. This is because the Riemann curvature contains the second order derivative of the metric potentials and hence it contains the dynamics of the field. This will be true for all the quantities like action and electromagnetic parts that are derived from it. In electrodynamics, fields involve first order derivative of the gauge potential and hence the dynamics could only emerge when they are differentiated. Since gravitational electric and magnetic parts already contain second derivatives, any relation between them could describe dynamics of the gravitational field. This is how the duality relation similar to electrodynamics leads to the vacuum field equation. This is the unique transformation involving both electric and magnetic parts which keeps the action invariant.

Another avatar of duality called electrogravity duality, which *Dadhich* had proposed last year, can be used to construct dual solutions to the well-known black hole solutions. It involves interchange of active and passive electric parts and keeps the vacuum equation invariant. Continuing the study of various aspects of it, he finds that - under this duality transformation - the Weyl tensor and the Ricci scalar change sign. Since the vacuum equation remains invariant, it would admit the same vacuum solutions but the constants of integration would change sign to agree with change of sign of the Weyl curvature. That is, for the Schwarzschild particle, $GM \rightarrow -GM$, which means, the gravitational constant changes sign. Since a symmetry of the vacuum equation must also be a symmetry of the action, that could only happen if G changes sign to compensate for the change of sign of the Ricci scalar. Does this mean that the duality transformation turns gravity into anti-gravity? A closer look at the sources of active and passive parts would resolve this question. It is non-gravitational energy distribution, the usual matter energy, that produces active part while passive part is produced by gravitational field energy. For an attractive field, the two always bear opposite sign, the former being positive and the latter negative. Hence, the interchange of active and passive parts under the transformation corresponds to interchange of their sources as well.

On the electrogravity-dual solution to stringy charged black holes

Electrogravity-duality transformation is defined by an interchange of the "active" and "passive" electric parts of the Riemann tensor. Such a transformation has been used to find new solutions that are dual to the Kerr family of black hole spacetimes in general relativity. In such a case, the dual solution is a similar black hole spacetime endowed with a global monopole charge. *S. Bose* and *N. Dadhich* have recently extended this formalism to obtain solutions dual to the static, charged black hole solutions of a four-dimensional low-energy effective action of heterotic string theory. Analogous to general relativity, they find that even in the present case, the dual solutions are similar black hole spacetimes, but with a global monopole charge.

Cosmology and Structure Formation

Geometrical analysis of large scale structure

Pioneering work in the late 60's and early 70's showed that, far from being distributed at random, galaxies tend to cluster together and that the two-point correlation function for galaxies had a distinctive power law form $\xi(r) \propto r^{-1.8}$ on scales less than $10h^{-1}Mpc$. Although the clustering of galaxies is now well established, a complete description of clustering which includes its geometrical features has so far proved elusive. This is partly due to the fact that while the two point correlation function, which describes a distribution uniquely while it is Gaussian, no longer does so when departures from Gaussianity become significant during cosmological gravitational clustering. As a result, the correlation function must be supplemented by other statistical measures, some of which are sensitive to the overall 'connectedness' of large scale structure. This is especially important in view of the fact that the distribution of galaxies in both N-body simulations and galaxy surveys, shows distinctive geometrical features which have on occasion been called filamentary, sponge-like, cosmic web, bubble-like, etc. In order to quantify the large scale structure more objectively one must be able to differentiate quantitatively between structures occurring in rival models of galaxy formation and also determine which model comes closest to the observed galaxy distribution on very large scales. This calls for the development of new tools of statistical analysis of large scale structure. During the past few years *V. Sahni* has been engaged in investigating statistical indicators of clustering which are sensitive to the geometry of a distribution. To this category belong minimally spanning trees, the genus curve and percolation analysis as well as the more recently introduced Minkowskii functionals.

Sahni, together with Sergei Shandarin and B.S. Sathyaprakash, have applied 'Shapefinders' (a statistic which describe the 'shape') both to observational catalogues of large scale structure as well as to N-body simulations. The Shapefinder statistic is based on Minkowskii functionals and has been shown by *Sahni*, et al. to be very sensitive to the geometrical and topological properties of a distribution. For instance, *Sahni* and collaborators have analysed the shapes of clusters and superclusters in N-body simulations of gravitational clustering using Shapefinders and several other shape-statistics which hope to quantify the shape of an object using its mass moments. The results of *Sahni*, Sathyaprakash and Shandarin have shown that whereas, for very simple shapes all statistics give mutually consistent results, for more complex objects the Shapefinder statistics performs distinctly better and clearly distinguishes between pancakes, filaments and ribbons in a distribution. It can also probe the *topology* of an object, and is, therefore, able to tell whether a given supercluster is simply, or multiply connected. Results of a sophisticated analysis of N-body simulations by *Sahni*, Sathyaprakash and Shandarin has unambiguously shown that filaments are more prominent than pancakes. This is true during virtually all stages of gravitational clustering and for a wide range of initial spectra. Nevertheless, pancakes too remain statistically significant. This result is supported by an independent study of the volume fraction occupied by the percolating supercluster in which *Sahni* and collaborators have shown that, as an N-body system advances with time, the volume fraction occupied by the most massive supercluster gradually decreases, indicating that the percolating structure occupies less space and therefore (for a given mass) is more likely to be prolate/oblate rather than spherical.

It is important that analysis performed on gravitational N-body systems mimicking the Universe be supplemented by a similar analysis conducted on a sample of galaxies taken from the real Universe. Sathyaprakash, *Sahni*, Shandarin and Karl Fisher, have studied the morphology of superclusters and clusters in the IRAS 1.2 Jansky catalogue of galaxies using both percolation analysis and shape-statistics. One question that immediately arises when one wants to study individual objects in a distribution is the threshold above which the distribution is to be studied. Depending upon the threshold, vastly different results may be obtained and so it becomes important to be able to identify the density threshold in an objective manner. When dealing with a 'smoothed distribution' of galaxies one must choose a suitable 'density' threshold at which to study the statistical properties of the distribution. This can easily be done using percolation analysis. For instance, it is rather obvious that at very high density thresholds the 'filling factor' of the largest cluster in the distribution will be small, since only a few small clusters will have densities above a high threshold, and the largest of these will have a size comparable to the rest. At lower thresholds, the filling factor (equivalently, the fraction of volume in the largest cluster) will grow as nearby clusters link together to form superclusters. Lowering the threshold further the largest cluster will begin to *percolate*, its length spanning the entire region under study. It turns out that at thresholds slightly above percolation, the number of distinct clusters in the distribution reaches a maximum value, which makes this threshold convenient for carrying out a statistical analysis of the properties of large scale structure. Applying percolation and shape analysis to the IRAS survey, *Sahni* and collaborators find that superclusters in this survey have significant amounts of both planarity and filamentarity, the latter being more significant especially for larger and more massive clusters. Thus, the combined study of the morphology of structures in N-body simulations and in the IRAS survey appears to lend support to the hypothesis that structures in the Universe formed through gravitational instability. The geometrical properties of large scale structure are now being probed further in a study of clusters and superclusters in the Las Campanas Redshift Survey by S. Bharadwaj, *Sahni*, Sathyaprakash, Shandarin and C. Yess.

Gravitational clustering in D-dimensions

In the recent years, *T. Padmanabhan* and collaborators have been investigating the generic features of gravitational clustering in terms of nonlinear scaling relations. These relations allow one to express variables (like correlation functions) in the full non-linear theory in terms of known linear quantities, thereby providing a powerful semi-analytic-tool for handling gravitational dynamics. One of the key features which emerges from these studies is the remarkable robustness of these relations.

During the last year, *Padmanabhan* and Nissim Kanekar have investigated another facet of these relations. They have now shown that such nonlinear scaling relations exist in all dimensions $D \geq 2$. They provide detailed analysis of gravitational dynamics in arbitrary dimensions and work out the nonlinear scaling relations based on a theoretical model originally proposed by *Padmanabhan* in 1996. These results show that the scaling relations are in fact far more general than originally suspected and are not merely due to the fact that gravitational forces are involved in 3 dimensions. These authors conjecture that the new results suggest certain level of universality in the description of systems with long range correlations in terms of scaling relations.

Particle production, vacuum polarization and the cosmological constant

The recent discovery that the universe may be accelerating due to the negative pressure of a *cosmological constant* 'Λ', has generated wide interest both amongst the scientific community and the lay public. The cosmological constant has had a chequered history. Introduced by Einstein in 1917 in an attempt to create a static Universe, the cosmological constant was soon discarded after the discovery of expanding solutions to the Einstein equations. Interest in the cosmological constant rose again in the late 1960's when it was felt that there was unusual clustering of QSO's at a redshift 1.98, an effect that could be explained within the framework of the Λ-based Eddington-Lemaitre quasistatic Universe. Intrigued by the debate around Λ, Zeldovich suggested a physical model of a cosmological constant, by showing that zero point vacuum fluctuations have an energy momentum tensor $T_{ik} = \Lambda g_{ik}$ exactly like the one due to a cosmological constant. Unfortunately, the 'zero-point' vacuum energy is infinite and has to be regularised with a precision exceeding one part in 10^{123}, in order to give rise to a small cosmological constant today as demanded by observations.

A number of models have recently been presented to explain the small observed value $\rho_\Lambda \sim 10^{-29}$g cm^{-3}. In some scenario's a scalar field rolling down a potential mimicks a time dependent Λ-term. In a different approach, *V. Sahni* and S. Habib have re-examined zero-point vacuum fluctuations, generalising Zeldovich's original approach to an expanding Universe. The massive nonminimal scalar field equation in an expanding Universe (the Klein-Gordon equation) shows an amazing similarity to the one dimensional Schrödinger equation, in quantum mechanics. In the time-*independent* Schrödinger equation, the presence of a potential barrier which varies in space causes particles to be both reflected and transmitted. Similarly, in the time-*dependent* Klein-Gordon equation the spatial barrier is effectively replaced by a *potential barrier* which varies in time and its presence causes waves to move both *forwards* and *backwards* in time, after being reflected off the barrier. The scalar field at late times is, therefore, not in its vacuum state but is described by a linear superposition of positive and negative frequency states.

The role of reflection and transmission coefficients is now played by the Bogoliubov coefficients (α, β). The presence of waves moving backwards in time is interpreted as 'particle production' within the framework of quantum field theory. The form of the time-dependent barrier $V(t)$ is shown in Figure 1 for the inflationary epoch. In analogy with quantum mechanics, the Bogoliubov coefficients α, β are determined by matching modes in the 'in' state with modes in the 'out' state, the 'in' and 'out' states being defined during inflationary and matter dominated epochs respectively.

Performing a detailed calculation of particle production, *Sahni* and Habib reached the interesting conclusion that, for ultra-light fields, the vacuum energy momentum tensor describing particle production and vacuum polarization would have the precise form of a cosmological constant, $\langle T_{ik}\rangle = \Lambda_{vac} g_{ik}$, where Λ_{vac} contained contributions from the particle mass m as well as its coupling to gravity ξ. In this manner, particle production in the Universe could generate a small value of the cosmological constant today, in agreement with observations. *Sahni* and Habib, therefore, demonstrated that the inflationary scenario has the ability to resolve both the flatness problem as well as generate a small cosmological constant at the present epoch, giving rise to $\Omega_m + \Omega_\Lambda = 1$.

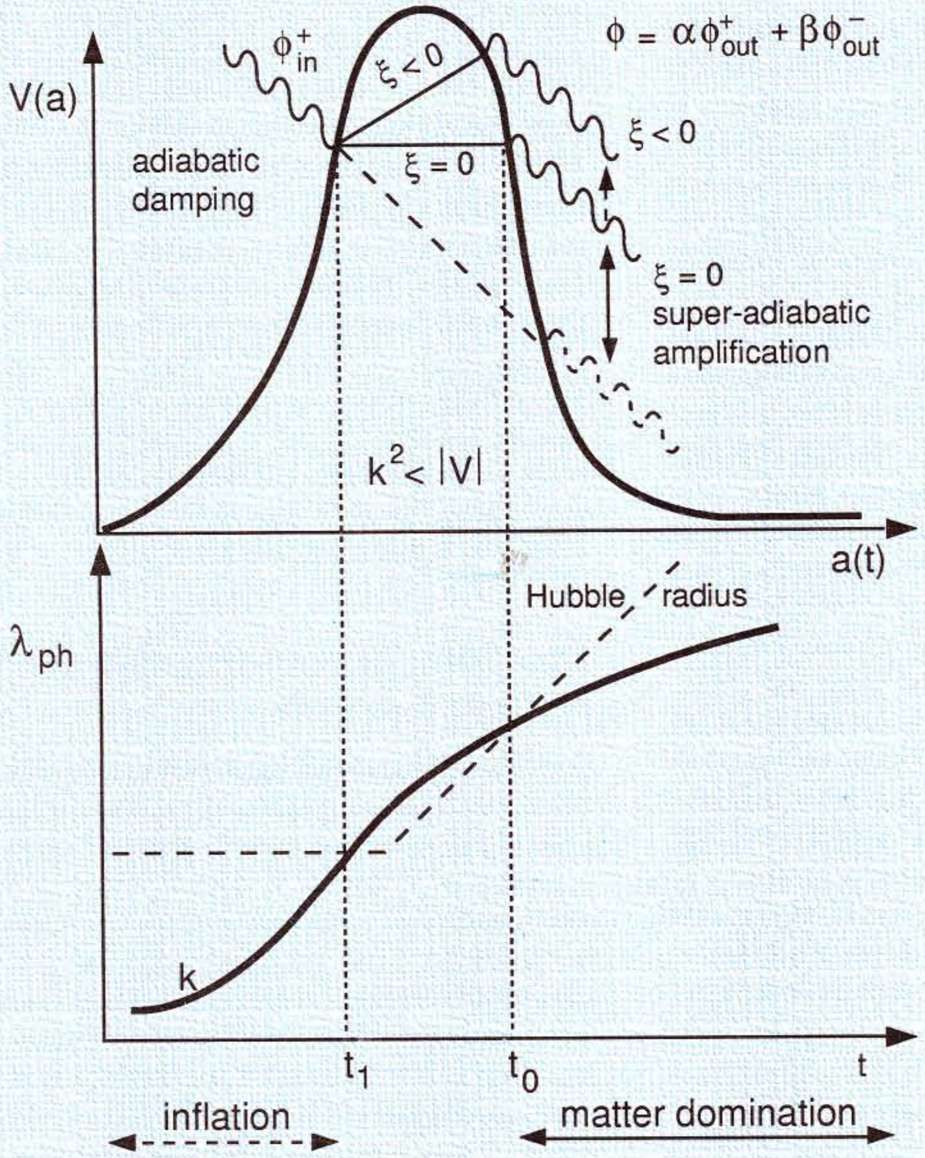


Figure 1: The process of super-adiabatic amplification of zero-point fluctuations (particle production) is illustrated. The top panel shows the time-dependent potential V which leads to particle production in an expanding Universe. The bottom panel shows the physical wavelength associated with a particle as it is stretched beyond the Hubble radius during inflation and after it reenters the Hubble radius during the matter dominated epoch. (The dashed line shows the Hubble radius.) The amplitude of modes having wavelengths smaller than the Hubble radius decreases conformally with the expansion of the Universe (adiabatic damping), whereas that of larger-than Hubble radius modes freezes (if $\xi = 0$) or grows with time ($\xi < 0$). Consequently, modes with $\xi \leq 0$ have their amplitude 'super-adiabatically amplified' on re-entering the Hubble radius after inflation (from *Sahni* & Habib 1998).

The quasi-steady state cosmology

After successfully demonstrating that the angular-size/ redshift relation for ultracompact radio sources can be well simulated in the quasi-steady state cosmology (QSSC), *S. K. Banerjee* and *J. V. Narlikar* looked at the magnitude (m)-redshift (z) relation for galaxies whose distances were estimated by observing the light curves of Type IA supernovae. It has been shown that a non-zero cosmological constant is needed to explain the observed m-z relation in the standard cosmology. In the QSSC, the creation field with its negative stress-energy tensor, produces a repulsive effect qualitatively like the cosmological constant. So how would it fare vis-a-vis this cosmological test? Work on this has been going on in collaboration with Fred Hoyle, Geoffrey Burbidge and Allan Sandage. The findings so far are these: (i) As in the case of the angular size-redshift relation, the QSSC models with negative spatial curvature provide a better fit. (ii) The fit improves if one assumes that the creation of matter in the QSSC is not confined to epochs of minimum scale factor (maximum density), but continues in a reduced fashion throughout the cycle. (iii) There are several caveats that still need to be sorted out to rule out any significant systematic errors in the data.

The first phase of work on structure formation in the QSSC through random mini-creation events has been completed by *Ali Nayeri, Sunu Engineer, Narlikar* and Fred Hoyle by showing that the two-point correlation function for the computer-simulated distribution of clusters of galaxies has the observed -1.8 power law. A typical simulation showing clusters and voids is shown in Figure 2. Work is also continuing to try to understand these findings from probability and statistics.

Anomalous redshifts

In 1980, P.K. Das and *J. V. Narlikar* had worked out the consequences of ejection of newly created matter in the modified Hoyle-Narlikar Machian theory of gravitation. If a quasar is ejected from a galaxy then – in this theory – it starts with zero rest-mass, which grows with the age of the object. How does such a variable-mass object travel in the gravitational field of the parent galaxy? This was studied by Das and *Narlikar* and this led to prediction about the expected separation of quasar from the galaxy. *S.K. Banerjee* and *Narlikar* have revived the earlier programme of Das and *Narlikar* to apply to the cases of quasars of anomalously high redshifts discovered in recent years by H.C. Arp and others. This work is in collaboration with Arp.

Dynamics of non-singular cosmological models

Since the discovery of the first non-singular cylindrical cosmological model by Senovilla, a family of spherical models has also been found by *N.K. Dadhich.* This family has a free function of time analogus to the scale factor of the FRW model. It can be chosen suitably to have non-singular behaviour for the model which is filled with imperfect fluid and radial heat flux. *Dadhich* and A.K. Raychaudhuri have noticed that the energy conditions as well as non-singularity allows for a periodic choice for it. Here it is possible to have an oscillating, non-singular, spherical model satisfying the energy conditions, which is quite remarkable. In this model, the universe oscillates between two finite and regular states. It can be envisioned as expanding from a high density, which can be chosen as high as one pleases, to low density and then again contracting to the initial state, and then the next cycle ensues. Periodic cosmology has always aroused interest. It is important to note that here the periodicity is obtained

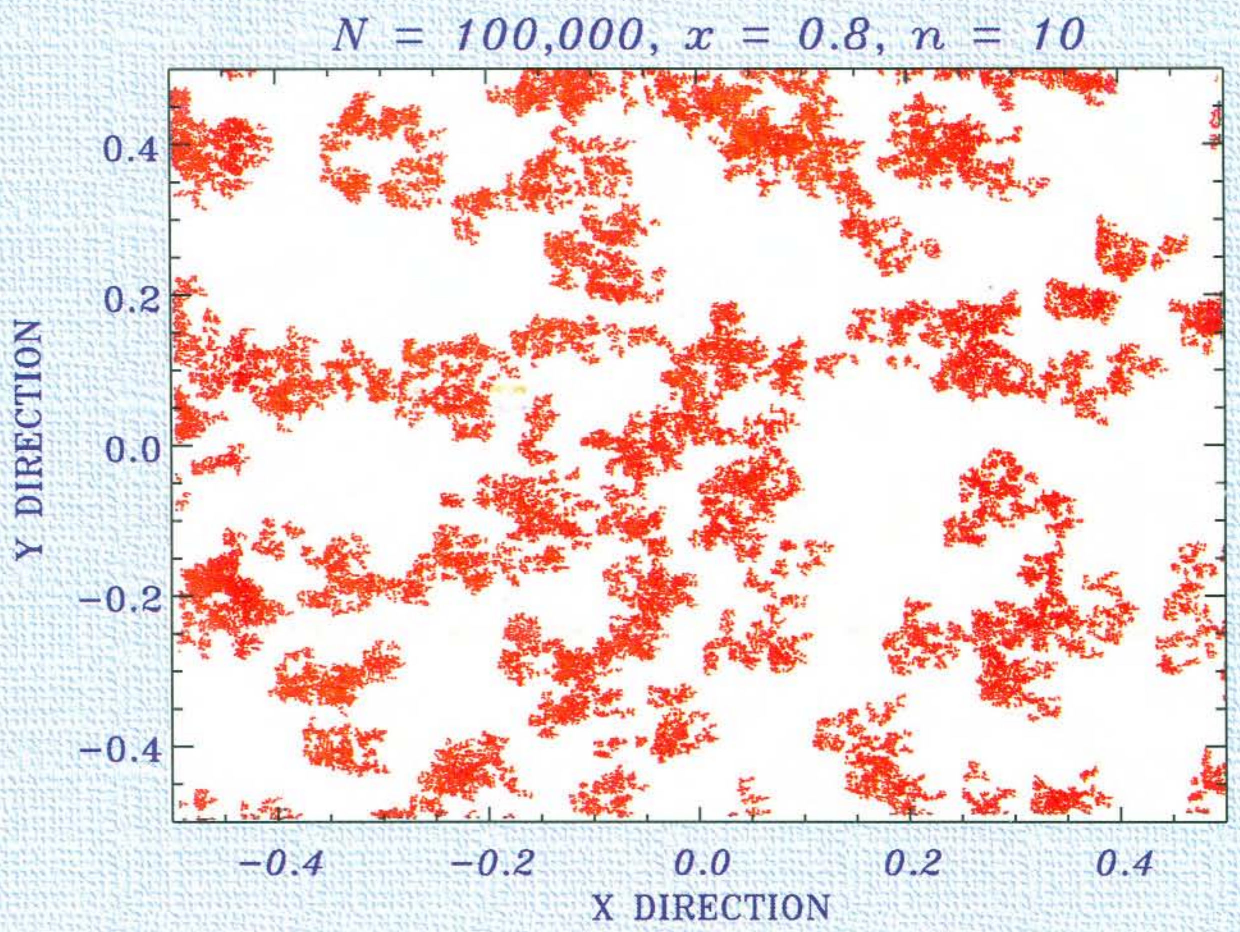


Figure 2: A computer simulated filament-void distribution with $n(>2)$ iterations of aligned ejection for $N = 100,000$ initially randomly distributed particles, with typical separation parameter $x = 0.8$, and the number of iterations $n = 10$. Each particle resembles a galaxy.

as an exact solution to the Einstein equation and without violating conservation law and the energy conditions. The oscillating model could, like the Quasi Steady State Cosmology, account for blue shifts if they were to be discovered in future.

An oscillatory non-singular spherical model is a novel and interesting example, though tentative in application to practical cosmology. It indicates the potential of classical relativistic cosmological solutions. All the known non-singular models have non-zero shear. Though shear contributes positively to focusing density in the Raychaudhuri equation, it was argued by *Dadhich* that the presence of shear makes collapse incoherent, which works against formation of compact trapped surface. This is why presence of shear along with acceleration may be necessary. Raychaudhuri has recently proved a general theorem that for a non-singular universe, space average of all kinematical and physical quantities must vanish. A direct application of this theorem leads to the general result that presence of shear or heat flux (which joins acceleration directly in the equation of motion) along with acceleration is necessary for avoiding the singularity. That is, at least one of shear and heat flux must combine with acceleration so as to avoid singularity.

The crucial condition for avoiding singularity is not allowing compact trapped surface to form. For this (apart from acceleration/heat flux, that can directly oppose collapse), the convergence of fluid congruence would also play an important role. This is where shear makes its entry in dynamics of the model. If two neighbouring fluid lines are connected by a spacetime vector, the time rate of change of its magnitude (i.e. relative distance between the lines) and its direction depend upon shear non-trivially. This will essentially determine the rate of convergence of the fluid congruence. It is this dynamical feature which is most relevant for formation of trapped surface. *Dadhich* has shown that in all non-singular models the rate of convergence tends to zero with time. In contrast, this rate diverges for singular models. This would be the characteristic property of non-singular cosmology consistent with GR and the energy and causality conditions.

On the other hand, L.K. Patel and *Dadhich* have obtained a very simple non-singular spherical model which has shear free isotropic fluid with radial heat flux as its matter content. This is the first case of a shear free non-singular model. In accordance with the Raychaudhuri theorem shear or heat flux must be non-zero for avoiding the singularity. Senovilla models have only shear non-zero while both shear and heat flux are non-zero in the case of spherical models (including the oscillating model) referred above. The model by Patel and *Dadhich* is an example of vanishing shear and non-zero heat flux. This model satisfies the weak and strong energy conditions but it fails to satisfy the dominant energy condition.

Based on these investigations, *Dadhich* conjectures that the presence of shear along with acceleration is necessary (shear free cases like the above would perhaps violate one of the energy conditions), while vanishing of rate of convergence of fluid congruence with time may be sufficient for non-singular exact cosmological solutions of the Einstein equation obeying all the energy conditions.

Quasars, Active Galactic Nuclei and Absorption Systems

The host galaxies of quasars

The properties of quasars are very similar to the properties of the Active Galactic Nuclei (AGN) which are found in Seyfert, radio and other galaxies. But the former appear to be point sources like the stars, while the AGN reside in more or less normal galaxies. There is ample evidence to show that quasars as well as the different kinds of AGN are all basically the same type of object, with many of the observed differences being mainly due to the different angles from which an observer views these objects. From the similarity between quasars and the AGN, it follows that one may expect that the former may be simply extreme forms of the latter, in which case the quasars too must reside in galaxies.

Quasars are at high redshift, which affects the host galaxy in two ways. First, because of the expansion of the universe, the surface brightness of the galaxy decreases rapidly as the redshift increases. Second, at different redshifts, different parts of the intrinsic spectrum of the galaxy are probed, which again makes the galaxy dimmer. In addition to this, the very presence of the bright quasars tends to swamp the faint galaxy, so that it becomes rather difficult to observe it against the dazzle of the quasar. In spite of all these difficulties, very long exposure with large aperture telescopes on the ground, or with the Hubble Space Telescope has revealed the presence of a faint host galaxy. For many years, these detections were limited to quasars with redshift less than 0.6 or so, but careful CCD and IR array observations have recently revealed the presence of host galaxies around quasars with redshifts as high as 2.5 or so. But the hosts here are so faint that they can barely be detected, and it is almost impossible to reach any conclusion about their nature. One does not even know whether the hosts have regular forms like elliptical or spiral, or any other details of their morphology or nature. But their luminosities appear to be several times higher than the luminosities of the brightest galaxies in our neighbourhood.

A.K. Kembhavi, *Ranjeev Misra* and *Yogesh Wadadekar* have been investigating into the types of galaxies which could be the hosts of quasars. Their approach has been to simulate galaxy-quasar combinations using detailed models of their light distribution, and taking into account the spreading of the light due to the effects of the Earth's atmosphere. Such a model galaxy, when taken further away becomes small in angular extent and dimmer, and at some limiting redshift becomes indistinguishable from a point source. The limiting redshift depends on the properties of the galaxy, the brightness of the quasar and the cosmological model used. Detailed investigation shows that even the brightest galaxy known in our neighbourhood, when combined with a moderately luminous quasar, would disappear at redshifts less than those at which hosts have been observed. This means that the observed quasar host galaxy must be several times more luminous than the very bright galaxies in our neighbourhood. This requires that there must be processes like starbursts occurring in these galaxies, which make them brighter while leaving their overall geometrical structure more or less the same.

Most quasars have been discovered in surveys which were not sensitive enough to reveal the faint host galaxy. These quasars are generally counted separately from Seyfert galaxies, and the relationship between the two populations is not clear. The formalism described above shows how the changing appearance of host galaxies with redshift can be quantified, and the proportion of Seyfert galaxies and quasars determined. This is very important in interpreting the observed number densities of these two types of objects from the point of view of galaxy and quasar formation models.

The radio emission from quasars

A small fraction of all quasars have high radio luminosities, while the rest appear to be radio quiet, and can be detected at radio wavelengths only with most sensitive radio surveys. Some of the radio quiet quasars, of course, appear to be very faint at radio wavelengths simply because they are very far away, while others are intrinsically very weak. It is important to observe as many faint quasars as possible so that models for the emission can be developed, but it is difficult and time consuming to observe a large number of faint quasars even with the biggest radio telescopes.

Recently, a large area of the sky has been observed at radio wavelengths with the Very Large Array (VLA), and the results were compiled into the FIRST radio catalogue. This contains about 200,000 sources, and includes every source, in the area of the sky observed, to a flux limit of 1 millijansky, which is very much fainter than any other large radio survey. *Yogesh Wadadekar* and *A.K. Kembhavi* have compared the postions on the sky of sources in the FIRST survey with the postions of quasars in the catalogue of Hewitt and Burbidge. From this procedure, the radio emission from hundreds of quasars has been obtained, with about 150 of these being first time radio detections. The large sample of faint quasars forms a valuable resource for the study of quasar radio emission.

It is of interest to see whether the optical and radio emission of quasars are related to each other. There has been much discussion in the literature on this topic. It was believed in the early years after the discovery of quasars that as the optical luminosity of a quasar increases, so does its radio luminosity in such a manner that the distribution of the ratio of the two luminosities was the same for the entire quasar population. In an alternative model, the optical and radio luminosities are distributed independently. Most quasars in this model are like Seyfert galaxies, with relatively low radio luminosities, while a small fraction are highly luminous radio emitters and are like radio galaxies. The large number of radio quasar radio detections made with the help of the FIRST survey allow the reexamination of these two models. It has been established that there is no correlation between the radio and optical luminosities. This rules out a universal distribution of the radio to optical luminosity ratio. The distribution of the radio luminosity itself appears to be bimodel, with a significant fraction of quasars having very low radio luminosities, and forming a population distinct from the radio loud objects.

Gravitationally redshifted iron emission line?

Recently the detection of broad iron emission line from AGN has generated considerable interest. It has been proposed that the line is produced close to a black hole and the line is broadened due to gravitational red-shift. If this interpretation is correct this would be the first direct observation of the effect of a strong gravitational field near a black hole. Earlier, *Ranjeev Misra* and *A.K. Kembhavi* had pointed out that a high density cloud surrounding the source could also give rise to a similar line profile. *Misra* and *F. Sutaria* have now shown by examining the X-ray data from the ASCA satellite that observations do not rule out the presence of such a cloud. However, *Misra* pointed out that the recent data from the BeppoSAX satellite may indeed rule out such a model thereby confirming that the broadening is produced by gravitational red shift.

Model for AGN

There seem to exist tantalizing clues from demographics of supermassive black holes that they are relics of a violent earlier universe and it has been argued that it is a consequence of the galaxy formation process. Some of the issues involved are the angular momentum barrier, star formation and the formation of a single black hole with a mass $\sim 10^6 M_\odot$.

A detailed model for the formation of massive objects at the centres of galaxies by *A. Mangalam*, completed recently, has addressed these issues. An over-dense region of mass $10^{10}M_{\odot}$ with Ω_b/Ω of order 0.1, collapses at $z = 8$. Taking into consideration supernovae heating in detail, the conditions of gas loss and its consequences in the allowed mass range of the halo is calculated. It is seen that enough gas is retained to form massive dark objects and quasars even for moderately massive halos. Subsequently, a gaseous disk forms with a radial extent of a kiloparsec, spun up by tidal torques and magnetized by supernovae fields. It is shown that about $10^8 M_{\odot}$ accretes via small magnetic stresses (or alternatively by self-gravitational instability) in background potential of the dark halo in 10^8 years. A model of a self-consistent, self-gravitating collapse of a magnetized disk has a rapid collapse time scale of about a million years. The two disk solutions in this work has more general applications to protostellar disks and it can be adapted to other prescriptions of viscosity. Implications for a large scale field are also discussed.

Probing the BLR in AGNs using time variability of associated absorption lines

It is known that roughly 10% of the high redshift QSOs show associated absorption lines, (*i.e.*, systems with absorption redshift, z_{abs}, greater than or equal to the emission redshift, z_{em}) super-imposed on the broad emission lines. It is believed that these absorption systems could be due to gas intrinsically associated with the central engine of the QSO and/or with the ambient medium surrounding the QSO (for example, interstellar medium of the galaxies in the cluster in which QSO is also a member).

IUE observations suggested only 3% of the low z, low luminosity, AGNs (Seyferts) show narrow absorption lines. However, HST spectra with better resolution and signal-to-noise (S/N) show that the incidence of intrinsic absorption lines in Seyfert 1 galaxies is much higher than 3% and could be as high as 50%. Shull and Sachs (1993) have shown the associated C IV absorption in NGC 5548 vary over a time-scale of few days and there is a weak anti-correlation between the continuum luminosity and the continuum equivalent width. Such a variability in the associated absorption lines are also seen in a few other Seyfert galaxies and QSOs. The variability seen in the absorption is usually assigned to variability in the ionizing conditions in the clouds and the time-scale of variability is used to get the density.

It is also known that most of the clouds producing associated absorption in the spectra of AGNs and quasars do not completely cover the background source (continuum + broad emission line region, BLR). *R. Srianand* and *S. Shankara Narayanan* have illustrated that, due to complicated velocity structure in the BLR, the covering factor derived will not be the fractional area covered; rather it will be the fraction of photons emitted from the region occulted by the absorbing clouds. They have also shown that the variability in absorption lines can be produced by the changes in the covering factor caused by the variation in the continuum and the finite light travel time across the BLR. Using simple illustrative examples they have shown how such a variability due to covering factor variations can be distinguished from the variability caused by other effects and how one can use the variability in the covering factor to probe the BLR.

The $z_{abs} \sim z_{em}$ absorption line systems towards QSO J2233-606 in HDFS:

In order to investigate in more detail the nature of associated systems and their possible connection to warm absorbers (soft X-ray absorption due to ionized oxygen), absorption from species with a wide range of excitation states should be studied. Moreover, column densities should be determined taking into account the effect of partial coverage. In this prospect, absorption from Ne VIII, if present, is crucial as its ionization potential, 207 eV, is much higher than the ionization potential of other easily observable species. The Ne VIII$\lambda\lambda$770,780 absorption doublet seems to have been detected in only two systems, in the line of sight to HS1700+6416 at $z_{abs} = 2.7126$ (Petitjean, et al. 1996) and in the line of sight to UM675 (reported by Hamann, et al. 1995, spectrum still unpublished) at $z_{abs} = 2.1340$. Analysis of the latter system leads the authors to conclude that, although the detection of Ne VIII provides strong evidence for a link between the associated system and the warm absorber, the total hydrogen column density in the Ne VIII phase is too small to produce the warm absorber phenomenon.

The QSO J2233-606 ($z_{em} = 2.24$) has received tremendous interest as it is located in the middle of the STIS Hubble deep field south making this field an ideal target for studying the connection between the diffuse gaseous component of the universe and galaxies. There are several associated systems at $z_{abs} \sim 2.2$ with broad C IV and N V absorption lines. HST STIS spectra, together with the available ground-based data, provide different pieces of information about these systems over the rest-wavelength range 375-2800 Å. Such a wide coverage in rest wavelength provides a good case to investigate the associated systems in greater detail.

R. Srianand and Patrick Petitjean have investigated highly ionized absorption systems, observed over the redshift range $z = 2.198$–2.2215 in the $z_{em} = 2.24$ HDFS-QSO J2233-606, in greater detail. They have reported the detection of absorption due to Ne VIII ions. The strength and covering factor of the O VI and Ne VIII absorption lines suggest that the gas is closely associated with the AGN. Most of the lines show signature of partial coverage and the covering factor varies from species to species. This can be understood if the clouds cover the continuum emission region completely and only a fraction of the broad emission line region.

Using photo-ionization models they have analyzed the component at $z_{abs} = 2.198$, for which they could derive reliable estimates of column densities for H I and other species. Though the absolute abundances are close to solar, the [N/C] abundance ratio is larger than solar. This result, which is consistent with the results obtained from the analysis of high-z QSO broad emission-lines, again confirms the physical association of the absorbing gas with the AGN. The observed column densities of N IV, N V and Ne VIII favour a two-zone model for the absorbing region where Ne VIII is predominantly produced in the highly ionized zone. Lack of information on the spectral energy distribution of J2233-606 and a poor S/N ratio over the Ne VIII absorption line spectral range prevent them from drawing any firm conclusion about the connection between this highly ionized zone and X-ray "warm absorbers".

They have reported a Lyα absorption line at $z_{abs} = 2.2215$ with a flat bottom typical of saturated lines and non-zero residual intensity in the core, consistent with partial coverage. There is no metal-line from this Lyα cloud detectable in the spectrum which suggests either large chemical inhomogeneities in the gas or that the gas is very highly ionized. If the latter is true the cloud could have total hydrogen column density consistent with that of X-ray absorbers. It is, therefore, of importance to check whether (or not) there is an X-ray warm-absorber in front of this QSO.

Study of quasar broad emission region from spectroscopy of multiple images

The flux ratio, line strength and Doppler profile of broad emission lines in the multiple images observed in gravitationally lensed systems are in general not same, essentially because of the non-negligible size of the emission region. If the angular separation of the source from the caustic (which delineates the regions of different image multiplicities) is comparable to the size of the line emission region, the images could be merging in the broad line though they may be distinct in the continuum. By modeling the line emission and comparing the observed flux ratio as well as Doppler profile, it is possible to infer the structure of the broad line emission region in addition to providing stringent tests of the gravitational lens models. *R. Srianand* and D. Narasimha have investigated the gravitationally lensed systems Q1422+231 and PG1115+080 using the HST FOS spectra obtained from the archives.

Their analysis suggests that in both cases : (i) The continuum flux ratio between the images is different from that of various line emissions (ii) The difference is substantial in the brightest images which are close to each other and (iii) there is difference in the Doppler profiles of the emission lines when the flux ratio varies. Using fairly generic properties of the lens, they are able to construct models with very few parameters which explain most of these features. Since the quality of the optical data is not very satisfactory they are not in a position to provide quantitative results on the structure and dynamics of the parsec scale features in AGNs. A crucial input that determines the shape of the lens (and through it, the scale length of its mass distribution) is the ratio of the magnification of the two near-merging images. A value, very different from unity, for this ratio is indicative of a highly asymmetric lens of large scale length. In their work they address the lens models only through the singularity theory with the simplest kind of *unfolding*. It is evident the difference in the observed fluxes of the two brightest images are naturally explained and possible, milliarcsecond scale, jet type of structures could further test the reliability of the model. But in this generic study of the lens, the scale of the source plane cannot be fixed without having external input on the scale length of the lens galaxy. Consequently, the size of the emission region cannot be predicted. More realistic models are being constructed taking into account the available VLBA data.

Observational Cosmology

The nature of the cosmological constant

Studies of standard candles (Type Ia Supernovae) at redshifts up to z=1 (Perlmutter, et al. 1998, Riess, et al. 1998) suggest that the luminosity-distance relation is best fit by an $\Omega > 1$ (closed) Universe. If $\Omega_{tot} = 1$, then the most likely values of its components are $\Omega_M = 0.3$ and $\Omega_\Lambda = 0.7$. This has necessitated a closer look at the properties of Universes with a small positive value of the cosmological constant.

Tarun Deep Saini, *Somak Raychaudhury* and *Varun Sahni*, in collaboration with Alexei Starobinsky, are attempting to determine an effective potential for the Lambda-field using the most recent supernovae data of both Perlmutter, et al. and Riess, et al., based on an ansatz given by Starobinsky. They are examining whether the observed data are compatible with a minimally-coupled scalar field model for the origin of the Lambda term, the nature of the potential, and whether it implies a time-dependent cosmological constant.

Gravitational lensing

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

The most direct way of measuring the distribution of matter in a cluster of galaxies is to study gravitationally lensed images of galaxies lying behind the cluster. *Tarun Deep Saini* and *S. Raychaudhury* have been examining a few clusters where arcs and arclets ("strong lensing") can yield information about the distribution of matter. In particular, they have been successful in modeling the lens B1422+231 on the basis of available optical (HST), radio (VLBI) and x-ray (ASCA) data, where they have modeled the mass distribution. Currently, they are in the process of comparing their model to that predicted by time-delay measurements by A. Patnaik and others with the VLA, which would yield a reliable value of the Hubble constant.

Observing the topology of the universe

Quantum cosmology will enter the domain of observational astrophysics if the global topology of the Universe is measured and found to be non-trivial. Reviews of the different observational techniques and the prospects of their applications to existing and new catalogues were studied by *B. Roukema*. New results include a comparison of an observationally-based hypothesis for the topology of the Universe with COBE observations of the cosmic microwave background (CMB), a technique of measuring galaxy velocities transversal to the line-of-sight (Roukema & Bajtlik 1999) and a method of constraining the metric parameters (Ω_0, λ_0) via detection of multiple (topologically) images of astrophysical objects.

Measuring the galaxy correlation function:

An estimate of the clustering of galaxies, as represented by the two-point autocorrelation function, was estimated for galaxies at high redshift ($z \sim 2$) in the Hubble Deep Field (North) by *B. Roukema* (in collaboration with Valls-Gabaud, Mobasher & Bajtlik 1999). Correction for the integral constraint was done in a way which avoids the usual assumption that the angular correlation function should be a power law with a given slope. The low value of the correlation length suggests that the epochs of high bias in the correlation function expected at high redshift, is over by $z \sim 2$.

Dynamics of Coma-Sculptor Cloud

Galaxies within a distance of 10 Mpc of the Sun reside in a flat disk (ratio of longest to shortest axis = 1 : 5, the 'Coma-Sculptor Cloud'). Together with D. Lynden-Bell, *S. Raychaudhury* has been examining the dynamics of these galaxies to find dynamical evidence of the collapse of this unusual cloud, and how it happens to be aligned with the supergalactic plane, which is a structure over ten times larger, and is better studied. They have studied the luminosity function of galaxies belonging to this disk, using a variant of the C^- method, and found evidence for a significant excess of bright galaxies than that expected from a global galaxian luminosity function.

The mass of the Coma-Sculptor disk is estimated from the Jeans mass, and the mass-to light ratio thus obtained is $M/L_B \simeq 180$.

Galactic Structure and Dynamics

The structure of galaxies

Galaxies have a very complex structure, with stars, gas and dust intermingled and distributed in different proportions through the volume of the galaxy. But in spite of a structure which appears to be rather involved over scales of hundreds of light years, there is much overall regularity. In this respect elliptical galaxies are the simplest, because in their case what we see in the sky is the projection of an ellipsoidal structure, consisting mostly of old stars. Here the proportion of gas is much less than in spiral galaxies, which leads to lesser star formation activity. The surface brightness of an elliptical galaxy can in fact be described as a very simple function of the distance of the point from the centre of a galaxy. This was first discovered by G. de Vaucouleurs in 1948, and provides a rather good fit to most elliptical galaxies. The model has only two parameters in it : (i) the half light radius which encloses half the total light of the galaxy, and (ii) the surface brightness at this radius. Apart from ellipticals, de Vaucouleurs' law also applies to the bulges of spiral galaxies. The structure of spirals consists of a bulge and a disk, with the bulges behaving more or less like elliptical galaxies, and the disks having an exponential distribution of intensity.

It is now possible to test such a law to a much greater accuracy than before, because of the availability of high quality data in the optical region of the spectrum obtained with CCD detectors, and in the near infrared (IR) region with IR arrays. Over the past several years, it has become clear that a generalization of de Vaucouleurs' law, which involves an additional parameter n, which affects the shape of the light distribution is required. While an extra parameter always improves the formal statistical quality of a fit, such a parameter turns out to be useful only if it shows specific correlations with other properties of the galaxies, or their environment. In that case the new parameter can be used as a pointer to the processes that led to the formation and evolution of galaxies.

H. Khoshroshahi, *Y. Wadadekar* and *A.K. Kembhavi* have considered the application of the generalized de Vaucouleurs' law to a sample of 40 elliptical galaxies, and the bulges of about 30 spiral galaxies. These galaxies have been observed in the near IR band by different groups. The near IR intensity distribution is far less affected due to dust and star formation than intensity in the optical band, and is therefore ideal for tracing the overall structure of galaxies. It has been found that the parameter n, the half light radius, and the central bulge intensity of disk galaxies can be used to define a 3-dimensional plane. The parameters of individual galaxies are distributed in this plane, with very little scatter around it. What is most interesting is that the parameters of elliptical galaxies also lie on a plane which is nearly coincident with the plane for bulges. This is an important result, as it provides a setting in which bulges of disks and ellipticals appear to be quite similar. The usual 2-dimensional correlations between galaxy properties, like the Kormendy plot, are projections of the plane onto different axes, and in each of these projections the scatter appears to be greater than around the plane itself. The existence of the plane shows that the parameter n is indeed a useful parameter, and must be included in the theories of the way in which galaxies form and evolve.

Stellar orbits in triaxial clusters around black holes in galactic nuclei

Niranjan Sambhus and *S. Sridhar* investigate the orbital structure of a model triaxial star cluster, centered around a supermassive black hole (BH), appropriate to galactic nuclei. *Sridhar* and Touma (1999) proved that the presence of the BH enforces some regularity in the dynamics within the radius of influence of the BH. The authors employ their averaging method to reduce the degrees of freedom from three to two. Numerical orbit integrations, together with Poincaré surfaces of section allow them to draw a global portrait of the orbital structure. In their calculations, the authors employ a model cluster potential that is triaxial and harmonic. Observing that the averaged dynamics of the axisymmetric case is integrable, the authors present a detailed comparison of orbits in oblate and prolate axisymmetric potentials. Both these cases supported resonant orbits with fixed values of eccentricity, inclination, and periapse, whose line of nodes rotates steadily. These occur for all values of oblateness, but only for axis ratio greater than two, in the prolate case. The authors identify this phenomenon with the (in)stability of the long axis orbit. The authors then systematically explore significantly triaxial potentials, possessing small oblateness, or prolateness. They conducted a study of resonant orbits and their families, both numerically, and through secular perturbation theory. Chaos was highly suppressed for all the cases they studied, and they obtained effective third integrals. The authors observed that some of the orbits appear to reinforce the shape of the potential, and they provide phase space, as well as real space portraits of these orbits.

Galaxy dynamics

Violent relaxation during the collapse of a galaxy halo is known to be incomplete in realistic cases such as cosmological infall or mergers. *A. Mangalam*, R. Nityananda and *S. Sridhar*, in a study that was completed recently, argue that the appropriate parallel from plasma physics is wave particle interaction as described in the quasi-linear theory of Landau damping. Unlike particle-particle scattering, this does not drive the system to an equilibrium distribution function of the exponential type, even in regions of phase space allowed by the constraints. They motivate a distribution function which does not involve the exponential functions of the energy used so far, and present the simplest realization of this proposal. It possesses the desirable features of earlier treatments, such as an energy distribution, density and surface brightness profiles, and anisotropy, consistent with simulations.

Mangalam and Sellwood carried out cold collapse simulations whose properties had a remarkable agreement with the predictions of the model. Furthermore, they found that temperature of bar instability for smooth initial conditions ($1/r$ density profile) is higher than reported in the earlier works. Preliminary results based on analytic criteria from this ongoing work also suggest that the model is stable to radial orbit stability, which is to be confirmed with N-body tests.

Galaxy and Interstellar Medium

Interstellar dust and extinction by porous grains

Following the ongoing work on modeling of interstellar dust grains and fitting with the interstellar extinction curve, *Ranjan Gupta* and D.B. Vaidya have explored the possibility of finding composition of dust along various directions of the galaxy. Though this is still at a preliminary stage the Figure 3 shows an example of such fits for four typical stars from the IUE database. It is evident from this figure that the top two stars' spectra fit closely to the average interstellar extinction curve but the bottom two stars show deviation from the general law. Figure 4 shows a clearer view of a typical proposed dust grain with 1184 dipoles.

The dust in interstellar medium is known to polarise light of the background stars. This polarisation is caused by alignment of non-spherical grains, and the observations of polarisation can be used to draw conclusions about the process of alignment. Magnetic fields are believed to be an important agent for alignment of the grains, and hence, the orientation of the fields can be inferred from polarisation measurements. The details of the orientation mechanism are not fully clear, e.g., how the radiation field, etc. affect the efficiency of alignment. In order to study such questions, *Gupta*, A.N. Ramaprakash, A.K. Sen, and *S.N. Tandon* have been observing a large sample of dark galactic clouds with an imaging polarimeter (IMPOL) with the 1.2 m telescope of the Physical Research Laboratory, Ahmedabad (for more details, see the Report for the year 1997-98).

Observations of several dark clouds were carried out in April 1998 and in March 1999. The data for about a dozen dark clouds have been analysed and a detailed compilation with polarization maps for these objects has been made .

Fluid Mechanics

The classical problem of the magnetic dynamo concerns the question of the amplification (or maintenance) of the magnetic field in a fluid. It is known that dynamo action is impossible under certain symmetries and are constrained by "antidynamo theorems". These theorems have been crucial to the development of dynamo theory and its applications to astrophysical dynamos.

The induction equation yields only decaying solutions for the magnetic field when the velocity and magnetic field are both axisymmetric or if the geometry has planar symmetry. In both situations, the velocity and magnetic field can be three dimensional but do not depend on at least one of the coordinates. In situations where the velocity is two dimensional, but the magnetic field is three dimensional, the impossibility of dynamo action has been proven if the flow is planar or spherical.

A. Mangalam has used a generalized toroidal-poloidal representation of the magnetic field to extend the above results. Incompressible two-dimensional velocity flows in situations other than in the above special cases, lead to linear growth in one of the field components and are otherwise slow. The approach taken also lends itself to a unified and simpler exposition of the previous results. It is now attempted to *uniquely* determine the conditions that satisfy antidynamo theorems, especially Cowling's theorem.

Stellar Physics

Evolution of multi-polar magnetic field in isolated neutron stars

Strong multipole components of the magnetic field have long been thought to play an important role in the radio emission from pulsars. Multipole fields have been invoked for the generation of electron positron pairs in the pulsar magnetosphere. Magnetic multipole structure at and near the polar cap is also thought to be responsible for the unique pulse profile of a pulsar. Significant evolution in the structure of the magnetic field during the lifetime of a pulsar may, therefore, leave observable signatures. If

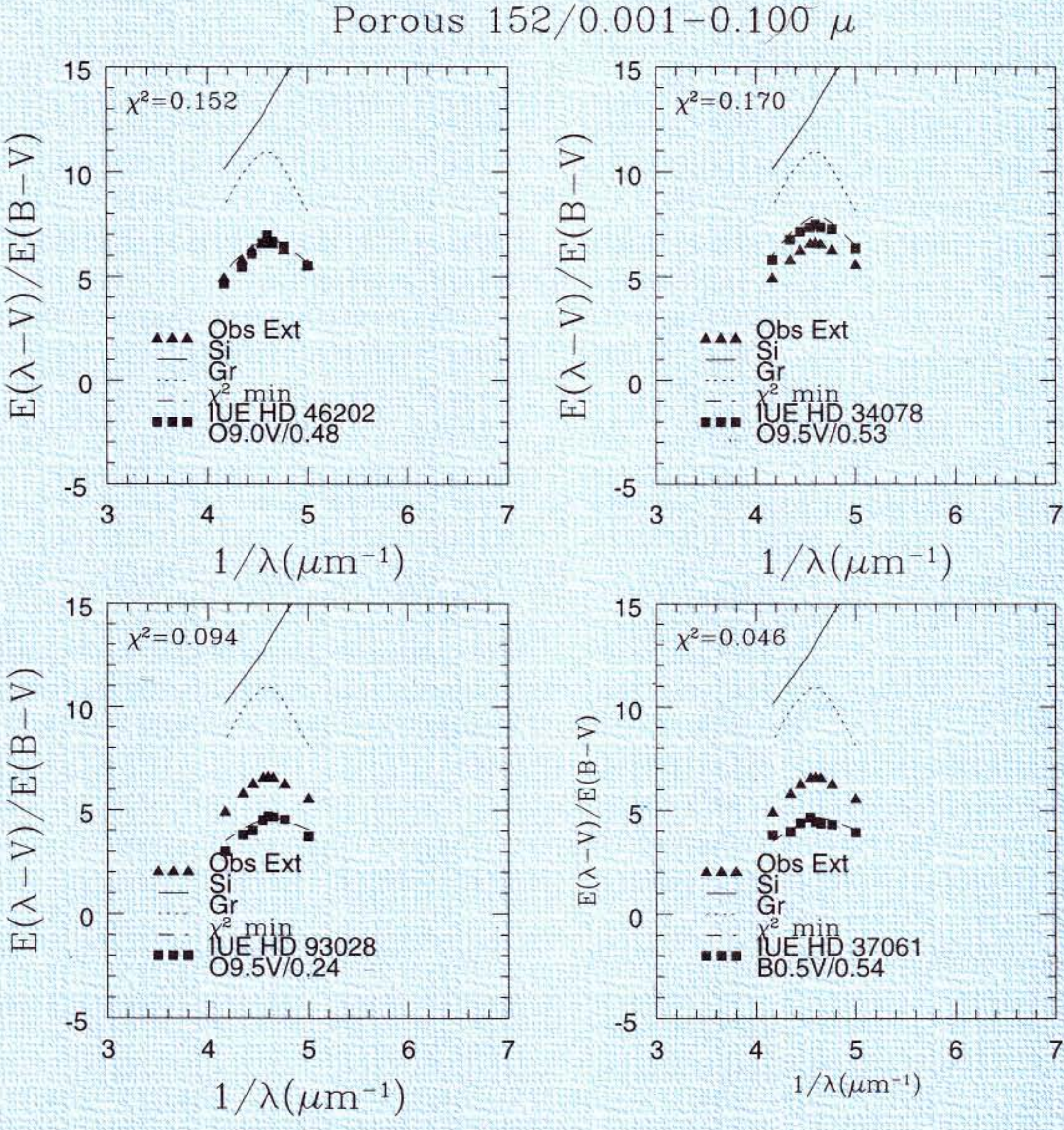


Figure 3: Comparison of interstellar extinction curve with the best fitted model combination curve of porous graphite and silicate grains with n=152 dipoles and actual IUE spectra of four stars.

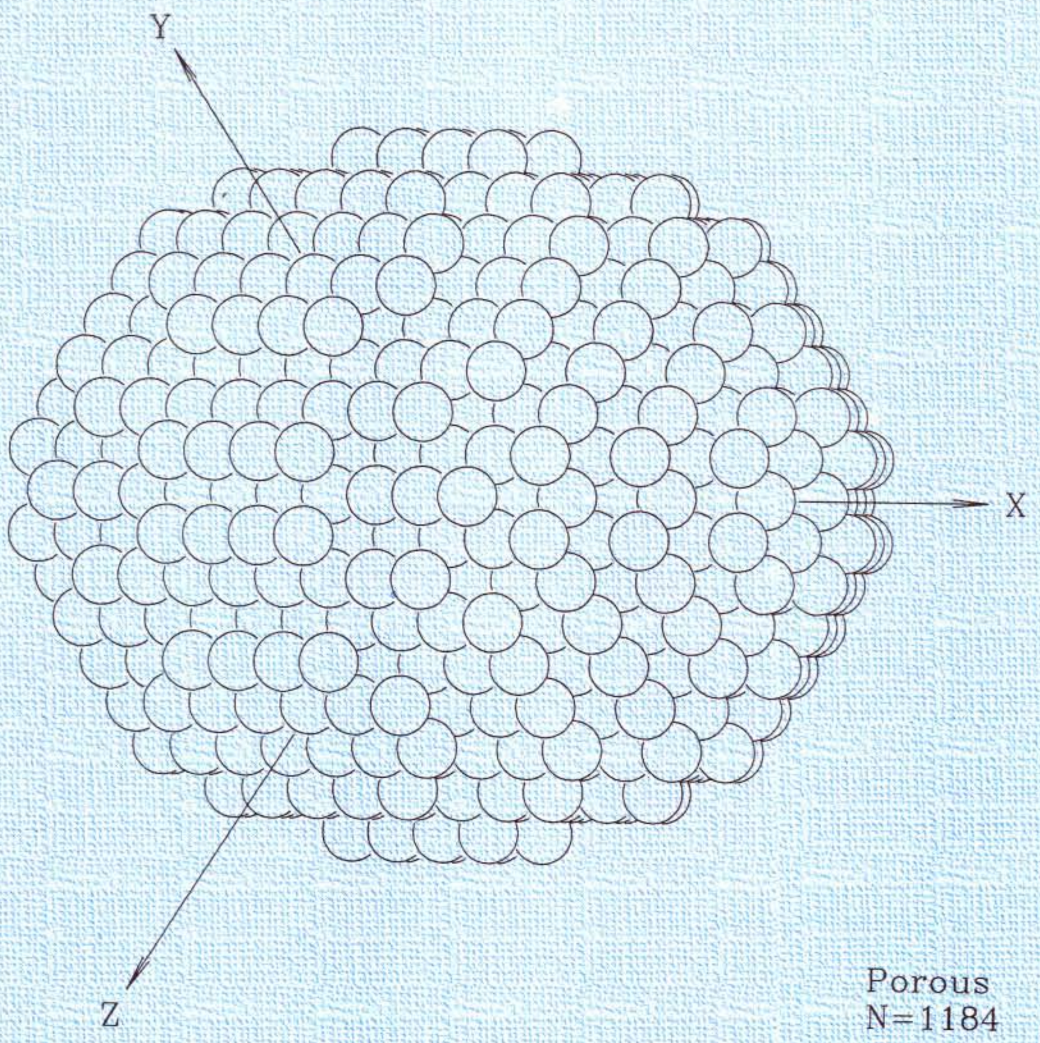


Figure 4: A 3-D view of the shape of the dust grain with 1184 dipoles.

the multipoles grow progressively weaker in comparison to the dipole then one can expect pulse profiles to simplify with age and vice versa. The evolution of the magnetic fields in neutron stars is still a relatively open question. During the last decade, two major alternative scenarios for the field evolution has emerged. One of these assume that the field of the neutron star permeates the whole star at birth, and its evolution is dictated by the interaction between superfluid vortices (carrying angular momentum) and superconducting fluxoids (carrying magnetic flux) in the stellar interior. The other scenario assumes that most of the field is generated in the outer crust after the birth of the neutron star. The later evolution of this field is governed entirely by the ohmic decay of currents in the crystal layers. The evolution of the dipole field carried by such currents has been investigated in some detail in the recent literature. The results show interesting agreements with observations lending some credence to the picture. In a recent work, *S. Konar*, D. Mitra and D. Bhattacharya have studied the evolution of the multipolar structure of the magnetic field of isolated neutron stars assuming the currents to be confined to the crust of the stars. They find that except for very high order multipoles, ($l \sim 25$) the evolution is similar to that of a dipole. Therefore, no simplification of pulse profiles of isolated radio pulsars with age is expected on this count.

Whither strange pulsars ?

The *strange matter*, composed of u, d and s quarks, could be the ultimate ground state of matter. If metastable at zero pressure then this phase could exist in the cores of the neutron stars stabilized by high pressure. If, however, this form of matter is absolutely stable at zero pressure then the existence of *Strange Stars* (stars made up entirely of such strange matter apart from a small hadronic crust) is a possiblility. It is found that the stable range of mass ($1M_\odot - 2M_\odot$) for the strange stars is quite similar to that for the neutron stars. Furthermore, in this range, the radii of the strange stars are not very different from those of the neutron stars. This implies that both neutron stars and strange stars are capable of supporting fast rotation observed in pulsars. On this basis, it has been argued that some of the pulsars could be strange stars. *S. Konar*, D. Mitra and D. Bhattacharya investigated whether strange stars can sustain characteristic pulsar magnetic fields ($10^8 - 10^{13.5}$ Gauss) over astronomically significant time-scales. Furthermore, they checked whether strange stars fit into the general scenario of field evolution of pulsars. It is found that as far as the evolution of the magnetic field is concerned the strange pulsar hypothesis runs into serious difficulties to explain the observational data.

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

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

Magnetars - Do we understand them ?

There has been strong observational indications for the existence of a class of neutron stars with extremely large magnetic fields ($B > 10^{14} - 10^{15}$ G). These exotic objects, known as *magnetars*, are expected to go through a phase of rapid field decay in massive binary systems. In order for this expectation to conform with the present theories of field evolution in binaries, it is imperative that there should be a faster decay mechanism operating in the presence of very large fields. Also, as and when the field value decreases to canonical normal pulsar field strengths ($B \sim 10^{12}$ G) the decay should slow down. This suggests a decay mechanism that has a strong dependence on the field strength. *S. Konar* is investigating the possible nature of such strength-dependent decay of magnetic field in neutron stars.

Faraday effect : a field theoretical point of view

The phenomenon of Faraday rotation, i.e., the rotation of the plane of polarization of a plane polarized light passing through a medium in the presence of a magnetic field, is extremely important in astronomical context due to the large scale magnetic fields pervading in the universe. *S. Konar*, A.K. Ganguly and P.B. Pal analyze the structure of the vacuum polarization tensor in the presence of a background electromagnetic field in a medium. The most general gauge invariant structure for the vacuum polarisation tensor can contain many form factors. They use various symmetry properties to constrain these form factors. Taking the background field to be purely magnetic, they evaluate the vacuum polarization to linear order in the field and obtain the expression for Faraday effect. They also show why this effect vanishes when there is a background magnetic field but no background medium. Finally, the authors calculate the amount of Faraday rotation in different kinds of media — non-relativistic, completely degenerate, and ultra-relativistic. As mentioned earlier, it is important to understand the nature of light passing through a medium in presence of a magnetic field from an astronomical viewpoint. In an extension of the above mentioned work on Faraday effect, *Konar*, et al. are looking into the absorptive part of the vacuum polarisation tensor in the presence of a background magnetic field and a medium. They will be applying these results to different kinds of astrophysical situations.

Analytic model for inverse Compton spectra

The recent high resolution X-ray spectroscopy of AGN and black hole binaries require accurate and numerically computable methods to predict the spectra for different parameters. *R. Misra*, A.A. Zdziarski and M. Gierlinski have developed a semi-analytical scheme, which describes the inverse Comptonization of photons by a mildly relativistic thermal plasma. The spectra obtained are accurate to 10% as compared with Monte Carlo results.

S. Bhattacharya, A.V. Thampan, *Misra* and B. Dutta have estimated the neutron star spin rates in low-mass X-ray binaries by comparing theoretical predictions of boundary layer and disk spectra with observations. This also constrains the equation of state for neutron stars and the evolutionary models for X-ray binaries.

Optical survey of post-AGB candidates

Jyotsna Vijapurkar has been analysing optical spectroscopic data from the survey (with M. Parthasarathy and J.S. Drilling) of IRAS selected post-AGB candidates. In this survey, spectrograms at moderate resolution were obtained from the 2.3m Vainu Bappu Telescope in Kavalur and also the 1m telescope at Cerro-Tololo Inter-American Observatory.

Apart from the two candidates which were found to have evolved into planetary nebulae, (one of them with a hot central star), and several post-AGB stars where the nebulae had not yet been ionised, two stars, IRAS 18489-3703 and IRAS 17041-2709 were identified as possible pre-main sequence stars. These stars have late type spectra with Ca, H and K and Balmer lines in emission. For one star, an IUE spectrum was available and it showed chromospheric lines. This result is puzzling as they are at high galactic latitude in a region which are not associated with any dust clouds. The authors have now obtained high resolution Echelle spectrograms from ESO which confirm the presence of strong LI 6707 lines expected in these stars. Also, one of them, IRAS 17041-2709 is a double lined spectroscopic binary.

Instrumentation

Instrumentation Laboratory

The laboratory has facilities for the design, construction, and testing of the instruments for optical observations. The facilities are also used by visitors from the universities and colleges for developing and testing their instruments.

A workshop was organised by *A. Paranjpye* to introduce the teachers from universities and colleges to the basics of stellar photometry. In order to get introduced to the elements of observational techniques, each of the participants made a small photo-diode based photometer for his/her laboratory. (In addition to *A. Paranjpye, P. Chordia, R. Gupta*, and *V. Mestry* conducted the activities of the workshop.)

Liquid nitrogen cooled CCD cameras are the most common detectors used for optical astronomy. During this year, a CCD camera with a thinned 1024 X 1024 pixels device from Site was integrated, by *A. Chakraborty*, with the Fabry-Perot interferometer of the Physical Research Laborartory, Ahmedabad. *Chordia, T. Deoskar, D. Gadre*, and *S.N. Tandon* have continued the development of a Version III controller, which uses DSPs for communicating with the host controller as well as for setting the clocks for the CCDs in real time. The design allows for simultaneous reading of upto eight outputs from a single or multiple CCDs, and it is being modified for use with near infrared arrays.

The liquid nitrogen cooled cameras mentioned above tend to be quite expensive as well as bulky, and are therefore not suitable for small telescopes. Thermoelectrically cooled CCD cameras are suitable for small telescopes, and therefore development of such a camera was started in one of the earlier years, as a student project, by Sven Sattler. The development was completed in this year by *Gadre*, V. Joshi, D. Joshi, and R. Kharoshe. Astronomers from the universities and colleges can use the facilities at IUCAA to duplicate this camera for use in their departments.

As reported earlier, a versatile imager spectrograph is being developed for the IUCAA telescope, in collaboration with the CSIO of Chandigarh, and Copenhagen University Observatory. As the weather has a lot of variability, there is a great advantage in having a focal plane instrument which can be switched from one mode to the other, e.g., from photometric imaging (which requires excellent conditions) to spectroscopic observations (which can be done in less than excellent conditions). The instrument would be similar to the well known instrument EFOSC of the European Southern Observatory, and it would have the capacity to either image a field of about 11.5 arcmin square, or do long slit or multislit spectroscopy (with a resolution upto 3000) in the band 400 nm to 8500 nm. The mechanical parts and the controls are being fabricated at Copenhagen and the optics is being made at Chandigarh. *H.K. Das* and *Tandon* have been working on this; the Council of Scientific and Industrial Research, and the Department of Science and Technology are providing financial support for this instrument.

The IUCAA telescope

As reported in previous annual reports, IUCAA is setting up a 2 m telescope for observations in the optical and near infrared bands. The telescope was ordered with the Royal Greenwich Observatory (RGO) of UK; after the closure of the (RGO), the Particle Physics and Astronomy Research Council of UK (the parent agency of the RGO), has made alternative arrangements for the fabrication of the telescope. The site is at a distance of about 80 km from IUCAA and within the constraint of easy logistics for efficient operations of the observatory, it provides good observing conditions.

The telescope has an alt.- azimuth mount, and would only have a f/10 Cassegrain focus. A corrector would provide a large field of 40 arcmin. diameter with sub-arcsecond images in the optical band, whereas, the uncorrected field would give sub-arcsecond images upto a radius of 10 arcminute.

The fabrication of a wide-field ($\sim$ 11 arcmin. square) imager-spectrograph is in progress, and it is expected to be ready by the end of the year 1999 (for more details, see page 44). In addition to this instrument for the optical band, a similar instrument is being planned for the near infrared band.

The enclosure for the telescope has been designed for simplicity of construction and to minimise the thermal perturbations. In particular, based on the experiments done by *H.K. Das*, it has been decided that the dome would be painted with metallic alluminium to minimise the radiative cooling during the night.

There has been some delays in acquiring the land for the site, but it is hoped that the construction would start soon, so that the buildings could be ready before the arrival of the telescope in the second half of the year 2000.

(II) RESEARCH BY ASSOCIATES/ SENIOR ASSOCIATES

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

Quantum Theory and Gravity

Quantum cosmology

S. Mukherjee

Recently, Hawking and Turok (HT) have suggested that Hartle-Hawking no boundary proposal provides for the quantum creation of an open inflationary universe in a generic sense. The suggestion has led to considerable activity and some controversies. The HT instantons, which describe the creation of the open universe, is singular and its role in the approximate evaluation of the path integral remains to be fully understood. B.C. Paul and S. Mukherjee studied the R^2 - theory which is known to give a non-singular de Sitter type instanton. Converting the R^2 - theory into an interacting scalar field theory by a conformal transformation, it was found that singular instantons could be obtained only in a small region of the parameter space. The singular instanton solution is not very generic. The probability of the creation of the open universe is also estimated in this theory.

Quantum field theory in curved spacetime

S. Biswas

S. Biswas (along with Amita Shaw and Nanigopal Sarkar) is studying the behaviour of quantum fields in curved spacetime. Biswas (along with J. Guha) had used complex trajectory WKB approximation as an effective tool to understand particle production in curved spacetime. It is argued that in expanding spacetime, particle production can be considered as a process of reflection in time. In RW geometry, the evaluation of a quantum field is described by an one dimensional Schroedinger-like equation, not in space but in time. The turning points of this Schroedinger-like equation serve as reflection points. They used semiclassical WKB approximation to obtain the reflection co-efficient considering complex trajectories in time variables. The method is called complex time WKB (CWKB) approximation. They obtained standard results using the method of CWKB. Biswas (along with D. Biswas) is also working on the various aspects of the current proposals on the wave function of the universe. Generalizing this proposal, called wormhole dominance proposal, they have been able to show that if one takes quantum corrections to the standard Hartle-Hawking and the Vilenkin proposal (also called tunneling proposal), the dispute that there is sufficient inflation in the tunneling proposal but not sufficient inflation in Hartle-Hawking proposal, can be resolved. They are also working on decoherence mechanism in R^2 cosmology to study quantum to classical transition. They considered the Starobinsky model where deSitter universe nucleates spontaneously due to one loop quantum corrections. They found that wormhole dominance, at least with the Hartle-Hawking boundary conditions, correctly reproduces the classical universe provided we assume a Gaussian adiabatic state as a boundary condition for the ground state of the Schroedinger-Wheeler-DeWitt equation. They are also studying the problem of time in this context.

Particle Physics and Field Theory

Particle physics

P.C. Vinodkumar

P.C. Vinodkumar has been working on the spectroscopy of heavy flavour hadrons based on qcd motivated models. A unified confinement scheme based on gauge constrains on pure gluon fields has been proposed and employed for the study of low flavour hadronic sector in collaboration with S.B. Khadkikar. This scheme has been extended for the study of heavy hadrons containing light-heavy quarks as well as heavy-heavy quarks. Among the properties studied include the hadronic masses, the leptonic decay widths of vector mesons, the pseudo-scalar, decay constants, radii, etc. He has been able to show the importance of the confined gluon exchange effects in the spectroscopic study of hadrons. Within the qcd motivated unified confinement scheme, he has studied the possibility of a massive neutron star under going a phase transition to quark star.

Quantum field theory

G.P. Malik

During the year under review, the temperature dependent approach to dynamics of systems arising out of a fusion of the concept and methods of quantum field theory with those of the many body systems, initiated in the context of astrophysical plasma, was extended to the realm of QCD. Specifically, this work was concerned with an explanation of meson formation in quark-gluon plasma using a temperature-dependent Bethe-Scalpeter equation. The kernels considered are: a linear plus a Coulomb kernel, a square-root plus a Coulomb kernel, and a logarithmic kernel. In each of these cases, good fits to experimental masses of the charmonium and the upsilonium families have been obtained. This work was done in collaboration with V.S. Varma and R.K. Jha.

Supersymmetry

P.N. Pandita

There is considerable interest in the study of infra-red stable fixed points of the standard model and its extensions, especially those of the minimal supersymmetric standard model (MSSM). This interest follows from the fact that in these models there are large number of unknown dimensionless Yukawa couplings, as a consequence of which the fermion masses cannot be predicted. One may attempt to relate the Yukawa couplings to the gauge couplings via the Pendleton-Ross infra-red stable fixed point (IRSFP) for the top-quark Yukawa coupling, or via the quasi-fixed point behaviour. Since supersymmetry necessitates the introduction of superpartners for all known particles in the SM, there are additional Yukawa couplings in supersymmetric models which violate baryon number or lepton number. P.N. Pandita with his collaborator, B. Ananthanarayan, has carried out a detailed analysis of MSSM with baryon or lepton number violating Yukawa couplings with a view to study the infra-red structure of these couplings. From this analysis it has been shown that only the baryon number violating coupling approaches a non-trivial infra-red fixed point, whereas all other non-trivial fixed point solutions are either unphysical or unstable in the infra red region. However, this fixed point solution predicts a top-quark Yukawa coupling which is incompatible with the observed value of the top quark mass.

L.P. Singh

The Dirac equation not only exhibits the spin content of the relativistic electron naturally but also seems to possess beautiful mathematical structure. L. P. Singh and B. Ram have deciphered a three dimensional supersymmetric (SUSY) quantum mechanical structure of the full 3 +1 - dimensional Dirac equation in both zero and non zero mass cases. This result, on one hand, corroborates the assertions of A. Das, S. Okubo and A. Perice that higher dimensional SUSY quantum mechanics necessarily involves a spin structure and generalises the result of P. Vahle and B. Ram with respect to 1+1-dimensional Dirac equation to 3+1-dimensions, on the other.

Singh and B. B. Deo have been working on the idea on unearthing a supersymmetric structure in the top-sector of the standard SU(2) x U(1) model. The idea is motivated by the observation that in the top-sector of the standard model, there is exact matching of bosonic and fermionic degrees and freedom, which is a prime requisite for existence of supersymmetry. The total bosonic degrees of freedom associated with four massless gauge bosons (W^1, W^2, W^3, B) doublet of complex Higgs fields is 12. Carrying this idea forward, they have constructed the supersymmetry charge whose anticommutator with its hermition conjugate generates the energy-momentum four-vector. They are engaged in finding if the mass sum rule valid for supersymmetric gauge theories can also be obtained in this present case, which will make the existence of supersymmetry in the top-sector of standard model more concrete.

Solitons

V.C. Kuriakose

The increasing applications of superconducting technology based on Josephson junction have been demanding for theoretical investigations on the fluxon dynamics in these junctions. The magnetic properties are central in the fabrications of high speed, high density and low power memory and logic devices. The soliton motion in a nonlinear medium is drastically modified by the presence of periodic spatial inhomogeneities. The collision of solitons with localised impurities can produce phenomena like emission of linear waves, creation of solitons, annihilation of solitons, etc. Creation and annihilation of solitons due to the presence of periodic perturbations under the action of a pulse like biasing has wide practical applications. Shaju and V.C. Kuriakose have investigated through numerical simulations the phenomenon of soliton creation and annihilation in long Josephson junctions under the action of a dc bias current and found that in all zero field step cases the created soliton is in a bunched mode with other solitons.

Soliton-soliton interactions also find application in optical communication systems. When non-Kerr like nonlinearities are present, nonlinear cubic-quintic Schrodinger equation is found to be suitable for describing the wave propagation through the fibre. Manzoor, Ganapathy and Kuriakose have studied the solitary wave interaction in nonlinear fiber directional couplers and in weekly birefringent optical fibres and found analytically the conditions for the existence of stable bound states for the two cases. The results are verified using numerical simulations. Bindu and Kuriakose have studied the effect of nonlinearity and dissipation on the electromagnetic wave propagation through a saturated ferromagnet in the presence of an external magnetic field and found that the excitations in the medium can exist in the form of solitons and kinks. Bindu, Vinoj and Kuriakose are currently investigating solitary wave interactions in plasmas and also studying integrability of certain nonlinear partial differential equations.

Geometric formulation of quantum theory

Renuka Datta

The quantum state of a fermion does not return to its initial form under a rotation of 2π; it takes a rotation of 4π to return to its initial state. Neutron interferometer experiments show what happens when neutrons are rotated by 2π using a magnetic field and demonstrate how a fibre bundle can arise in quantum theory. In the neutron-rotation experiment, which in fact concerns the topology of the fibre bundle, the global structure of the fibre bundle is significant. Furthermore, the counterpart is the one-sidedness of a Mobius strip. Renuka Datta, B K. Datta and V.De Sabbta have considered the fibre bundle picture of the neutron interferometer experiment in quantum theory and showed how it can be explained in a straight forward manner with proper geometric significance by means of multivector calculus in real spacetime. To reconcile general relativity with quantum theory, they have considered the geometric algebra with multivector concept and

the interpretation of imaginary units as generators of rotations.
In another work, they have studied the evolution of the concept of numbers having correspondence with linear continuum and showed that it would depend more on the geometric notion than on linear continuum and also showed that with a proper symbolic expression for direction and dimension came the broader concept of directed numbers-"multivectors".

Super conductivity

V.C. Kuriakose

High temperature superconductors possess several properties which are not shown by the conventional superconductors and the mechanism which yield high transition temperature is not yet well understood. However, it does appear that whatever be the mechanism, the properties of these materials can be described by the Ginzburg - Landau type of theory. Lawrence and Doniach in 1970 have proposed a model to account for the superconducting properties of conventional superconductors having layered properties of high temperature superconductors. V.C. Kuriakose and Raju K. John used a modified LD model wherein the interlayer coupling is taken into account to explain some of the experimental results such as temperature dependence of the critical magnetic fields, fluctuations in specific heat and paraconductivity and dimensional cross over. The agreement between experimental results and theoretical calculations is good.

Classical Gravity

Exact solutions to Einstein's equations

S. Chaudhuri

The search for exact solutions modeling physical reality is a challenging task. Considerable amount of effort has been directed by many workers in the study of the exact solutions of the Einstein's field equations. S.Chaudhuri has been working in obtaining some exact solutions of Einstein field equations for stationary axially symmetric space-times under the influence of external gravitational fields. He constructed one-and two-soliton solutions of Einstein field equations. The solutions are asymptotically flat and possess an event horizon surrounded by the infinite red shift surfaces.

In the last three decades different transformation techniques have been put forward to generate new solutions of Einstein field equations as well as to recover the already known ones. Chaudhuri is now exploring the relationship between some of these transformation techniques. For axisymmetric stationary space-times, Chaudhuri has established a correlation between the solution generating technique of Gutsunaev-manko and the inverse scattering method of Belinskii-Zakharov (for two- solution solutions).

G.P. Singh

It is well known that during the early stages of evolution of the universe, matter could be in highly ionised state and subsequently started forming neutral matter due to expansion of the universe. Hence, the presence of the magnetic field in the string cosmological models has been considered by several researchers. G.P. Singh, in collaboration with T. Singh, has presented a new class of exact solutions representing string cosmological models with and without magnetic field. G. P. Singh (in collaboration with R. Tikekar) has obtained a static three-parameter family of solutions of coupled Einstein-Maxwell equations on the background of spheroidal spacetimes. These solutions have been discussed to describe the interior spacetime of the superdense stars.

R. Tikekar

Exact closed form solutions of Einstein's field equations are known to provide deeper insight into the interior spacetime structure of relativistic stars. Ramesh Tikekar (in collaboration with V. O. Thomas) has been working on models of compact stars whose interior spacetimes are endowed with pseudosperoidal geometry, characterised by two curvature parameters measuring the sphericity and departure from sphericity. A number of exact solutions for the case of static spacetimes in this context have been obtained for suitably chosen form for the magnitude of the anisotropic matter tensor. The models based on these solutions are found to admit high degree of density variation from the centre to the boundary of the star. Equation of state being unknown for such systems, the utility of such models is established by indicating the range of physical parameters such as mass, radius, etc. of stellar objects they represent. Core envelope models based on these solutions with anisotropic core surrounded by a fluid envelope with isotropic pressure are being studied in this setup. They have also studied the non-adiabatic gravitational collapse of spherical distributions of matter on the background of pseudospheroidal spacetimes and critically examined various physical and thermodynamical aspects of the collapse using analytical numerical methods.

Alternative theories of gravity

Asit Banerjee

The renewed interest in recent times in the cosmological significance of the light domain walls of enormously large thickness as a consequence of late time phase transition may be helpful in explaining the structure formation in the context of the proposal given by Hill, Schramm and Fry. It is already known that the equations of general relativity are not consistent with a thick static domain wall. Asit Banerjee and his collaborators have shown that even in Brans-Dicke theory of gravitation the problem remains and the static walls, thin or thick, have spacetime not everywhere regular. They have also generalized the domain wall problem in the context of the higher dimensional spacetime. The exact solutions were obtained in 5D spacetime, where the energy density decreases on both sides away from the wall showing reflection symmetry. There may be expanding as well as collapsing walls.

Narayan Banerjee

Cosmic no hair theorem says that the only information regarding a black hole, available for an external observer, are those of its mass, electric charge and angular momentum. Narayan Banerjee is looking at the validity of this theorem when a scalar field is present. For a wide class of non minimally coupled scalar fields, the theorem appears to be valid. Banerjee is also investigating the nature of scalar potentials driving inflation in cosmological models and the role of a viscous fluid in such models. He has also given exact solutions for the spacetime metric describing the gravitational field of a cosmic string loop and that of an infinitely long straight string in generalized scalar tensor theory.

G. P. Singh

Due to wide scope of co-ordinate transformations in general relativity, the conservation laws in general relativistic theories differs from those in non-relativistic theories. The problem of energy conservation has plagued the theory since its inception. A number of authors have considered energy-momentum conservation in general relativistic system. In view of the interest of researchers in scalar-tensor theories, it is worthwhile to consider the energy-momentum conservation in Brans-Dicke theory for studying the effects of scalar field. G. P. Singh, in collaboration with V. B. Johri, has studied the behaviour of gravitational energy during the evolution of the universe. They have shown that (i) total energy of the universe is always zero. (ii) The Brans-Dicke scalar field for all positive value of omega, contributes negative energy to the gravitational field and this gets transferred to the vacuum energy which accelerates the expansion of the universe.

S. Biswas

S. Biswas (in collaboration with B. Modak and S. Kamilya) studied the Brans-Dicke version of the scalar tensor theory within the framework of Noether symmetry approach. In all standard inflationary models, the potential $V(\phi)$ is chosen in an adhoc way deviating from particle-physics motivated Coleman-Weinberg potential. It is, therefore, necessary to determine the potential $V(\phi)$ as well as coupling $\omega(\phi)$ (which multiplies the kinetic term in Brans-Dicke theory) from symmetry arguments. Using Noether symmetry arguments, they calculated $\omega(\phi)$ and $V(\phi)$ and obtained some exact solutions that follow an exponential expansion and asymptotically becomes an attractor of general relativity. Further, works are in progress to investigate various inflationary scenarios using Noether symmetry approach to cosmology.

Kalyani Desikan

A large number of theories have been proposed in the framework of extended inflation. The most successful is the inflation model based on the Weyl scaled theory of gravity, in which the Jordan metric is conformally transformed into the Pauli metric and the matter sector is scale invariant under this transformation. But there are some problems in these theories because the constraints upon successful inflation are derived from the standard model. So it is necessary to examine the evolution of the universe in the framework of Weyl scaled theory of gravity, which has been termed as the generalised Brans-Dicke (GBD) theory. Exact solutions for the matter-dominated epoch, radiation-dominated epoch, stiff matter-dominated epoch and inflationary epoch have been obtained in the framework of GBD theory. It has been found that the expansion of the universe is the same as that in standard cosmology during the radiation-dominated era and inflationary epoch. During the stiff matter era we have a static universe.

Cosmology and Structure Formation

Cosmology

Daksh Lohiya

Daksh Lohiya and his students have been studying the viability of a cosmology in which the scale factor increases linearly with time. The concordance with the age of old stars, nucleosynthesis in the early universe, the magnitude -red shift relations observed in type 1A supernovae and an effective resolution of the cosmological constant problem are some of the issues that have been successfully dealt with. Large scale structure formation in such a cosmology that would follow from explosion models are being examined. Such a cosmology has characteristic predictions: a vanishing declaration parameter, a vanishing cosmological constant, equality of the relic photon and neutrino temperatures and anisotropy in the cosmic microwave spectrum that increases with the beam-width are some of issues that have been studied so far.

S.K. Srivastava

Recent work by S.K. Srivastava is based on the dual role of Ricci scalar at high energies i.e., above 10^9 GeV. The Ricci scalar is a geometrical field, but from the theory of higher-derivative gravity, it is found that it also behaves like a spinless physical field above 10^9 GeV, provided the coupling constants in the gravitational action are chosen properly to avoid the ghost problem. In the field theory, fields are mathematical concepts representing particles. The physical aspect of the Ricci scalar is manifested by a field of the dimension of mass in natural units. The particle represented by this field is called a Riccion. Using the dual role of the Ricci scalar, Srivastava has obtained inhomogeneous and anisotropic cosmological models of the early universe using physical techniques of the phase transition and spontaneous symmetry breaking. Srivastava has shown that the Riccion also behaves like an instanton in a homogeneous cosmological model and instanton solution causes primordial inflation.

V. B. Johri

V.B. Johri continued his investigation on the role of the gravitational energy in matter creation and evolution of the universe. . He has considered a new cosmological model of the universe in which the universe starts expanding from a vacuum fluctuation (instead of a big bang); continuous particle creation leads to inflation; the graceful exit to Friedmann era takes place in a natural way as the creation stops and the universe undergoes the fireball phase as in the big bang theory. Johri has studied conservation laws in general relativity especially with reference to the expanding universe, and applied pseudo tensor techniques to Brans- Dicke theory to establish that the B-D scalar field has negative energy.

Raj Bali

In recent years, there has been a considerable interest in the cosmological models in which matter does not move orthogonally to the hypersurface of homogeneity. These models are called tilted cosmological models. The magnetofluid models have significant contribution in the evolution of galaxies and stellar bodies. The break down of isotropy is also due to the magnetic field. Raj Bali (along with B.L Meena) has investigated magnetized stiff fluid tilted Bianchi Type I anisotropic cosmological models for perfect fluid distribution in general relativity. It has been shown that tilted nature of the Bianchi Type I model for perfect fluid distribution in general relativity is preserved due to the magnetic field. The physical and geometrical aspects of the models are also discussed. Raj Bali and V.C. Jain have investigated generalized expanding and shearing anisotropic Bianchi Type I magnetic fluid cosmological models for perfect fluid distribution in general relativity.

Structure formation

Farooq Ahmed

The basic parameters for understanding gravitational galaxy clustering require correlation functions and density distribution function. A description of gravitational galaxy clustering evolving through quasi-equilibrium thermodynamics is examined on the basis of thermodynamic fluctuations and ensemble theory. The evolution of galaxy clustering depends on the functional form of the ratio of correlation potential energy to (twice) the kinetic energy of peculiar velocities denoted by b. When higher order density fluctuations in the thermodynamics and grand canonical ensemble are combined, a second order differential equations for $b(nT^{-3})$ is obtained. The series solutions of this equation gives a simple functional form of b with nT^{-3}, having minimum physical constraints. A new method is developed to evaluate the density distribution function for gravitational galaxy clustering on the basis of ensemble theory of statistical mechanics. The distribution function fits the N-body computer simulation as well as observational galaxy distributions. These results can provide a deeper understanding of gravitational galaxy clustering on the basis of statistical mechanics.

Quasars

Pushpa A. Khare

Observations with the KECK telescope have recently enabled detection of weak absorption lines in the spectra of quasars. It is thus possible now to address the question of chemical enrichment of the intergalactic matter at high redshifts. Pushpa Khare (along with S. Das) has tried to understand the relevant observations of quasar absorption lines, reported in the literature in the past couple of years, in the framework of the theories of structure formation in the universe. According to these theories, structures can be classified as minihalos and galactic halos. The difference between the two lies in their masses and densities. The miniholes do not have in situ chemical enrichment due to suppression of cooling and therefore, of star formation. Khare has made a detailed comparison between the predictions of the theoretical models and the observations and has studied the possibility of an earlier generation of, Pop III, stars which could have chemically enriched the entire universe at redshifts of about 15.

Galactic Dynamics and ISM

Galactic dynamics

D.K. Chakraborty

The determination of the intrinsic three-dimensional shape of an elliptical galaxy is an important problem. The problem is difficult because the parent distribution of a vector of intrinsic parameters **i** of the galaxies (which also include the viewing angles), are unknown, and the probability P(**o**) of obtaining a vector **o** of the observed parameters depends on the product of parent distribution F(**i**) and the likelihood L(**i**/**o**) that a galaxy of intrinsic parameters **i** will reproduce the observed parameters **o**. The underlying assumption in this approach is that the observed galaxy is one of the objects drawn at random from the parent distribution. Taking a model of the elliptical galaxy which have a set of intrinsic parameters, one can calculate the likelihood which is regarded as ellipsoidal Gaussian centred on the predicted values-evaluated at observed values. One can then study the likelihood as a function of intrinsic parameters **i**. In case the likelihood is sharply peaked, the probability is relatively insensitive to the form of F (**i**). In such a "likelihood-dominated" situation, the likelihood itself gives reasonably good information about the probability that the observed parameters **o** have arisen from the galaxies (models) whose intrinsic parameters lie within certain limits. D.K. Chakraborty and his collaborators are working on a project along these lines. They have developed a family of mass models which is a triaxial generalisation of the modified Hubble model. It has been shown by other workers that a distribution function leading to such density distribution exists, making this model physically plausible. Profiles of the projected photometric properties, namely (1) the position angles of the major axis and (2) the axis ratios of the approximate elliptical isodensity contours have been calculated and using these as the observed parameters, the likelihood as a function of intrinsic parameters is investigated. The work is in progress and the preliminary results indicate that the likelihood is sufficiently sharply peaked.

Interstellar matter

Suresh Chandra

A line emitted by a cosmic molecule is the net effect of collisional and radiative transitions between various levels in the molecule. Suresh Chandra and his group have developed good computer programmes for calculation of very accurate values for Einstein A-coefficients for vibrational-rotational transitions in a diatomic molecules. The calculation has been done for CS and CO molecule. Computer programmes for computation of Einstein A-coefficients for rotational transitions in an asymmetrical top molecule have been developed by this group. The calculation have been done for a number of molecules by Chandra in collaboration with A.K. Sharma and Rashmi. At present this group is concentrating on collisional transitions between the rotational levels of an asymmetrical top molecule colliding with 4 molecules. The computer programmes for this task are being developed by Sunil P. Jagtap and others.

Plasmas and dusty plasmas

S.N. Paul

Recent studies on the propagation of waves in a dusty plasma show that both the electromagnetic and electrostatic waves are effected by the presence of dust charge fluctuation in the plasma. It is observed that existence of ion – acoustic solitary wave and double layer depend upon the charge and density of dust grains. The electrostatic potential may be positive or negative due to variable charge density of dust particles. Abundance of charged dust particles, streaming motions of electrons and ions have significant contribution on the propagation of waves in a magnetized dusty plasma when the phase velocity of the wave is in the low frequency region.

Manoranjan Khan

Plasma parametric decay instability mechanism is one of the important aspects of coronal physics and have been taken for investigation in the study of long wave-length radiation in plasmas. Magnetic field also plays an important role in the occurrence of various processes in laboratory plasma as well as in space plasma. Some problems of magnetic moment generation have been studied theoretically and experimentally in collaboration with different groups of BARC (Mumbai), CAT (Indore), and some other group members of the Centre for Plasma Studies Jadavpur University.

In collaboration with S. Sarkar (J.U.), and H. C. Pant and T. Desai (both from CAT, Indore), a mechanism of stabilization of stimulated Brillouin Scattering (SBS) process due to magnetic anisotropy induced by the temporally exponentially growing magnetic moment has been studied theoretically. It has been shown that the phase velocities of the incident and scattered radiation decay exponentially with time in this SBS process. In collaboration with Sarkar, and S. V. Lawande and M. K. Srivastava (BARC), the generation of poloidal magnetic field in an inhomogeneous cold, collisionless plasma by an elliptically polarized radiation is investigated theoretically. It has been shown that poloidal magnetic field of about 1.4 tesla may be generated for CO_2 laser (λ=10.6μm) with plasma.

In collaboration with Pant and Desai, an experimental programme was taken by Manoranjan Khan for the detection of axial magnetic field by an obliquely incident laser radiation on a copper target by Faraday rotation technique. Experiment was conducted at BARC Laser Laboratory using Nd glass laser (λ=1.06μm) capable of delivering a plane polarized output of 20J in 5 nsec. A theoretical model was developed in collaboration with Lawande and Srivastava to interpret the experimental results. It was numerically estimated from the theoretical model that the Faraday rotation is about 8^0.628 whereas, experimental observation of Faraday rotation due to self generated axial magnetic field about 8^0

In collaboration with M.R. Gupta and Sarkar theoretical investigation of various characteristics of dusty plasmas and its application in space and astrophysical plasmas is being carried out. A report on the wave propagation characteristics and dispersion relation for the propagation of low frequency wave in a dusty plasma has been published in Planetary and Space Science.

Stellar Physics

Variable stars

G. Ambika

G. Ambika (in collaboration with A.K. Kembhavi of IUCAA and Janet A Mattei of AAVSO, Massachusetts, USA) has analysed some semi-regular and irregular variable stars using nonlinear time series analysis. The three stars chosen for the studies are R-Scuti, TV Gem and SxHer. R. Scuti belongs to the RV Tauri type which are low mass red giants. Low dimensional chaos in this star was established by Buchler, et al. TV Gem is an SR_c type variable which are Population II stars belonging to open clusters, while Sx Her is a SR_D type super giant. The statistical analysis of the data gave high values for the higher order moments indicating non-stochastic behaviour in these stars.

Lomb periodogram analysis, that returns the most prominent periodic component and the probability against the null hypothesis that the series is generated from stochastic noise, was tried in the case of R. Scuti and SX Herr. Sharp peaks were obtained and the corresponding periods agreed well with the observed values of 142 and 102 days respectively. However, for TV Gem, the analysis shows many peaks; though different from white noise, the significance level for the calculated probability in all cases was near zero, indicating again non-stochastic nature.

The correlation dimension D2 for all the stars was below 3, establishing low dimensional chaos in their dynamics. Surrogate analysis also gave almost double values, just as in the case of synthetic data from the Lorentz system. Further, detailed analysis is being done to study the nature and strength of chaos in these systems.

X-Ray binaries

K. Yugindro Singh

X-ray binaries with an accreting neutron star or a blackhole as the X-ray source constitute the brightest class of X-ray sources in the X-ray Universe. Study of their periodic and a periodic variability and spectral characteristics provides information about the nature of the sources and the physical processes responsible for X-ray emission in them. Studies of several X-ray binaries have been made with the Indian X-ray Astronomy Experiment (IXAE) on board the Indian satellite IRS P3. K. Yugindro Singh has been collaborating with P.C. Agarwal (TIFR) and his group on the analysis of data acquired with the IXAE. Singh has also been collaborating with the instrumentation group of IUCAA.

Equation of state

R.S. Kaushal

Studies of the mass-radius relation for a star through Tolman- Oppenheimer-Volkoff equation, the stability of a star against radial oscillations through the amplitude- pressure connection, etc. have certain degree of arbitrariness in the results. This is due to (I) a model dependent equation of state, and (II) insufficient boundary conditions in the model. Sometimes the equations of state derived from altogether disconnected sources for different density regions and involving several parameters, lead to similar values of the mass and radius of a star. With a view to putting a constraint on such an arbitrariness of the equation of state with reference to the dependence on the parameters and model, a geometrical constraint has been examined in rigorous mathematical terms. It turns out that such a constraint is space-invariant and accounts for the global geometry of the system under study, rather than just the boundary conditions of localized nature which are often assumed at the end points of the given spatial coordinates. While these features are investigated in the above specific context, they can be attributed, in general, to the Sturm-Liouville theory of differential equations.

Neutron stars and quark matter

Somenath Chakrabarty

It is generally believed that neutron stars are produced with trapped neutrinos immediately after supernova explosion. Such an object is known as proto-neutron star. It takes a few seconds to convert a proto-neutron star to an ordinary neutron star by the emission of neutrinos. It is also believed that the strength of magnetic field for such objects, in particular immediately after their formation, may be large enough to affect the motion of charged particles present in the system. S. Chakrabarty (along with Prantic Dey and other collaborators) has studied in detail the cooling of such objects by the emission of neutrinos. They have considered the effect of strong magnetic fields as well as the effect of hyperons present at the core region on various neutrino emission processes. It is generally expected that at the core region of a compact proto-neutron star, a small fraction of hyperons ($\Lambda\Sigma$, etc.) are produced by strong interaction processes. They have shown that the presence of strong magnetic field as well as the hyperons significantly affect the cooling of proto-neutron stars.

A deconfinement transition to quark matter may occur at the core of a neutron star / proto-neutron star if the matter density exceeds a few times normal nuclear density. Chakrabarty (along with Tanusri Ghosh) has investigated in detail the neutrino emissivity and mean free path in degenerate quark matter which may exist at the central region of compact proto-neutron / neutron star. The effect of strong magnetic field on neutrino emissivity and trapping in such dense exotic matter have been considered in detail. They have considered all possible absorption and scattering processes of neutrinos with charged currents and neutral currents.

If the density at the core of a compact neutron star / proto-neutron star exceeds a few times normal nuclear density, a deconfinement transition to quark matter may occur. On the other hand, in some of the newborn neutron stars / proto-neutron stars the magnetic fields are large enough to affect the motion of charged particles present in the system. In an investigation, Chakrabarty (along with Tanusri Ghosh) has shown that a first order transition from hadronic matter to quark matter is absolutely forbidden if the strength of magnetic field at the core region exceed 10^{15} Gauss. However, a metal-insulator type second order transition (since neutrons and protons do not carry colour charges, the matter consisting of neutrons and protons and some hyperons may be considered as colour insulator; quarks, however, carry colour quantum number, and hence, deconfined quark matter is equivalent to a colour metal) is possible provided the magnetic field strength is less than 10^{20} Gauss, which is too high to achieve even at the core of a newborn neutron star / proto-neutron star. Assuming a second order metal-insulator type of transition at the core of a newborn neutron star / proto-neutron star in presence of a strong magnetic field ($>10^{15}$ Gauss) they have studied the chemical evolution of nascent quark matter core. They have shown that in chemical equilibrium, the quark matter core becomes energetically unstable with respect to the corresponding hadronic matter case if magnetic field strength exceeds the above mentioned value. They have concluded that a quark star / hybrid star can not be produced immediately after explosion if the magnetic field strength exceeds the above mentioned value. However, such a transition (first order) is possible in the case of a very old compact neutron star when the magnetic field reduces to very low value by ohmic decay, or in the case of a newborn neutron star of very low magnetic field.

Ashok Goyal

Pulsar observations indicate the existence of strong magnetic fields of strength 10^{12} - 10^{14} Gauss on the surface of a neutron star and the field strength in the core is expected to be much higher. Such magnetic fields would affect the neutrino interaction rates and an anisotropic neutrino emission may provide explanation for pulsar kicks observed in newly born neutron stars. Ashok Goyal has recently studied the neutrino propagation in hot, dense magnetized star at densities near the neutrino sphere and finds that the neutrino sphere gets modified and distorted. This has implications for the explanation of pulsar velocities.Goyal, V.K.Gupta, Vinita and Kanupriya have also studied the effect of magnetic field on the composition of interacting nuclear matter at super nuclear densities and find that neutron matter can become predominantly proton matter in the presence of strong magnetic fields. They also studied the effect of magnetic field on dominant neutrino emission processes in neutron stars. Goyal and Deepak Chandra studied the dynamics of first order QCD phase transition in the early universe. The nucleation of the hadron phase introduces a new distance scale which was estimated along with the hadron fraction, nucleation time, etc. to follow the phase transition. The possibility of a relic signature of the transition in the form of quark nuggets was explored along with its possible identification with MACHOS, in our galactic halo to account for dark matter.

S. Mukherjee

A star like Her X-1 is very compact and it cannot be described by any of the standard models for a neutron star, strange star or other hybrid stars. Recently, Horvath, et al. have considered the possibility of describing such a star by assuming it to consist of a plasma of free quarks and interacting diquark bosons. R. Sharma and S. Mukherjee tried to study these compact objects by making use of a class of solutions for compact objects obtained earlier by Mukherjee, B.C. Paul and N. Dadhich. Since the solution is unique, (when the mass and radius of the star are given), it is, a priori, quite uncertain if the model will describe a star like Her X-1. It is, however, seen that the equation of state given by the model provides very good agreement with that for the quark-diquark mixture considered by Horvath, et al. This permits one to make use of the scaling properties of the model to predict stars with varying compactness. A more accurate calculation of the equation of state is underway.

T.C. Phukon

It is now believed that the type II supernova (SNII) explosion results in the formation of a neutron star. Recent neutrino observation from SN 1987A explosion suggests the formation of a neutron star. On the other hand, the ever decreasing optical luminosity of the remnant suggests arguments against the presence of a neutron star at the explosion site. T.C. Phukon and B.P. Sarmah have considered a model of type II supernova explosion where it was assumed that the neutron star collapses to black hole immediately after its formation due to the accretion of matter which can push the newborn neutron star into a gravitational instability. The study of the evolution and stability of the newborn star with respect to the adiabatic radial pulsation and the emission of gravity waves and observable signatures of the collapse to black hole are being studied.

Solar and Planetary Physics

Solar corona

U. Narain

The heating of solar corona is one of the outstanding problems in solar physics. One of the most important mechanisms proposed so far is the heating by magnetohydrodynamic (MHD) waves, made of the slow, fast and Afven modes. The solar convection zone is understood to be one of the primary sources of MHD waves. U. Narain (with P. Agarwal and R.K. Sharma) has investigated the production of MHD waves in the solar convection zone using the best available data on turbulent (convective) velocities. The MHD waves are produced by the turbulent motions in the convection zone of the sun in presence of a magnetic field.

Narain and R.K. Sharma have studied the damping of Alfven waves propagating along the boundaries of the solar coronal holes via viscosity of the medium in nonlinear regime by taking the spreading of the magnetic field lines near the edges of the coronal holes into account. It is found that the viscous damping of surface Alfven waves in nonlinear regime, in the presence of strong spreading of magnetic field, is quite effective in heating solar polar coronal holes.

Three body problem

B. Ishwar

B. Ishwar has been studying the important problem of non-linear stability of triangular equilibrium point of the restricted three body problem. He has performed first order and second order normalisation of the Hamiltonian. The basic frequency is perturbed by the radiation repulsive forces and oblateness of the primaries.

Asteroids

T. Subba Rao

Information about Rich (Au,Pt) materials available in asteroids and their impact on earth have been published in Telugu language. Meteorite like materials have been synthesised in the laboratory and their dielectric and structural parameters have been studied. These properties have been compared with those of available matenite materials.

Atomic Physics

K.N. Joshipura

K.N. Joshipura and his students are involved in the theoretical studies on the collision process of electrons with atoms, molecules and radicals. Calculations on simple diatomic and triatomic molecules have already been made. Now, the polytomic targets – which are difficult theoretically – and the neutral radicals which have been studied only scarcely so far, are being investigated. Total cross sections for electron collisions with C_2H_2, C_2H_4, CH_3X_1, SiH_4, C_3H_6 etc. as well as with radicals CH_n, NH_n (n=1,2) have been calculated and further calculations are in progress. An exotic study of the electron scattering with H_2O in ice and liquid phase has been done and work on $(H_2O)_2$ dimer has been initiated. An important outcome of the study is an estimate of total ionization cross section for different targets. The processes studied here are quite relevant in atmospheric and astrophysical systems. The theoretical results provide important comparative data to experimental lists. Joshipura is also engaged in studies in science education and in popularizing science, including astronomy, at various levels.

R. Ramakrishna Reddy

A knowledge of the precise value of the dissociation energy of diatomic molecules is of importance for thermochemistry and is often of interest in astrophysics. The formation of a given molecule in the astronomical environment depends mainly on the abundance of the constituent atomic species, the temperature and the physical properties (dissociation and ionization potentials of the molecule and fundamental parameters) of the atoms. Diatomic molecules and their positive ions have gained interest over the past years in both experimental and theoretical studies because of their importance in astrophysical processes and in many chemical reactions. Dissociation and Ionization energies are estimated utilizing (modified) Pauling's empirical relations. These values are in reasonably good agreement with the available literature values.

The potential energy curves for the electronic ground states of astrophysically important MgO, SO, SiN, TiO, GeH and SnH molecules have been constructed by R. Ramakrishna Reddy. The dissociation energies are determined by curve-fitting techniques using the five parameter Hulburt Hirschfelder function.

Photometry of Stars and Galaxies

S.K. Pandey

Optical as well as infra red studies made so far have amply demonstrated that presence of the cold component of interstellar matter (ISM), the dust is quite common in early type galaxies. The distribution of stellar light in early type galaxies is inherently smooth and are, therefore, most suitable target for studying properties of dust extinction in extragalactic environments. Studies of this kind are limited to only a handful of galaxies. Such studies bear important significance as far as the nature, origin and evolution of dust in early-type galaxies are concerned. S.K. Pandey and D.K. Sahu, therefore, have focussed their attention on studying properties of dust in a sample of early-type galaxies having large scale dust features. They have carried out detailed investigation of properties of dust in few galaxies (NGC 1052, NGC2076, NGC3497 & NCC4374) containing well defined dust morphologies. The optical extinction curves for these galaxies are found to run almost parallel to the extinction curve of the Milky Way suggesting that the properties of dust in these galaxies are quite similar to those of our galaxy. However, the grain sizes estimated using the extinction curve in these galaxies are on the average found to be smaller than the particle size of dust grains in the Milky Way. They have also estimated dust contents in these galaxies using the optical colour excess, total optical extinction as well as FIR data to find that the dust mass from FIR data turns out to be larger than the dust mass obtained using optical extinction methods, except for NGC2076 where these estimates are equal.

With a view to provide a better understanding of the existence of the multiphase ISM in early-type galaxies using the high resolution data in all wavelength bands, (in collaboration with M.K. Patil and Vijay Mohan) has obtained broad band optical images of five early-type galaxies having large scale dust features during December 1998 from UPSO, Nainital.

Photometric observations of six prominent RS CVn stars carried out during the period November 1995 - February 1997 using the 0.35m Schmidt-Cassegrain 14" telescope of Ravishankar University by Pandey and Padmakar Parihar was analysed to examine the changes in the shape and amplitude of light curves of these binaries. The traditional two-starspot model was used to obtain the spot parameters from the observed light curves. The analysis points to changes in spot area and their location on the stellar surface during the period of observations. Some of these stars are found to have significant variation in (B-V) and (V-R) colour indices.

During the period 1998-99 H_α spectroscopic observations on several RS CVn binaries including the well known and suspected ones were carried out using the lm telescope at Vainu Bappu Observatory at Kavalur. Photometric data on these stars were also obtained using the 16' Meade LX200 telescope of IUCAA. Detailed analysis of the data is in progress.

Instrumentation

P.S. Naik

During the last three years, design and construction of a stellar photometer has been carried out by P.S. Naik at the Instrumentation lab of IUCAA, in collaboration with S. N. Tandon and Ranjan Gupta. The constructed photometer, an imported C8 - plus telescope ST - 4 and CCD camera computer system for the image analysis were funded by the DST. These observational facilities are useful to train M.Sc. and M. Phil. students and teaching faculty and for their research activity in the University. Observations have been started on some standard stars.

S.P. Bhatnagar

S.P. Bhatnagar has been building an Automated Photoelectric Telescope in collaboration with the IUCAA Instrumentation group. This activity has been funded through a DST project. A number of improvements have been made to the control programme and work in automating telescope functions is in progress. The pier and mounting system have been designed and fabricated.

(III) IUCAA-NCRA GRADUATE SCHOOL

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

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

Two IUCAA research scholars, Ashish Mahabal and Bala Subramanian have defended their Ph.D. theses to the University of Pune during the year of this report. The abstracts of the theses are given below :

Interferometric detection of gravitational waves from coalescing binaries

by R. Balasubramanian

Though the existence of gravitational waves was demonstrated convincingly by Hulse and Taylor through their analysis of the timing data of the binary pulsar PSR 1913+16, their direct detection still eludes us. However, technological advances in the past few decades have brought us to the threshold of direct detection of gravitational waves from astrophysical sources. Interferometric detectors of gravitational waves, such as the LIGO and the VIRGO, are under construction and will become operational by the turn of this century. Space based interferometers such as the LISA are expected to be functional in a couple of decades from now. It is expected that such sensitive detectors will open a new window to the Universe.

Coalescing binary systems will be particularly important sources of gravitational radiation for the interferometric detectors. These systems are comprised of two compact objects, such as black holes or neutron stars, in orbit around each other. General relativity predicts the decay of the orbit, leading to inspiral with eventual merger of the two compact objects. Waves from such sources will carry information about the geometry of strongly nonlinear spacetimes as well as equation of state of compact objects. These sources will be detectable to cosmological distances and hence, will also give valuable cosmological information.

Gravitational waves from coalescing binaries being intrinsically weak will not stand above the broadband noise in the detector. Since the gravitational waveform from coalescing binary systems is well understood, the matched filtering technique is used to enhance the signal to noise ratio (SNR). However, this technique requires a bank of filters involving a large amount of computational effort and one must attempt to find methods which save on the computational costs. Secondly, estimating the parameters of the signal is of crucial importance. Since noise is present in the output of the detector, errors are made in the estimation of parameters. One must, therefore, perform an error analysis. The estimator used, is the maximum likelihood estimator, which in Gaussian noise amounts to maximising the output of matched filters. This thesis is devoted to the study of the above mentioned problems for the case of a single detector.

The main results of this thesis are as follows.

- Differential geometry was applied to signal analysis to search for an optimal set of templates which save on computational time.
- The performance of Newtonian templates for a first stage on-line search for the actual waveform was investigated.
- Monte Carlo simulations were carried out to determine the errors in the estimation of parameters of the coalescing binary signal. The errors were found to be much larger (at astrophysically relevant signal to noise ratios) than those expected from theoretical considerations, such as the Cramer-Rao bound.
- A new statistical model was derived which adequately reproduced the essential features of the simulations and accounted for the discrepancies between earlier theoretical estimates and the Monte Carlo simulations.

We describe below in brief, the content of the thesis, emphasizing the salient results obtained.

Geometric approach to signal analysis: We have applied the techniques of differential geometry to the data analysis of the chirp signal from coalescing binaries. Such a formulation allows one to explore the merits and demerits of a detection scheme independent of the parameters chosen to represent the waveform. An ensemble of data trains at the output of the gravitational wave detector, constitutes a vector space $\mathcal{V}$, and the data trains corresponding to just a signal but no noise, define a manifold embedded in the vector space, namely, the signal manifold $\mathcal{S}$. A natural metric can be obtained on $\mathcal{V}$ by using the correlation between two vectors in $\mathcal{V}$ as a scalar product on $\mathcal{V}$. This in turn induces a metric on $\mathcal{S}$ which turns out to be nothing but the Fisher information matrix. The geometrical formalism generalizes the problem of choosing an optimal set of templates to detect a known waveform buried in noisy data. An algorithm is proposed to choose templates *off the signal manifold* and show that by such a strategy the computational cost could be lowered by a factor of two or more. This algorithm, though certainly not the best, motivates the search for more efficient templates. We also show that the chirp manifold corresponding to the second post-Newtonian waveform is effectively one-dimensional. This has important implications for the computational requirement for an on-line detection of the chirp signal.

The use of a convenient set of parameters of the chirp waveform for carrying out numerical and analytical calculations is stressed. These parameters are such that the metric components are independent of the parameters, which implies that the signal manifold is flat in the stationary phase approximation and the 'coordinate system' is Cartesian. The covariance matrix, being the inverse of the Fisher information matrix, is also independent of these parameters. This implies that for high SNRs the actual errors in the estimation of these parameters will be constant over the parameter space.

Performance of Newtonian filters We investigated the possibility of using the simple Newtonian family of templates to detect the full post-Newtonian waveform from a coalescing binary system. The alternative strategy would be to increase the number of parameters of the lattice of filters which might prove to be prohibitive in terms of computing power. Post-Newtonian terms contribute to a secular growth in the phase difference between the actual signal and the Newtonian template. The consequent loss in the correlation is partly compensated for, by allowing for a shift in the Newtonian filter parameters.

The analysis was carried out for the point mass case, *i.e.*, $\mu << M$ where μ is the reduced mass and M the total mass of the binary system. For the initial LIGO, the correlation is 0.65 on an average and for the advanced LIGO it is about 0.45. These are only the normalized correlations. The absolute values of the signal to noise will be much higher (by a factor of about 20) for the advanced LIGO. The distance upto which we can detect the binary will come down by a factor equal to the normalized correlation. This means that for the initial LIGO the distance to which we can detect the binary will be brought down by 35% and for the advanced LIGO it will be brought down by 55% from their respective maximum ranges. But it must be emphasized here that the Newtonian filters will be employed mainly in the preliminary stage of the data processing. Therefore, one may lower the threshold for a coarse search of signals. The effect of the discreteness of the filter bank in producing a further drop in the correlations was investigated. It was found that for a one-gigaflop machine the drop in correlation due to the discreteness was very small. We find that even for a 100msecs shift in the parameter τ_0 of the optimally matching Newtonian template the correlation with the signal falls by just 2%.

Monte Carlo simulations for the estimation of parameters: The covariance matrix has been frequently used to characterize the errors involved in the estimation of parameters of a gravitational wave signal. Since the covariance matrix is a valid measure of the errors only in the high SNR regime, one needs to check on the validity of using the covariance matrix for astrophysically relevant SNRs. Monte Carlo simulations of the detection process were performed 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 higher than this value, the covariance matrix is grossly inadequate to describe the errors in the measurement of the parameters of the waveform.

Beyond the Covariance matrix Why are the errors in the estimation of parameters, in the simulations so much larger than the predicted lower bounds? This question was taken up and we found that the answer lay in examining the non-linear equation which provides the maximum likelihood estimates. The covariance matrix errors are merely obtained by linearizing this non-linear equation. The non-linear equation yields *multiple* solutions for the estimates of the parameters. Thus the problem was found to be of a *global* nature, in that the estimated values for the parameters fall into *disjoint* islands. Although, there are very few points in the islands that are far from the actual parameters of the signal, they contribute substantially to the variance. In a situation such as this, when multiple solutions occur, a better measure than the variance, is needed to characterize the estimation procedure adopted. One such measure could be the percentage of points that lie within a certain region of the parameter space, around the actual parameters, for a given signal-to-noise ratio. With this measure, it was found that the maximum likelihood estimator performs reasonably well. A statistical model was given that matches very well with the results obtained from Monte Carlo simulations. This model was derived from geometrical considerations.

Optical morphology of radio galaxies

by Ashish Mahabal

This thesis is about the optical and near-infrared morphology of low-redshift ($z < 0.3$) radio galaxies. It is based on observations of a radio selected sample of galaxies from the Molonglo Reference Catalogue. We have observed these galaxies with 1.0m and 2.5m telescopes at the Las Campanas Observatory in Chile, using broad band B and R and near-infrared K' filters. The morphology and structure of the galaxies have been studied through a series of steps involving the analysis of the 2-dimensional brightness distribution of the galaxies. We outline below the motivation behind this work, summarize the techniques and mention important results.

Traditionally, radio galaxies have been believed to be ellipticals consisting of a coeval population of old stars, and almost no dust or gas. However, photometric studies carried out over the past few years have demonstrated that elliptical galaxies not only have dust and/or gas, but also possess fine structure indicating some amount of activity in the past $\sim 10^2$ million years. Radio galaxies host an active galactic nucleus (AGN) and are associated with highly energetic phenomena like the radio jets which transport a very large amount of energy over hundreds of kiloparsecs. Such phenomena are likely to be associated with morphological features not found in normal elliptical galaxies. A motivation of this thesis has been to identify such features in the radio galaxies.

We have (1) studied the 2-dimensional brightness distribution, in the B, R and K' bands of the galaxies in the plane of the sky by fitting elliptical shapes to isophotes; (2) fitted standard bulge and disk laws to 1-dimensional major-axis profiles extracted from the elliptical model isophotes; (3) studied distributions of fitted parameters and correlations between them; (4) studied colour distribution in the galaxies using different techniques; (5) correlated radio, optical and near-IR properties; (6) used morphological image processing techniques to identify faint features and (7) carried out simulations and modeling to confirm the validity of the extracted features.

In order to differentiate between the properties of radio galaxies as a class from those of normal galaxies, we have compared radio galaxy properties with those of a control sample consisting of non-radio selected early-type galaxies. The comparison sample has been drawn from the CCD frames of the radio galaxies. This ensures that the radio and control samples are subject to identical data processing and photometric calibration. Comparison has also been made with properties of galaxies from the literature wherever adequate data has been available.

We begin the thesis by presenting an overview of the properties of radio galaxies and elliptical galaxies. We explain the importance of the study of the morphology of galaxies to the understanding of the physical phenomena that give rise to these morphologies.

We then go on to describe in detail (1) the sample that has been used for the present study; (2) the instruments used and the data acquisition techniques; (3) preprocessing to remove the signature of the instruments from the data; (4) calibration using the observations of standard stars and (5) various corrections applied to the data to account for the galactic extinction and the redshift of the object. Finally, we describe the control sample used in this thesis.

We next discuss the isophotal shapes of the programme and control galaxies. We expect the projected shapes of isophotes of elliptical galaxies to be ellipses. We describe a programme, which, for an isophote at a given semi-major axis length, provides the best fitting ellipse characterized by an ellipticity and position angle. A series of such ellipses with different semi-major axis lengths then provide an intensity profile for the galaxy image. The deviation of the isophotes from the best fitting ellipses yield important parameters which are indicative of disky or boxy nature of the isophotes. We describe the various correlations that we find amongst the parameters which are obtained from the ellipse fitting exercise. These parameters provide useful information about the 3-D shapes of the galaxies. A section is devoted to the present understanding of the 3-D intensity distribution in elliptical galaxies.

The radial intensity profile of a galaxy is well described by two components viz. the bulge, which is well approximated by de Vaucouleurs' $r^{1/4}$ law, and the disk which is exponential in nature. Each of these components is characterized by a scale length (r_e for the bulge, r_s for the disk) and the intensity at a characteristic radius. In case of an elliptical galaxy, the bulge dominates over the disk. In fact, until a few years ago, it was believed that elliptical galaxies do not contain a disk component at all. We have obtained the scale lengths for each galaxy by fitting the intensity profile, in the different filters available, with a bulge-disk combination. Such a decomposition into bulge and disk parameters plays an important role in determining various properties related to the morphology. We present details of the technique along with a working algorithm and its implementation.

We then describe the distribution of various fitted parameters and the relations between them. Since the bulge is dominant in ellipticals, we particularly emphasize bulge related properties. While absorption due to dust, age and metallicity tend to redden a galaxy in its central region, star formation occurring near the centre causes to have a greater concentration of blue light there. All these factors affect the scale lengths and the scale lengths in different filters (e. g. , B, R, K') indicate the more dominant factor in each filter. For normal galaxies, one expects that r_e is larger at shorter wavelengths since normal age and metallicity effects dominate over star formation. From a study of bulge scale lengths we show that radio galaxies tend to have excess blue colours in their central regions compared to normal ellipticals (See Figure 1). The origin of the extra blue light, seen over several kpc from the centres of these galaxies, is likely to be the formation of stars over the last several 100 Myr. The modeling that we have carried out in this context is described later on in the thesis.

Galaxies that have a disk-to-bulge ratio $(D/B) > 0.3$ are classified as lenticulars or spirals. We find that $\sim 20\%$ of the galaxies in our radio sample have $D/B > 0.3$. We have investigated these *disky ellipticals* in detail (Figure 2 shows one such). In two cases we find that the D/B value, as well as parameters describing the disk-like structure, are similar to those obtained for Sb and Sc galaxies. In the remaining cases the D/B value is high because of contribution from a disk-like structure having a small scale length. The bulge is dominant and the disk scale length to bulge scale length ratio

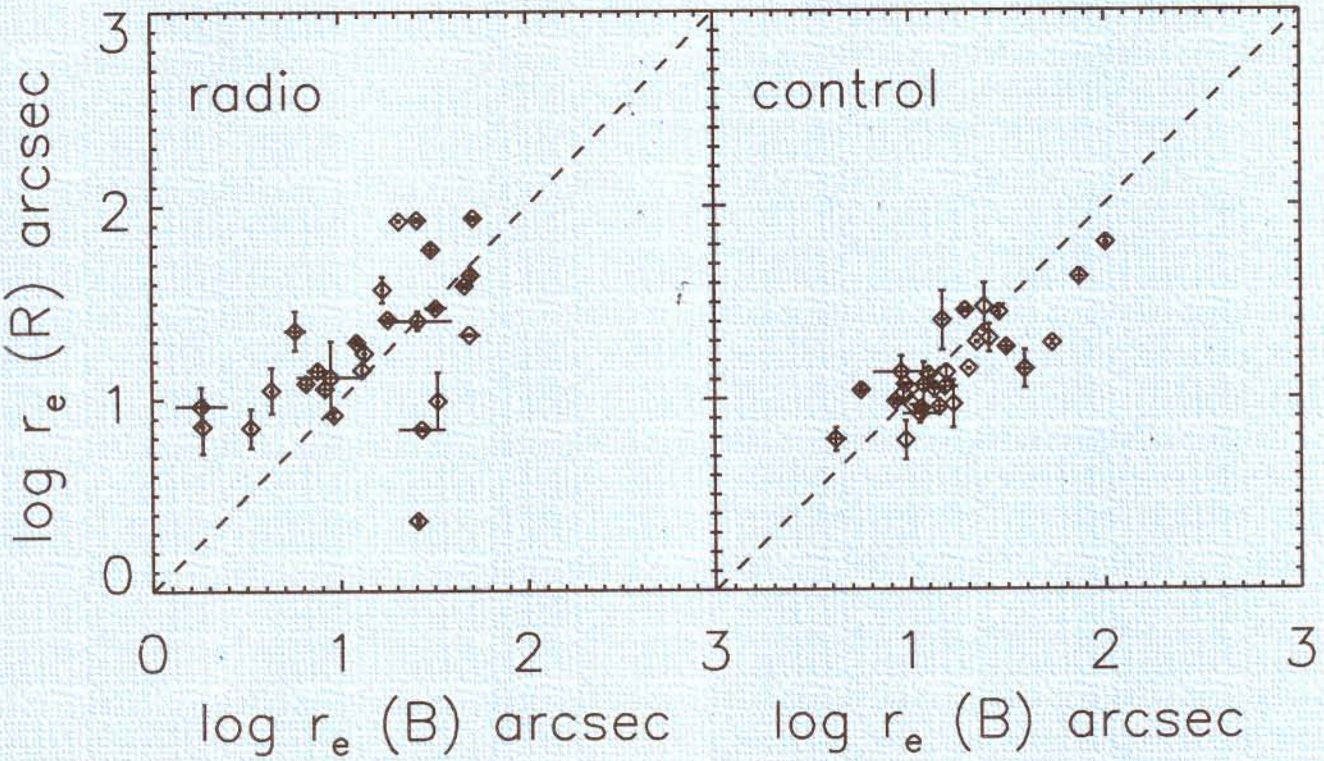


Figure 1: r_e in B and R filters for the radio sample (left) and the control sample (right). The dotted line is the locus $r_e(B) = r_e(R)$. Points above it denote galaxies which become bluer inwards. There is a large number of such cases amongst the radio galaxies.

(r_s/r_e) for these galaxies is much smaller than in lenticulars and spirals.

To better isolate these disks and other faint features in the 2-D images, we have developed a number of morphological filters. As the name suggests, these filters deal with shapes within images. The *morphological gradient* filter has been found to be, especially, useful in locating changes in the luminosity levels since it depends less on edge directionality than the *Sobel operator*. We describe in detail the gradient and other morphological filters.

We then discuss the detailed morphology of individual galaxies in the sample. We say a galaxy is disturbed if it possesses at least one of the following. (1) A secondary nucleus (a non-stellar brightness peak within 10 kpc of the galaxy brightness peak); (2) tidal features; (3) other features that result in distorted isophotes. We look for these signs of disturbance by making use of colour maps, distribution of intensity profile parameters and morphological image processing techniques. We show that radio galaxies, though they possess a morphology very similar to that of elliptical galaxies, more often exhibit signs of disturbance than normal elliptical galaxies: there is a higher incidence of secondary nuclei in radio galaxies, their isophotes deviate from being elliptical more often than for normal galaxies and there is a greater incidence of blue structures that are indicative of recent star forming activity.

We explore in some detail the connection between radio properties and features and parameters in the optical and near-IR bands (e. g., Figure 3 shows the relationship of radio power with dust content and scale length ratio). We find that FR II radio galaxies are more likely to possess a disk than FR I radio galaxies. We find that blue central regions preferentially occur in the more powerful radio galaxies. In some of the radio galaxies, star formation is seen to preferentially lie along the radio axis and is likely to have been induced by the radio emission. Such a phenomenon has been noted before but for higher redshift radio galaxies.

We model the age of the recent star formation using synthetic spectra in the optical and near-IR bands. We assume that the galaxy is formed at some epoch in the past, with the *Scalo* stellar initial mass function (IMF). To such a galaxy we add a starburst, again with the Scalo IMF. The spectrum of the galaxy, at the present time, is the sum of the individual spectra of appropriately evolved stars originally formed, and in the starburst. We compare broad band colours of the spectrum with observed colours, and determine the burst mass and epoch for the best correspondence.

Finally, we provide a summary of the thesis and discuss the new lines of investigation, for studying the morphology of radio galaxies, that have been suggested by the present work.

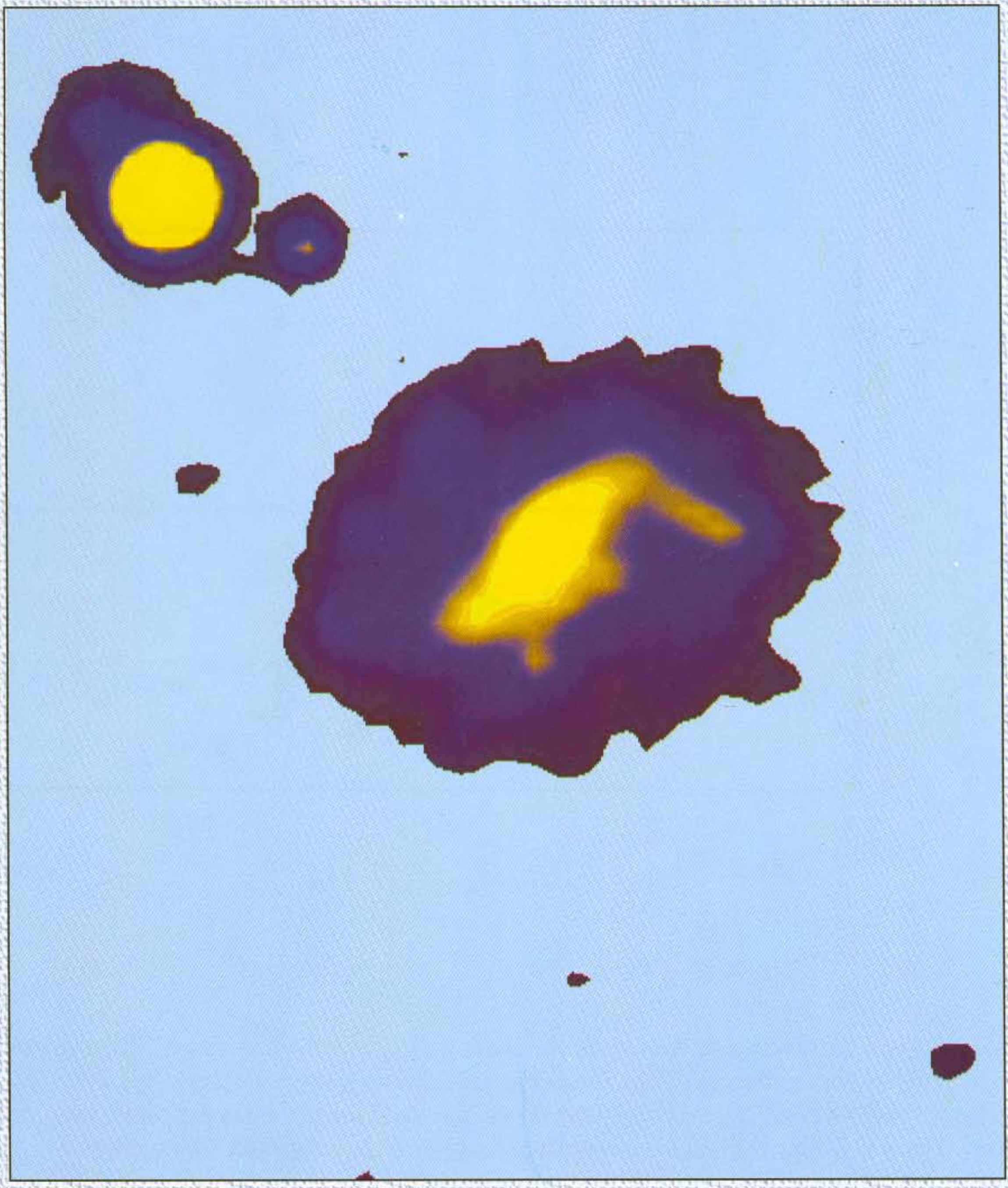


Figure 2: *B* image of MRC 1222-252. The morphology clearly indicates a disklike and flocculent structure. We have used the bulge-disk decomposition of the radial surface brightness profile to quantify the disk parameters in this and other galaxies.

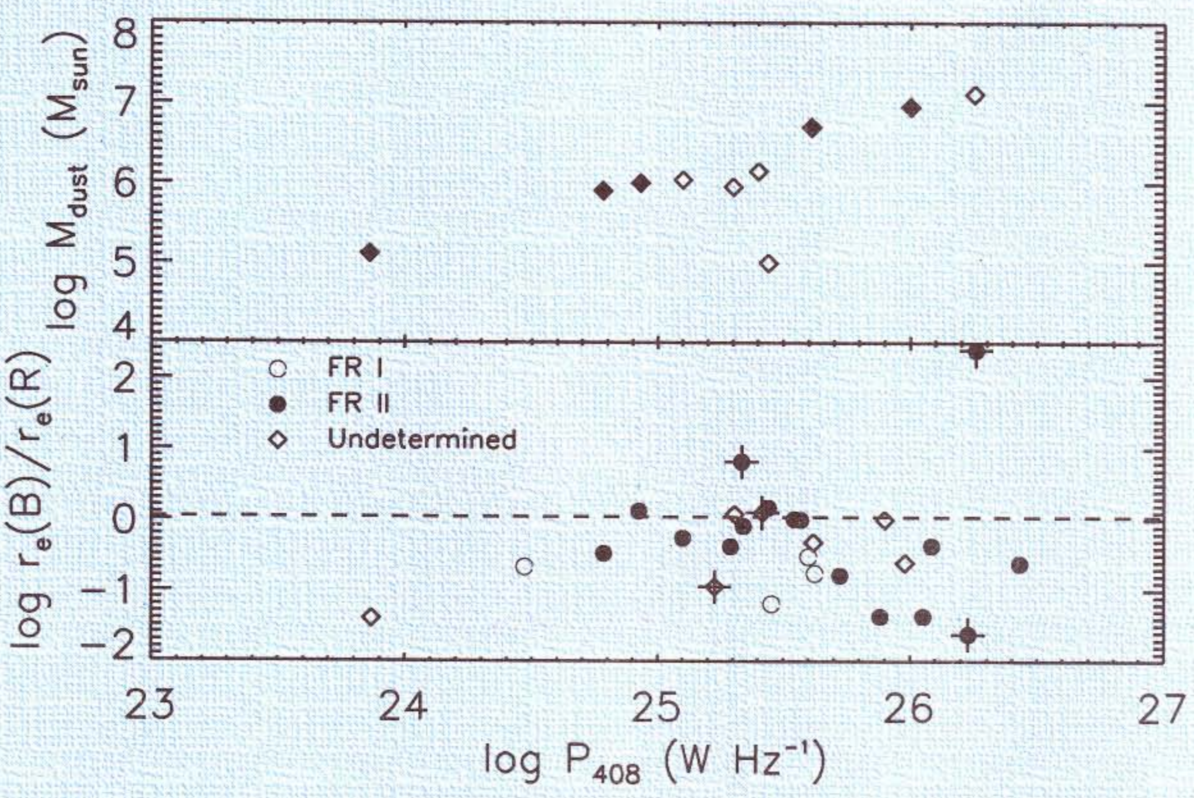


Figure 3: Top: correlation of dust mass in radio galaxies with dust lanes (filled diamonds) or dust patches (open diamonds) at the centre with radio power. Bottom: $r_e(B)/r_e(R)$ as a function of radio power. The dashed line shows the scale length ratio expected for a normal galaxy. There is a hint that more powerful galaxies are bluer towards the centre.

(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.

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b) Proceedings

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(V) PEDAGOGICAL ACTIVITIES

a) IUCAA-NCRA Graduate School

N.K. Dadhich: Methods of Mathematical Physics - II
A.K. Kembhavi: Stellar Structure and Evolution
T. Padmanabhan: Quantum and Statistical Mechanics - I
T. Padmanabhan : Electrodynamics and Radiative Processes - II
S. Raychaudhury: Galaxies: Dynamics and Evolution
V. Sahni: Cosmology
S. Sridhar: Methods of Mathematical Physics - I
F. Sutaria: Electrodynamics and Radiative Processes - I
S.N. Tandon: Astronomical Techniques - I

b) Other Graduate Schools

N.K. Dadhich: General Relativity (University of Barcelona, June)

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

S. Bose: Astronomy and Astrophysics-II (jointly with R. Srianand).
Ranjan Gupta: Astronomy and Astrophysics-I
Ranjan Gupta: Laboratory course (Semesters III and IV)
R. Srianand: Astronomy and Astrophysics-II (jointly with S. Bose)

d) Supervision of Projects

S. Bose

Rajat Basu
Mandar Gadre
Anupam Garge
Juliee Hapse
Anant Karve
Nikhil Kulkarni
Deepesh Lad
Medha Phadke
(School Students' Summer Programme)
Trigonometry and using the transit to measure stellar distances

Mrinal
Vaidehi V. Vidwans
(Introductory Summer School on Astronomy and Astrophysics)
Nucleosynthesis in the early universe

Ameya Kolarkar (VSP)
Towards an explanation of critical phenomena in gravitational collapse

Sushan Konar

Priya Gopal (B.Sc.)
Understanding stellar evolution

J.V. Narlikar

Mayuresh Karandikar
Mayank Deo
Shashank Jawale
Supriya Godse
Rahul Khule
Dambar Thapa
Sadashiv Hendre
Vaibhav More
Dinesh Kate
Manali Chikane
Snehal Shah
Isha Pawar
Ajinkya Navale
Anant Bhandari
Dimple Haygunde
(School Students Summer Programme)
Spin of the Earth

Sachin Nanavati (M.Sc.)
Synchrotron radiation from radio sources

Shripad Kulkarni (M.Sc.)
Radiation processes

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

T. Padmanabhan

Rihan S. (PICT, Pune)
Roychowdhury A. (PICT, Pune)
Shitole S. (PICT, Pune)
Distributed information systems for scientific data-distribution and visualization

Vinay Venugopal (JNCASR student)
Cosmological models

Vijayaraghavan Ramanan (IIT, Mumbai)
Rindler frames, Quantum theory and gravitation

Rajesh Gopal (IIT, Mumbai)
Particle production in curved space-time

Sandipan Mohanty (IIT, Kanpur)
Anisotropies in CMBR spectrum

S. Raychaudhury

D. Dutta (IIT, Kharagpur)
Designing a parallel virtual machine for fast n-body simulations

R. Guruprasad (IIT, Delhi)
Models of clusters of galaxies using gravitational lensing

G. Soni (University of Delhi)
Mass models of spiral galaxies using multiple images of quasars

A. Juneja (IIT, Guwahati)
Is the Universe a fractal?

S. Sanjuktha (University of Madras)
Globular cluster ages based on Hipparcos results

D. Maiti (IIT, Kharagpur)
The mass of the Milky Way Galaxy from its rotation curve

Swati Kochar and Arjun Jayaraman (Vikhe Patil Memorial School)
Sumedh Degaonkar, Mukta Deobagkar and Soumyak Sen (NCL English School)
Kapil Jethwa and Vikram Bhure (Indira Gandhi High School)
Rakesh Saini (Judson High School)
Kunal Rao and Sudeep Chatterjee (St Joseph's High School)
Srijan Deshpande (R. B. Academy)
Sweta Rathod (St. Ursula's High School)
Smita Sunder (SVS High School)
(School Students' Summer Programme)

V. Sahni

Nirmala Vasudevan (VSP)
Aspects of Newtonian cosmology

R. Srianand

Ganesh B. Bagler (M.Sc.)
Determination of matter density using QSO absorption lines

S.N. Tandon

J. Deepa
(Introductory Summer School on A & A)
Precision astrometry and photometry

d) Supervision of dissertation / Thesis

S.V. Dhurandhar

R. Balasubramanian
Interferometric detection of gravitational waves from coalescing binaries
Ph.D. thesis

Ajit Kembhavi

Ashish Mahabal
Optical morphology of radio galaxies
Ph.D. thesis

S. Raychaudhury and Varun Sahni

Samik Dasgupta (University of Pune)
Observational constraints on the cosmological constant
M.Sc. dissertation, University of Pune

(VI) IUCAA COLLOQUIA, SEMINARS, ETC.

a) Colloquia

A. Khare: *Exact ground state of a class of N-body problems*, April 6.

P. Majumdar: *Quantum characteristics of black holes*, April 13.

P. Ganguly: *Atoms in molecules*, April 27.

J. Maharana: *String cosmology*, May 12.

S.B. Patel: *Extremes of nuclear structure*, August 3.

S.G. Dani: *Some questions in diophantine approximation*, August 10.

A. K. Kamra: *Thunderstorm electrification*, September 21.

J. Nandi: *Infection by HIV versus life in space: The unlikely comrades?*, September 28.

Anil Kakodkar: *New R&D thrusts in BARC*, November 13.

John Sclater: *The Andrew Bain fracture zone (southwest Indian ocean): An example of distributed extension within a large offset oceanic transform fault*, December 4.

Jeffery Lewins: *Variational Monte Carlo*, January 25.

David Malin: *Faint features of bright galaxies*, February 18.

b) Seminars

K.S. Balasubramanian: *Solar pores: The smallest visible magnetic elements on the Sun*, April 21.

Sayan Kar: *Ripples and kinks on strings and branes*, April 28.

S. Shankara Narayanan: *Nature of associated C IV absorption system in NGC 5548*, June 15.

R.P. Saxena: *Bubble nucleation in ϕ^4 theory in the thin wall limit and beyond*, June 24.

A. Ambastha: *Recent developments in the understanding of solar flares*, July 14.

Valerio Faraoni: *When Brans-Dicke gravity does not reduce to Einstein's theory*, July 30.

A.Mitra: *Gamma ray bursts, gravitational collapse, black hole and other stories*, August 5.

B. Irkaev: *International programme of searching delta scuti stars*, August 7.

N.C. Wickramasinghe: *Spectroscopic identifications of interstellar grains*, August 13.

N. Sambhus: *Stellar orbits near the centres of galaxies*, August 24.

S. Sethi: *CMP Polarization: Foregrounds and cosmological parameter*, September 16.

A. Patnaik: *Milliarcsec-scale structure in gravitational lenses*, September 18.

R.S. Kaushal: *Quantum analogue of Ermakov systems*, September 24.

R. Nityananda: *Gravitational clustering at long and short wavelengths*, September 30.

Michael Tobar: *Advanced gravitational wave detection project in Japan and Australia*, October 7.

Sukanta Bose: *How to cast your net and* *catch the wave?*, October 20.

Andrzej Zdziarski: *X-ray slopes, Compton reflection, and accretion disks in blackhole binaries and seyferts*, October 29.

N.D. Ramesh Bhat: *Pulsars and the local ISM*, November 12.

P.N. Pandita: *Neutrino mass and grand unification*, December 2.

Qirong Yuan: *Orientation of field galaxies in the local supercluster and Luminosity correlation of the X-ray selected radio-loud AGNs*, December 11.

John Drilling: *Spectral classification of hot subdwarfs*, December 16.

Chanda J. Jog: *Local stability criterion for stars and gas in a galactic disk*, December 24.

Hans Kastrup: *Quantum mechanics and quantum statistics of Schwarzschild black holes*, December 26.

Jeffery Lewins: *Variational principle for generalised Markov systems*, January 25.

K. Shivanandan: *Space technology transfer for industrial and medical applications*, January 28.

Jerry Sellwood: *Dynamical constraints on disk masses*, January 28.

Guy Pelletier: *The link between accretion, ejection and high energy radiation in AGN physics*, February 16.

Alexander Boksenberg: *What the quasar absorption lines tell us about the universe?*, February 23.

E.A. Speigel: *Vortices of disks*, February 24.

Tapas Kumar Das: *On the mass outflow from matter accreting onto compact objects*, March 3.

Arun Thampan: *KHz QPOs in X-ray binaries and their implications on neutron star structure*, March 17.

Aparna Chitre: *Photometric studies of Markarian starburst galaxies*, March 22.

Watson Varricatt: *Near IR photometric studies of algol light curves*, March 23.

U.S. Kamath: *Optical and near-infrared studies of novae*, March 24.

c) PEP Talks

Debojyoti Dutta: *Exposing the ultra fast morons*, May 27

Debojyoti Dutta: *Connecting the ultra fast morons*, June 1

Sayan Kar: *Uses and abuses of traversable wormholes*, June 19.

Debojyoti Dutta: *Introduction to algorithms for scientific computing*, June 25.

Debojyoti Dutta: *Hydrogen atom as harmonic oscillator*, June 29.

Rajaram Nityananda: *Some fibre bundles I have known*, July 7.

Bahor Irkaev: *Modern state of astronomy in Tajikistan*, August 6.

d) IDG (Informal Discussion Group) Meetings

Jayaram Chengalur (NCRA): *Temperature and opacity of HI in nearby galaxies*, April 16.

S. Raychaudhury: *On what scale is the universe homogeneous?*, April 16.

Pradeep Gothoskar (NCRA): *Hubble's turning fork*, April 30.

R. Srianand: *A galaxy at z = 5.34*, April 30.

Sayan Kar: *Can the universe create itself?*, May 14.

Gopal Krishna (NCRA): *A mechanism for terminating accretion in protostars*, May 14.

Ramesh Bhatt (NCRA): *On the prospect of discovering more millisecond pulsars*, May 28.

Firoza Sutaria: *Population synthesis of millisecond and submillisecond pulsars*, May 28.

Ishwar Chandra (NCRA): *Radio observations of the Hubble deep field*, June 11.

Sanjiv Kumar: *Inhomogeneities in the inner accretion disc structure*, June 11.

S.V. Dhurandhar: *Searching for continuous wave sources with LIGO*, June 25.

D.J. Saikia (NCRA): *Radio disks*, June 25.

R.T. Gangadhara (NCRA): *Polarization characteristics of millisecond pulsar emission*, July 9.

Arun Mangalam: *Observational implications of a primordial magnetic field*, July 9.

Pramesh Rao (NCRA): *Polarization structures and the ISM*, July 23.

Rainer Wichmann: *Pre-main sequence Lithium burning*, July 23.

Ranjan Gupta: *Antarctic fiber optic spectrometer*, August 6.

Rajiv K. Singh (NCRA): *The problem of consciousness*, August 6.

Yashwant Gupta (NCRA): *Pulsar evolution: Discovery of the missing link*, August 20.

T. Padmanabhan: *Playing Gott?*, August 20.

Vijay Kapahi (NCRA): *Submillimetre search for star-forming galaxies at high redshift*, September 3.

Valerio Faraoni: *Light deflection by gravitational waves*, September 3.

Subhashis Roy (NCRA): *Filamentary structures in our galactic centre*, September 17.

S. Sridhar: *Local stellar kinematics*, September 17.

e) MAHFIL

[IUCAA's inhouse spectrum of pedagogical activity was expanded further this year to include the MAHFIL-series (Mid-day Astronomy Hour For Interaction and Lunch), where all academics at IUCAA as well as visitors meet once a month. Three academics describe in 5-10 minutes each, the work they are doing and clarify any questions raised. The emphasis is on informality (no transparancies or equations!). These mahfils owe their origin including the acronym, to Rajaram Nityananda, who had spent a few months here as a Visiting Professor; and they serve a useful purpose in acquainting all of us with the work being done by our visitors and colleagues.]

Following were the speakers of mahfils that were held during the period under review:

R. Tikekar, R. Nityananda and F. Sutaria, August 12.

S. Konar, K.S.V.S. Narasimhan and H. Knutsen, September 16

A. Sen, M. Nouri and Sunu Engineer, October 14.

S. Karbelkar, Zafar Ahsan and T.Z. Naing, November 18.

S.S. Dey, P.S. Parihar and K. Srinivasan, March 17.

(VII) TALKS AT WORKSHOPS OR AT OTHER INSTITUTIONS

a) Seminars, Colloquia and Lectures

S. Bose

How to cast your net and catch the wave: Detection of gravitational radiation, IISc, Bangalore, November 2.

Black hole horizons and the Brown-York quasilocal energy, CTS, IISc, Bangalore, November 6.

Quasilocal energy, gravitational charge, and black hole horizons, TIFR, Mumbai, November 12.

Detection of gravitational waves from coalescing binaries, IIT, Kanpur, November 20.

On the network problem in the detection of gravitational waves, MRI, Allahabad, November 23.

Detection of gravitational radiation from coalescing binaries using a network of interferometric detectors, TIFR, Mumbai, November 12.

Using networks of interferometric or bar detectors for the detection of gravitational waves, Workshop on Cosmology: Theories confront observations, IIT, Kharagpur, India, January 16.

Quasilocal energy, gravitational charge, and black hole horizons, IAGRG Meeting, University of Gorakhpur, January 21.

N.K. Dadhich

Non-singular spherical cosmological models and *Electromagnetics of gravitation*, Orientation Meeting on Exact Solutions in Relativity and Cosmology, Gorakhpur University, January.

Electrogravity duality in general relativity, Queen Mary and Westfield College, London, July 7; Institute of Theoretical Physics, RTW, Aachen, August 28; Spanish Relativity Meeting, ERE-98, Salamanca, September 10; University of Madrid, September 16.

Energetics characterization of black hole, Institute of Mathematics, LMU, Munich, July 30.

Energetics characterization of black hole, University of Bilbao, September 11.

Energetics characterization of black hole, University of Salamanca, September 18.

Gravitation and the curved Universe, Symposium in honour of Professor A.K. Raychaudhuri on his attaining the age of 75, Jadavpur University, December 16.

On electrogravity duality in general relativity, IIT, Kharagpur, December 18.

Electromagnetics of gravitation, University of Natal, Durban, February 24.

Why is the universe curved?, University of Zululand, February 26.

Electromagnetic duality in general relativity, Symposium on Relativistic Cosmology in honour of George Ellis, Cape Town, March.

Ranjan Gutpa

Stellar spectra, Introductory Summer School on A&A, IUCAA, May 22 and May 25.

Stellar spectroscopy, Vacation Students' Programme, IUCAA, June 10.

Interstellar extinction and IUE observations, Workshop on Light Scattering by Small Particles and its Applications in Astrophysics, Physics Department, Bhavnagar University, August 19.

Neural networks for spectral classification, Workshop on Databases, Data Visualization and Image Processing, IUCAA, November 18.

Artificial neural networks: An application to stellar spectroscopy, S.N.Bose National Centre for Basic Sciences, Calcutta, November 30.

Interstellar extinction and dust modelling, IUCAA Decennial Year Meeting, IUCAA, January 8.

Observational astrophysics, Workshop on Astrophysics for Physicists, Department of Physics, Visva Bharati, Santiniketan, March.

A.K. Kembhavi

Compact stellar objects, Institute of Advanced Studies, Zanjan, Iran, April.

Galaxy photometry, Institute of Advanced Studies, Zanjan, Iran, April.

Nature of radio galaxies, Sterrenwacht, Leiden, June.

The host galaxies of giant radio sources, Astronomical Institute, Amsterdam, June.

Dust in radio galaxies, Kapteyn Astronomical Institute, Groningen. June.

The appearance of galaxies at moderate redshifts, Xth Recointres des Blois, Blois, France, July.

Astronomical databases, XVI International CODATA Conference, New Delhi, October.

Extragalactic astronomy with a 10m class telescope, XIXth ASI meeting, Bangalore, February.

Cosmic images, Visva Bharati, Santiniketan, February.

Multimedia techniques, Science and the Media - A Seminar, IUCAA, March 1-2.

Radiation processes, Workshop on Astrophysics for Physicists, Visva Bharati, Santiniketan, March.

Sushan Konar

Evolution of magnetic field in neutron stars, Theoretical Physics Seminar Circuit, Institute of Mathematical Sciences, Chennai; S.N. Bose Institute of Basic Sciences, Calcutta; Variable Energy Cyclotron Centre, Calcutta.

Magnetic field of strange stars, Variable Energy Cyclotron Centre, Calcutta.

Magnetic field of neutron stars, Thesis presentation, Annual meeting of ASI, Bangalore.

A. Mangalam

Physics of the central engine, Sino-Indian Workshop, IUCAA, December.

Violent relaxation, Delhi University, December 17.

N-body simulations and a model of a spherical halo, Indian Institute of Science, Bangalore January 27.

Formation of protoquasars, Raman Research Institute, Bangalore, February 21.

R. Misra

Evidence for advective flow in black hole novae, NCAC, Warsaw, Poland, July.

J.V. Narlikar

Quasi-steady state cosmology, General Colloquium at the University of de Liege, Institute d' Astrophysique, Belgium, April 5.

Quasi-steady state cosmology, Max-Planck Institute for Gravitational Physics, Postdam, April 16.

Structure formation in the quasi-steady state cosmology, Cambridge, April 22.

Metallic whiskers in extragalactic astronomy, Workshop on Light Scattering by Small Particles and its Application in Astrophysics, Physics Department, Bhavnagar University, August 18.

Observational cosmology, School on Gravitation and Cosmology, Cochin University, October 30 & 31.

Introduction to cosmology, G.C. College, Silchar, January 14.

The quasi-steady state cosmology : An alternative to big bang, Workshop on Cosmology : Observations Confront Theories, Indian Institute of Technology, Kharagpur, January 17.

Structure formation in the quasi-steady state cosmology, Workshop on Dynamics of Einstein's Field equations, Relativistic Conference, University of Cape Town, South Africa, February 1.

Mini-creation events in cosmology, Department of Applied Mathematics, University of Natal, Durban, February 2.

Rival theories in cosmology, Lecture at the seminar in Swami Ramanand Teerth Marathwada University, Nanded, February 14.

New Challenges in astronomy and astrophysics, Yangon University, Yangon, Burma, March 7.

The relationship between physics and astronomy, Physics Department, Mandalay University, Burma, March 8.

T. Padmanabhan

Radiative processes, Vacation Students' Programme, IUCAA, June 18.

General relativity, Vacation Students' Programme, IUCAA, June 19.

Quantum blackhole: The inside story, NCRA, Pune, December 4.

Event horizon and Planck scale physics, IPM School on Cosmology - Large scale structure formation, Iran, January 26.

S. Raychaudhury

A redshift survey in the direction of motion of the local group, IUCAA Decennial meeting, January.

Comparing x-ray and optical observations of clusters of galaxies, 19th meeting of the Astronomical Society of India, Bangalore, February 4.

B.F. Roukema

La fonction de corrilation des galaxies: un minimum z = 2?, Observatoire de Strasbourg, December 18.

V. Sahni

The cosmological constant revisited, Workshop on Cosmology: Observations confront theories, IIT, Kharagpur, January.

Pancakes and filaments in cosmological gravitational clustering, Workshop on Cosmology: Observations confront theories, IIT, Kharagpur, January.

Geometrical methods of analysis of large scale structure, IUCAA Decennial Meeting, January.

The large scale structure of the universe, Moscow State University, Russia, October.

R. Srianand

Inter-galactic medium, Introductory Summer School on A & A, IUCAA, May-June.

Introduction to radio astronomy, IUCAA-TIFR school on High Energy Gamma Ray Astrophysics, Pachmarhi.

Molecules in high z damped systems, NCRA, November.

Probing the BLR using associated absorption lines, IUCAA Decennial Meeting, January.

S. Sridhar

Stellar dynamics around black holes in galactic nuclei, Workshop on Discs in Astrophysics, Newton Institute, Cambridge, U.K., April 7.

Astrophysics, Colloquium on Dynamics at the centres of galaxies, Oxford University, U.K., May 12.

Turbulence, University of Newcastle, U.K., May 29.

Eccentric self-gravitating discs around black holes, EC Summer School on Astrophysical Discs, Isaac Newton Institute, Cambridge, U.K., June 25.

Dynamics of galaxies, IPR, Ahmedabad, December 29.

MHD turbulence, IPR, Ahmedabad, December 30.

Interstellar turbulence, IUCAA Decennial Meeting, January 10.

S.N. Tandon

Observational astronomy, VSP, IUCAA, May.

Y. Wadadekar

Galaxy image simulation, Workshop on Introductory Image Processing and

Astronomical Applications at Tezpur, Assam, February 10.

Morphological image processing, Workshop on Introductory Image Processing and Astronomical Applications at Tezpur, Assam, February 11.

b) Lecture Courses

S. Bose

Nonperturbative canonical gravity, Physical Research Laboratory, Ahmedabad, September 13-27, 6 lectures.

Canonical quantization of general relativity:The Ashtekar programme, School on Gravitation and Cosmology, Cochin University of Science and Technology, October, 4 lectures.

Ranjan Gupta

Introductory astronomy, Stellar spectroscopy and instrumentation, Introductory School on Astronomy and Astrophysics, Sri Venkateswara College, New Delhi, October, 3 lectures.

Observational astronomy and astronomical instruments, Introductory School on Astronomy and Astrophysics, Indira Gandhi Science Complex-Planetarium, Patna, November, 4 lectures.

Observational astronomy and instrumentation, Refresher Course in Space Physics, Department of Space Sciences, University of Pune, November 26 and 27, 4 lectures.

Observational astronomy and astronomical instrumentation, Introductory School in Astronomy and Astrophysics, Gurucharan College, Silchar, January, 4 lectures.

Fourier transforms and its applications, Workshop on Introductory Image Processing and Astronomical Applications, Department of Physics, Tezpur University, February, 3 lectures.

A.K. Kembhavi

Image processing fundamentals, Workshop on Introductory Image Processing and Astronomical Applications, Department of Physics, Tezpur University, February, 3 lecturers.

The end state of stars, Introductory School on A&A, Sri Venkateswara College, New Delhi, October, 3 lectures.

Sushan Konar

Statistical mechanics in astrophysics, Workshop on Astrophysics for Physicists, Visva Bharati, Santiniketan, March, 3 lectures.

A. Mangalam

Gas dynamics and MHD, Vacation Students' Programme, IUCAA, June 4-5, 4 lectures.

J.V. Narlikar

Quasi-steady state cosmology: An alternative to big bang, College de France, Paris, March 27, March 31, April 2, April 3, 4 lectures.

T. Padmanabhan

Particle production in external fields, School on Gravitation and Cosmology, Cochin, University of Science and Technology, October, 4 lectures.

Large scale structure formation - Linear and non-linear, IPM School on Cosmology - Large Scale Structure Formation, Iran, January, 7 lectures.

S. Raychaudhury

Stellar and galactic dynamics, Introductory Summer School on Astronomy and Astrophysics, IUCAA, May, 4 lectures.

Galactic dynamics, Vacation Students' Programme, IUCAA, June, 3 lectures.

Signal processing techniques in observational cosmology, Workshop on Databases, Data Visualization and Image Processing, IUCAA, November, 3 lectures.

Stellar and galactic dynamics, Workshop on Astrophysics for Physicists, Visva Bharati, Santiniketan, March 4-10, 4 lectures.

V. Sahni

Introductory cosmology and large scale structures in the universe, Introductory School on Astronomy and Asrophysics, India International Centre, Delhi, October, 3 lectures.

S.N. Tandon

Observational astronomy, Introductory Summer School on Astronomy and Astrophysics, IUCAA, May 18-June 5, 5 lectures.

c) Popular Lectures

Ranjan Gupta

Our position in the universe, Rotary International, Rotary Club of Pune Cantt., YMCA Hall, Pune, July 29.

New technology telescopes of the world, National Science Day, IUCAA, February 28.

J.V. Narlikar

The excitement of studying astronomy, Mahindra United World College of India, Mulshi, May 15.

Khagol vigyannatil saat ashcharye (Seven wonders in astronomy)(in Marathi), Kusumagraj Pratishthan, P.S. Auditorium, Nasik, June 6 & 7.

Khagol vigyan ke naye kshitij (New frontiers of astronomy) (in Hindi), Indian Institute of Chemical Technology, Hyderabad, July 16.

Universe : The ultimate laboratory, Special Mid-Year Meeting, Indian Institute of Sciences, Bangalore, July 17.

Science and religion : Approach towards a synthesis, Dalai Lama Foundation of Universal Responsibilities, Gulmohar Convention Centre, Delhi, September 2.

Khagol vidnyan ke kshitij (New frontiers of astronomy)(in Hindi), Bharat Heavy Electricals Limited, Bhopal, September 14.

Anomalous phenomena in astronomy, Sri Venkateswara College, New Delhi, October 5.

Khagol vidnyanatil kahi manoranjak goshti (Some interesting stories of astronomy)(in Marathi), Smruti Bhavan, Akluj, November 21.

The relevance of Raja Rammohun Roy in the present age of science and technology, The Fourth Rammohun Roy Lecture, Asiatic Society, Mumbai, December 12.

The role of science and scientific outlook in shaping the future of our country, Assam University, Silchar, January 15.

Are we alone in the universe, A.K. Chanda Memorial Lecture, Assam University, Silchar, January 15.

Theories and observations in cosmology, Indian Institute of Technology, Kharagpur, January 17.

Anu aani vishwa, (Atom and universe) (in Marathi), Acharya G.D. Deshpande Memorial Lecture, Nanded, February 13.

Antaralatil Rasayanshastra, (Chemistry in space) (in Marathi), Chemistry Department, Dr. B.A. Marathwada University, Aurangabad, February 15.

Krishna-vivar ani shweta-vivar, (Black holes and white holes)(in Marathi), National Science Day, IUCAA, February 28.

Are we alone in the universe, National Science Day, IUCAA, February 28.

Do astronomical observations require new physics, R.D. Birla Award Lecture, Tata Institute of Fundamental Research, Mumbai, March 12.

Vishvachi rachana, (Structure of the Universe) (in Marathi), Anand Dham, Dharmik Pariksha Board, Ahmednagar, March 26.

T. Padmanabhan

Journey through the universe, Jawaharlal Nehru Planetarium, Allahabad, August 7.

Structures in the universe, Vikhe Patil Memorial School, Pune, January 13.

Voyage through the universe, IPM School on Cosmology 1999: Large Scale Structure Formation, Iran, January 25.

Facets of astronomy, National Science Day, IUCAA, February 27.

Astronomical quest, National Science Day, IUCAA, February 28.

S. Raychaudhury

Is it necessary to popularize science?, Jyotirvidya Parisanstha, Pune, April.

The history of the universe, IUCAA, April.

Popularization efforts involving TSE99, Meeting on the Total Solar Eclipse 1999, IUCAA, October 24.

Our place in the universe (in Bengali), Patha Bhavana, Santiniketan, March 6.

B.F. Roukema

Vers une constante cosmologique non-nulle?, Institut d'Astrophysique de Paris, December 8.

Is the universite finite or infinite?, National Science Day, IUCAA, February 28.

L'Univers est-il fini ou infini?, Alliance Francaise de Poona, March 11.

R. Srianand

Understanding cosmos through light, IUCAA, October 10.

Y. Wadadekar

Adventures with the Hubble Space Telescope, National Science Day, IUCAA, February 28.

d) Radio/TV Programmes

J.V. Narlikar

'Gyan Vigyan', Amul Surabhi, DD-I, March 15.

'Gyan Vigyan', Amul Surabhi, DD-I, May 31.

Origin of the Universe, All India Radio, July 22.

'Aakashashee Jadale Nate', (First Part), Mumbai Doordarshan, July 23.

'Aakashashee Jadale Nate', (Second Part), Mumbai Doordarshan, July 30.

Baldoot, DD-I, August 30.

Baldoot, Teacher's Day Special, DD-I, September 6.

Baldoot, DD-I, September 13.

Baldoot, DD-I, September 20.

'Gyan Vigyan', Amul Surabhi, DD-I, September 27.

Post Independence Growth of Astronomy and Astrophysics (in Marathi), All India Radio, January 26.

S. Raychaudhury

Subject of an Interview episode for *Great Skies* a BBC Radio 4 programme that profiles astronomers in different parts of the world. Broadcast in the UK, September.

Scientific Advisor (along with J.V. Narlikar) for a series of TV programmes on Introductory Astronomy for high school students to be shown on E-TV (Produced by CIET/NCERT). Wrote the script and presented a pilot episode.

(VIII) SCIENTIFIC MEETINGS

Introductory Summer School on Astronomy and Astrophysics, IUCAA

A DST sponsored introductory summer school on Astronomy and Astrophysics, jointly organized by IUCAA and National Centre for Radio Astrophysics (NCRA), was held in IUCAA during May 18 to June 5, 1998. Twenty four students (second and third year B.Tech. as well as final year B.Sc. and first year M.Sc.) from all over the country attended the school. Different topics in A&A were taught in a more elementary level. The lectures were split into two broad classes (a) lectures on *'the physics of astrophysics'* and (b) a *'phenomenological introduction to astronomy'*. In addition to these courses, each student was also assigned a project. Students made a visit to GMRT during one of the weekends. R. Srianand (IUCAA) and Jayaram Chengalur (NCRA) coordinated the academic activities of the school.

Workshop on Light Scattering by Small Particles and Its Applications in Astrophysics

This workshop, sponsored by IUCAA, was organized at the Department of Physics, Bhavnagar University, during August 18-20, 1998. The aim of the workshop was to provide a platform to scientists working on different aspects of light scattering and to put together their expertise for astrophysical applications. Researchers from across the country participated very actively in this workshop.

J.V. Narlikar (IUCAA) provided the initial impetus by his ideas on whiskers in the interstellar dust. N.C. Wickramasinghe (University of Wales, Cardiff) discussed his revolutionary ideas of having biological molecules in the space among galactic dust. J.N. Desai (PRL, Ahmedabad) discussed about the results from various laboratory studies of light scattering and their possible application in astrophysical context. B.G. Anandrao (PRL) talked about the recent developments in infrared emissions from circumstellar dust. H.C. Bhatt (IIA, Bangalore) lucidly described details of HII regions in space. A.K. Sen (Assam University, Silchar) talked on recent observations of molecular clouds and their dust scattering properties. The scattering properties of porus grains were brought out in detail by D.B. Vaidya (PRL). Ranjan Gupta (IUCAA) gave a talk on interstellar extinction and IUE observations. R.V. Mehta (Bhavnagar University) discussed the various experiments of light scattering using magnetic fluids and their possible extensions. K.S. Baliyan (PRL) talked on recent observations of cometary dust grains, while S.K. Sharma (S.N. Bose National Centre, Calcutta) discussed his work on phase functions for scattering of light.

Partcipants of the Introductory Summer School on Astronomy and Astrophysics

All the talks were delivered in a very cordial atmosphere and everyone participated actively. Participants came from various colleges of Gujarat, and included research students and post-doctoral fellows from PRL, scientists from Remote Sensing Applications area. At the concluding session of the workshop, the participants expressed satisfaction and thanked IUCAA and Bhavnagar University for providing this opportunity to interact with prominent scientists. A few scientists who had earlier worked on light scattering applied to paints showed keen interest to utilize their experience in astrophysics.

Introductory School on Astronomy and Astrophysics, New Delhi

An Introductory School on Astronomy and Astrophysics was organised by the Department of Physics, Sri Venkateswara College, University of Delhi, during October 5-9, 1998. The school was sponsored by IUCAA with additional support from CSIR, UGC and DST. It was primarily aimed at B.Sc. (Hons.) Physics students of the university, who would be interested in pursuing the subject for their higher studies. Around 45 students from Delhi and neighbouring towns participated in it.

J.V. Narlikar (IUCAA) started the proceedings by giving an introduction and overview of the subject. He also delivered a public lecture on 'Anomalous Phenomena in Astronomy' in which UGC Chairperson Armaity Desai, Director of University of Delhi South Campus Abhai Mansingh and staff of Sri Venkateswara College were present. Ranjan Gupta (IUCAA) introduced the students to various definitions in Astronomy and Astrophysics, and Instrumentation through four lectures. A.K. Kembhavi (IUCAA) gave four lectures on Stellar Structure and Evolution and Compact Objects. Varun Sahni (IUCAA) delivered three lectures on Introductory Cosmology and Large Scale Structures in the Universe. L.M. Saha (Zakir Husain College, Delhi University), M.K. Das and H.P. Singh (both Sri Venkateswara College, Delhi University) gave talks on Coordinate System, The Solar System, the Sun and Helioseismology respectively. In addition, tutorials and video shows were arranged. An observing trip was organised at the historic Suraj Kund in the neighbouring Haryana, where the participants observed through a 5 inch reflector. A slide-show on comet Shoemaker-Levy Jupiter collision was presented by Ranjan Gupta. The participants were asked to fill up response sheets for their views and a bound copy of the feedback forms is being kept in the IUCAA library.

Workshop on Total Solar Eclipse 1999

A one-day workshop on Total Solar Eclipse was held at IUCAA on October 24, 1998, for activities to be planned for the Total Solar Eclipse of August 11, 1999. There were about 100 participants from all over India. In the morning, there were three plenary talks, "Where amateur astronomers can help professionals?" by J.N. Desai of the Physical Research Laboratory, Ahmedabad, "Instrumentation for eclipse observations" by A. Ambastha of the Udaipur Solar Observatory, and "Recording eclipse: Visually, chemically and electronically" by Arvind Paranjpye, IUCAA.

In the afternoon, there was a session of contributed talks by several participants, about their previous experiences and plans for the next eclipse. This was followed by a panel discussion on "Solar eclipse as a tool to popularize science", The workshop was organized on behalf of IUCAA's Science Popularization Committee by Ranjan Gupta and Arvind Paranjpye.

School on Gravitation and Cosmology

A School on Gravitation and Cosmology was held at the Department of Physics, Cochin University of Science and Technology (CUSAT), Kochi, during October 26-31, 1998, under the joint auspices of IUCAA and the Department of Physics, CUSAT. The

Participants of School on Gravitation and Cosmology

coordinators of the school were V.C. Kuriakose (CUSAT) and T. Padmanabhan (IUCAA). About 30 participants from different universities/ colleges participated in the school and a few of the participants presented their work as seminars. The main lecturers giving the courses in the school were, K. Babu Joseph, S.Bose, J.V. Narlikar, T. Padmanabhan and K.Srinivasan.

Workshop on Databases, Data Visualization and Image Processing

A workshop on Databases, Data Visualization and Image Processing was held at IUCAA during November 15-24, 1998. This workshop was supported by a generous grant by the International Centre for Theoretical Physics, Trieste under the UNU programme. Persons who lectured at the workshop were Francois Ochsenbein of CDS, Strasbourg; Jean-Luc Starck of CEA-Saclay; Steve Odewahn of Caltech; Anand Deshpande of Persistent Systems, Pune; S. Chaudhuri and Uday Desai of IIT, Mumbai; and Ashish Mahabal of PRL, Ahmedabad, as well as several persons from IUCAA. There were also seminars given by various experts. There were about 80 participants at the workshop from different parts of India and three participants from Iran. The topics covered ranged over different areas of image processing, restoration, data mining and data analysis. There were several demonstrations and practical sessions for the participants of the workshop. A number of possible collaborations have been planned during the workshop. A.K. Kembhavi was the coordinator

IUCAA-TIFR School on High Energy Gamma Ray Astrophysics

The 3rd school in IUCAA-TIFR winter school series was on the subject of "High Energy Gamma Ray Astrophysics". It was held at the High Energy Gamma Ray Observatory of the Tata Institute of Fundamental Research, Pachmarhi, during October 27 to November 4, 1998. In all, 17 participants, representing all the 5 regions (Northern, Southern, Eastern, Western and Central) of the country attended the meeting. Most of the participants were young research scholars. A few M.Sc. students and teaching faculty of universities also participated in the school.

The faculty for the school was drawn from TIFR, IUCAA, PRL, NRL/BARC and Cosmic Ray Laboratory, Ootacamund. The subject matter of Gamma Ray Astrophysics was covered in detail along with the related fields like X-ray Astronomy and Cosmic Ray Physics. Some introductory lectures were also arranged on General Astronomy, Radio and Optical

Astronomy to impress upon the relevance of multi-wavelength observations. Introductory lectures on particle detection techniques, Front-end-Electronics, Data Acquisition Systems, Statistical Treatment of Data, Monte Carlo Simulation Techniques, etc. were offered to train the participants in experimental techniques. Hands-on experience with some of the modern detectors were provided by arranging 5 experimental sessions. Participants were grouped in smaller numbers of 3-4 while doing these experiments. The experiments included concepts on the detection of charged particles using plastic scintillators, detection of Cherenkov radiation, orientation and tracking of telescope systems and measurement of background night sky light. The response from the participants to the lectures and experiments was very good. The school provided an informal atmosphere and an environment to interact with the faculty of the school and technical/scientific personnel of High Energy Gamma Ray Observatory.

Introductory School on Astronomy and Astrophysics, Patna

An Introductory School on Astronomy and Astrophysics was organised by the Indira Gandhi Science Complex-Planetarium, Patna, during November 9-13, 1998. The school was sponsored by IUCAA. It was primarily aimed at exposing students at the B.Sc. and M.Sc. levels to the various facets of the subject. In addition to the students, lecturers from various colleges also participated in the school. The participants were drawn from Patna, Magadh and Bihar universities.

The following resource persons were invited to deliver technical lectures: Ranjan Gupta (IUCAA), K.S.V.S. Narasimhan (Visitor, IUCAA), S. Biswas (Kalyani University) and Bhola Ishwar (Bihar University). The topics covered were Observational astronomy, Astronomical instruments, Time and co-ordinate systems in astronomy, Large scale structure in cosmology, and Two/Three body problem in celestial mechanics. Besides the above, popular lectures on some aspects of Astronomy with the help of slides were also given by: Ranjan Gupta, (*on* Shoemaker Levy - Jupiter collision), S. Banerjee, IIT, Kharagpur (*on* The dramatic life of stars and the origin of the solar system), Subasis Basu, SINP, Calcutta (*on* Solar system), Rupayan Bhattacharyya, Break Through Science Society, Calcutta (*on* Journey through the world of galaxies), and Champa Das, Break Through Science Society, Calcutta (*on* Solar eclipse). In addition to these lectures, a few video shows were also organised on interesting aspects of astronomy. The local coordinators of this school were B.K. Sinha, Indira Gandhi Science Complex-Planetarium, and S.P. Varma, Physics Department, Patna University. Ranjan Gupta co-ordinated the school from the IUCAA side.

2nd Sino-Indian Workshop on Astrophysics

The second Sino-Indian Workshop on Astrophysics was held at IUCAA during December 3-6, 1998. This was the second in a series of workshops which have been planned to provide a forum for scientists from China and India to interact and to set up long term collaborations. The first workshop in the series was held at Nanjing, China in 1995. Six Chinese astronomers, Qiao Guojun, Huang Keliang, Peng Qiuhe, Li Xiaoqing , He Xiangtao and Qiu Yuhai, attended the workshop while the Indian community was represented by about 15 people from different institutes and universities in India. The workshop had 2 main themes, pulsars and quasars. A number of lectures were given by the Indian and Chinese astronomers and there were also informal discussions and person to person contacts, which will hopefully lead to research projects. It is expected that the next workshop in the series will be organised in China in due course. From Indian side, A.K. Kembhavi coordinated this workshop.

Decennial Year Meeting

To mark 10 years of IUCAA's existence, a scientific meeting was organised during January

7-10, 1999. The meeting was not focused on a particular theme but rather covered the entire spectrum of gravitation, cosmology, astrophysics and astronomy. It was attended by about 125 persons. It included IUCAA's associates and other friends, philosophers and guides, and about 2 dozen colleagues from abroad.

A wide variety of topics were covered, like quantum mechanics, gravity and topology, supernovae and neutron stars, gamma ray bursters, deceleration parameter and distant supernovae, isotopes in different cosmologies, singularity problem, solar interior, galactic magnetism and dust, interstellar turbulence, probing QSO's, large scale structure, our own motion in the universe and so on.

On the afternoon of January 7, there was a special session of felicitation to Jayant Narlikar on his completing 60 years. It was marked by warmth, affection and informality which brought forth the high esteem in which his colleagues and friends hold him.

Introductory School on Astronomy and Astrophysics, Silchar

An Introductory School on Astronomy and Astrophysics sponsored by IUCAA, Pune was held at G.C. College, Silchar (Assam) during January 12-16, 1999. Experts delivered lectures to the student participants on various subjects in astronomy. They include: J.V. Narlikar, IUCAA (Cosmology); Ranjan Gupta, IUCAA (Observational Astronomy and Astronomical Techniques); H.P. Singh, Sri Venkateswara College, New Delhi (Star and Stellar evolution); K.S.V.S. Narasimhan, Chennai (Time and Co-ordinate System); U.C. Joshi, PRL, Ahmedabad (Extragalactic Astronomy) and A.K. Sen, Assam University, Silchar (Polarimetry). There were 64 persons mainly from Assam and adjoining north eastern states and one each from Kalyani University and Kerala University. There were two university/college lecturers, three research scholars, 32 M.Sc. (Physics, Maths, Computer Science, etc.) students; and 27 third year B.Sc. students. The lectures were very interactive and students showed a lot of enthusiasm towards astronomy.

Orientation Meeting on Exact Solutions in Relativity and Cosmology

An Orientation Meeting on Exact Solutions in Relativity and Cosmology was organised during January 18-19, 1999, at the Department of Physics, D.D.U. Gorakhpur University. This meeting was sponsored by IUCAA and was coordinated by N.K. Dadhich from IUCAA and D.C. Srivastava from D.D.U. Gorakhpur University. The meeting had discussion sessions on (i) Physical properties of solutions, (ii) Inhomogeneous cosmological solutions, (iii) Klauza Klein theory, and (iv) Cosmic strings. These sessions were coordinated by experts in the field who have presented review of current work, relevant problems, new methods and techniques. The importance of the meeting was the availability of experts: A. Krasinski (Polland), H. Knutsen (Norway) and B. Nolan (Ireland). The keynote address was delivered by P.C. Vaidya. The meeting was attended by about twenty outstation participants. The meeting was preceded by the 20th Meeting of the Indian Association for General Relativity and Gravitation, which was held during January 20-21, 1999. An excursion trip to Kushinagar, a place about 50 kms from Gorakhpur, was also arranged.

2nd Level 1 Workshop on Astronomical Photometry

The 2nd Level 1 Workshop on Astronomical Photometry was held at IUCAA during January 25-29, 1999. There were 12 participants (10 teachers and 2 amateur astronomers) from different parts of India. Ranjan Gupta, Hillol Das and Arvind Paranjpye (all from IUCAA) gave talks on topics related to astronomical photometry. All the participants built their own low cost photometers at IUCAA. Pravin

Partcipants of the Workshop on Introductory Image processing and Astronomical Applications

Chordia and Vilas Mistry (both from IUCAA) gave lectures on electronics related to the photometer. Participants were allowed to take the photometers made by them to their institutions.

Workshop on Introductory Image Processing and Astronomical Applications

A Workshop on introductory aspects of image processing was organised by the Department of Physics, Tezpur University and IUCAA at Tezpur during February 9 - 11, 1999. Short lecture courses on different topics in the area including elements of image processing, Fourier transforms, segmentation, morphological image processing, etc., with special emphasis on astronomical applications were conducted.

The lecturers included Ranjan Gupta, Ajit Kembhavi, Yogesh Wadadekar (IUCAA), Ashoke Sen (University of Assam, Silchar) and A. Choudhury (Tezpur University). There were about 25 participants at the workshop besides the lecturers. A number of practical demonstrations and discussions were conducted.

Science and the Media - A seminar

A seminar on Science and the Media was organised at IUCAA during March 1-2, 1999. The seminar brought together a wide cross-section of people including scientists, journalists and others concerned with propagating science to the public through the print, audio and visual media.

The deliberations were divided into: (a) Experiences in popularizing science in the developing world; (b) Science coverage in Indian newspapers, magazines, radio, television, etc. (c) Science in the hands of non-scientists; (d) Science communication through means other than mass media and (e) Changing face of science communication.

Invited talks which came under these categories were presented by a number of experts. Many participant of the seminar also had the opportunity to interact with visitors to the National Science Day at IUCAA on February 28, 1999.

Workshop on Astrophysics for Physicists

The joint IUCAA-Visva Bharati workshop on Astrophysics for Physicists was held at the Physics Department of Visva Bharati, in Santiniketan, West Bengal, during March 6-10, 1999. The purpose of the school was to highlight that the basic physics that is taught in university honours courses is directly applicable to frontline research in astrophysics. Thirty students from various parts of West Bengal, Orissa, Assam and Bihar attended this school, intended for M.Sc./B.Tech. students and young research scholars of physics, mathematics and engineering, studying or working in Eastern India. The Upacharya of Visva Bharati, D.K. Sinha, inaugurated the school on the evening of March 5th and hosted a welcome dinner for all participants.

The lecturers were A.K. Kembhavi (IUCAA, *on* High energy radiative processes), Kamalesh Kar (SINP Calcutta, *on* Neutrino astrophysics), Soumya Chakravarti (Visva Bharati, *on* Nuclear astrophysics), Ranjan Gupta (IUCAA, *on* Observational astrophysics), Somenath Bharadwaj (IIT, Kharagpur, *on* Newtonian Cosmology), Sushan Konar (IUCAA, *on* Statistical physics of compact objects) and Somak Raychaudhury (IUCAA, *on* Stellar dynamics). Evening lectures were given by A.K. Kembhavi and Sayan Kar (IIT, Kharagpur). Lectures were supplemented with tutorials (conducted by Dipanjan Mitra, RRI, Bangalore) for interactively solving problems related to these lectures. The school was coordinated by Soumya Chakravarti of the Department of Physics, Visva Bharati, who is also a Senior Associate of IUCAA, and Somak Raychaudhury of IUCAA, with financial support from IUCAA, Visva Bharati and the CSIR.

(IX) MEETINGS OF THE STATUTORY COMMITTEES

Among the five Statutory Committees of IUCAA listed in page 4, the Academic Programmes Committee meets about once a month and the Standing Committee for Administration meets about once in three months. These two committees handle the academic and administrative matters of IUCAA. The Finance Committee meets once a year to decide about the budgetary and financial aspects. A brief report on the Scientific Advisory Committee and Users' Committee meetings are given below.

The Scientific Advisory Committee Meeting

The seventh meeting of the Scientific Advisory Committee (SAC) of IUCAA was held from January 4 to 7, 1999. Richard Ellis, Ed van den Heuvel, K. Babu Joseph, Vinod Krishan, Jnanadeva Maharana, Franco Pacini, Ram Sagar and R. Rajaraman visited IUCAA and carried out an extensive exercise which included visits to the scientific facilities, presentations by the IUCAA associates, faculty, post-docs and students, informal discussions with the academic, scientific and administrative staff as well as a visit to the site of the proposed IUCAA Telescope. The feedbacks given by the SAC will be carefully followed up for suitable action.

While the SAC members may very well have been exhausted at the end of their meeting, they are assured that their visit, as on previous occasions, has been found by all of us at IUCAA to be very stimulating. This year the Decennial Year Meeting followed the SAC meeting and it had the benefit of participation by the SAC members.

Users' Committee Meeting

A meeting of the IUCAA Users' Committee was held on December 28, 1998. The meeting was attended by committee members, special invitees from amongst the regular users of IUCAA facilities, as well as senior members of the IUCAA administrative and scientific staff. There were useful discussions about the facilities offered at IUCAA , the pattern of the usage so far and the improvements required to make them more effective. It was agreed at the meeting that some journals which are not at the moment subscribed to by the IUCAA library, but are important to a section of the visitors, should be obtained after surveying the needs of the community. It was decided that in the peak season, a visitors' forum would be set up with a coordinator from amongst the visitors . The forum will help in organising seminars, setting up interactions amongst visitors and between visitors and IUCAA faculty. This forum will help in providing further structure and organisation to activities already taking place. It was also decided that heads of colleges and universities from which associates come to IUCAA would be appraised from time to time about activities taking place at IUCAA and they would also be encouraged to visit IUCAA.

(X) VACATION STUDENTS' PROGRAMME 1998

The 6 week long Vacation Students' Programme (VSP) for students in their penultimate year of their science or engineering degree course was held during June 1 - July 10, 1998. Of the 10 students selected to participate from over 100 applicants, 8 were from the IITs and 2 were from Delhi University. The lecture programme, which in the first week overlapped with the Introductory Summer School on A&A, included 5 lectures each of Introductory Cosmology (J.V. Narlikar), Radiative Processes and General Relativity (T. Padmanabhan), Physics of Interstellar Medium (R. Nityananda, RRI) and Gas Dynamics and MHD (A. Mangalam). There were lectures on special topics including Galactic Dynamics (S. Raychaudhury), Gravitational Waves (S. Dhurandhar), Structure Formation (V. Sahni), Pulsars (R. T. Gangadhara, NCRA) and Aspects of Optical and Radio Astronomy (S. Tandon, R. Gupta, V. Kapahi (NCRA)) and evening talks by S. Engineer, F. Sutaria, T. Saini, R. Wichmann and G. Swarup (NCRA). A trip to see the working of the GMRT was arranged on one Saturday.

The projects involved topics in quantum general relativity, gravitational lensing and cosmology guided by a subset of the lecturers and Sukanta Bose. Five students, were pre-selected for admission to the graduate school 1999 and offered research scholarships. Arun Mangalam was the coordinator of this programme.

Facilities

(I) Computer Centre

The Computer Centre caters to the computing need of users from IUCAA as well as visitors from the universities and institutions around the country and abroad.

In addition to the already existing excellent computing facilities, in the past year, a computer server with 1 GB of RAM and 31 GB of hard disk was acquired to meet the expanding needs of the high end computational requirements. Four Ultra sparc 10 workstations which provide high computing power have been added to the network. A printer with duplex printing capability and a CD writer have also been procured. The CD writer is greatly used by IUCAA Associates to carry their processed data and downloaded software from the internet.

Efforts are made to keep all the software available to the users on all heterogenous platforms in the centre. The graphical mathematical package mathematica and data visualization software IDL have been upgraded and ported to high end workstations. Web based helpdesk has been developed which provides online manuals and relevant documents to the users.

So far, ERNET Network Operation Centre (NOC) was part of the IUCAA network. Recently, a separate ERNET NOC has been set up with independent email server, name server and proxy server to cater to the needs of Pune regional nodes.

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

(II) Library

The total collection in the fully automated IUCAA library amounts to about 15,000 and the major activities of the library has been described in the annual reports of earlier years. During the current year, the library concentrated on the enhancement of the routine library services, namely, resource sharing, reprographic aid, long range reference service by the provision of selective dissemination of information, etc. to IUCAA members and visitors, especially from the university sector. The online subscription to the core astronomical periodicals and the availability of astronomical information through the INTERNET has equipped the library to serve its variety of users in a more efficient manner.

(III) Publications

IUCAA has a full-fledged publications department that uses the latest technology and DTP software for preparing the artwork of its publications like the Annual Report, Quarterly bulletin "Khagol", Posters, Academic Calendar, Conference Proceedings, etc.

(IV) Instrumentation Laboratory

The details regarding Instrumentation Laboratory are given in pages 44-45.

Science Popularization Programmes

Many of IUCAA's programmes for the popularization of science involve high school students because, the exposure to forefront areas of scientific research can inspire them to consider research as a viable option in their choice of careers. In addition, two of IUCAA's major goals are to help bring current scientific research into the public domain in the country, and to support and assist in the growth of the amateur astronomy community in India.

The current programmes involving high school students are restricted to the Greater Pune area. In the summer programme, more than a hundred high school students spend a week each during their vacation at IUCAA supervised by an IUCAA member. Lecture demonstrations in Physics, Astronomy, Mathematics or Biology are organised every alternate Saturdays (excluding school vacations) for high school students. In addition, during the annual Science Festival, IUCAA holds a number of inter-school competitions which brings a large number of students and science teachers together.

For the general public, annual open house is organised where the research areas pursued at IUCAA are presented to the public and visits to facilities are organised. Once a month, visitors may view the sky using the telescopes assisted by IUCAA members. Amateur astronomers from anywhere in India can visit IUCAA for a couple of weeks any time during the year to make a six-inch reflector for their club or institution, guided by members of our Laboratory. IUCAA also maintains several relevant pages on the world-wide web, organizes popular lectures in schools, colleges or clubs and assists popularizers of Science elsewhere in India by supplying them with audio-visual aids and copies of published material on astronomy.

(I) An Outdoor Science Park at IUCAA

On the tenth Foundation Day, December 29, 1998, IUCAA opened its first direct public interaction facility in the form of a Science Park. This outdoor ensemble of exhibits illustrate basic principles of astronomy, physics and mathematics that are of interest to the lay person. Most of these exhibits require the interactive involvement of the visitor in their operation. The park was formally inaugurated by Armaity Desai, the Chairperson of the University Grants Commission.

The park occupies a plot of 5000 sq. m. surrounding the Chandrasekhar Auditorium in

Director, IUCAA demonstrates a Moebius trip to distinguished guests

What's my weight on Mars?

the Aditi complex of IUCAA. Only the first stage of the park, consisting of 12 exhibits, is in place at the moment. The park will have about 30 exhibits in all, to be added in the course of the next two years.

The simplest of the exhibits are a couple of balances on which one can read one's weight on the Moon or on Mars. These are placed next to large fibre-glass reconstructions of sections of the surface of Moon and Mars, to show what the corresponding terrain is like.

The exhibits include a system of coupled swings on which the visitors can discover sympathetic oscillations for themselves, and a pair of parabolic reflectors showing how sound can be focussed such that whispers can be heard 80 metres away. The visitor can discover how the speed of planets vary in their orbit according to Kepler's second law by running along the Planetrek. As the electronic beeper keeps time, one is expected to cross over from one area to another in equal intervals of time, thus varying one's speed.

A scaled-down version of the Hampton Court Maze has already become popular with visitors, as has the mechanical demonstration of why one sees only one face of the moon. Among the other exhibits are demonstrations of the method of parallax for estimating distances, which is so crucial to astronomy. Weightlessness in freely-falling bodies is demonstrated in another exhibit.

In the park a Moebius band is constructed around a tree on which a visitor is invited to take a walk, which soon leads to the direct understanding of its unusual topology.

All the exhibits in the park have been fabricated and installed by the National Council of Science Museums (NCSM), Calcutta, who are involved in the planning and fabrication of the future exhibits as well.

(II) National Science Day at IUCAA

The annual National Science Day was celebrated at IUCAA over the weekend of 27 and 28 February 1999. On Saturday 27th, the Science Festival comprised of various competitions for high school students. On Sunday 28th, IUCAA was opened to the general public during the day, when visitors could view special displays on exciting new research areas in Astronomy and Astrophysics, and meet many of the academic, scientific staff and students. This was followed by night-sky viewing for all visitors till midnight.

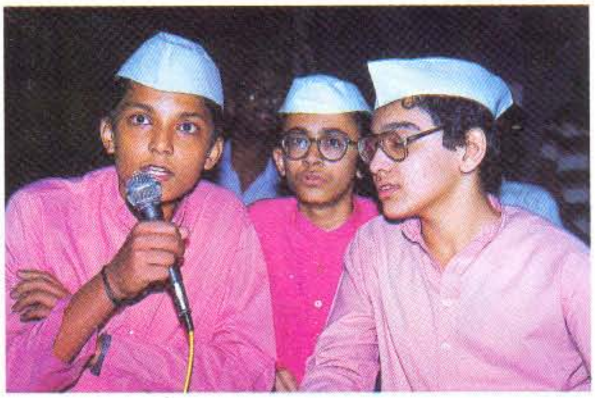
a) The Inter-school Science Festival

The science festival consisted of several inter-school science competitions for students up to Class X. About 500 students from 80 schools in the Greater Pune area (English, Marathi and Hindi mediums) participated in a Science Quiz contest, two Essay (English and Marathi) competitions and a Drawing competition on scientific themes. This day also saw the finale of the inter-school science project competition (described below). In addition, there was a science crossword contest for the teachers who had accompanied the students.

One student from each school took part in the Drawing competition, The first prize was awarded to Kavita Bhandari (St. Joseph's High School, for her portrait of an imaginary scientist), while the second and third prizes were given to Shivkumar Rambhor (Panditrao Agashe High School, for his depiction of a city street in the 22nd century) and to Chirag Baljekar (Symbiosis Secondary School, for his drawing of the world through x-ray eyes) respectively.

The participants in the Essay competitions were asked to write, in English or in Marathi, on any of the diverse topics like *"If I were an alien left on Earth by a Spaceship"*, *"If I became a science teacher"*, or *"What would I like to clone"*. The first prize winners of both the Marathi (Nilkantha Wani, Modern High School)

One participant from each school took part in the Science Drawing Competition



Over 90 schools participated in the Inter-School Science Competitions, which included the Science Quiz

and the English (Shalmali Bodas, Muktangan School) sections wrote essays on *"Industrial age, computer age, what next?"* The above topic was chosen also by the second prize winner in English, Abha Dhupkar (Rewachand Bhojwani Academy) and the third prize winner in Marathi, Anupama Kulkarni (Jnana Prabodhini Navnagar Vidyalaya). Bhargavi Venugopal (St Joseph's) won the third prize for her essay on *"What if our ancestors were not apes*?", while Anand Godse (Jnana Prabodhini Prashala) won the second prize for his Marathi essay on *"Life in a two-dimensional world"*.

In the qualifying round of the Science Quiz, each team had to answer 25 short questions in physics, astronomy, mathematics, chemistry and biology. In this event, each school was represented by a team of three students. Six teams were chosen to compete in the final round of the Science Quiz, which took place in the afternoon of the same day, in the Chandrasekhar Auditorium, in front of a capacity crowd of 550. There were four rounds of questions, many involving slides and pictures, conducted in English, with Marathi subtitles. The team from Sou. Vimlabai Garware High School were the clear winners of the quiz trophy, the first Marathi medium school ever to do so. Symbiosis Secondary School and Jnana Prabodhini Prashala won the second and third places respectively.

Before lunch, when the judges were busy with the various entries, T. Padmanabhan talked about exciting new discoveries in astronomy to the assembled students and teachers.

The science crossword competition was won by Kalpana Ramakrishnan, who is a science teacher at the Kendriya Vidyalaya, Range Hills.

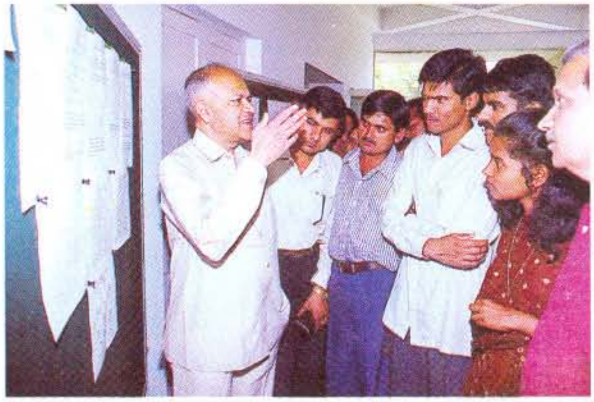
The trophy for the best overall performance (the N.C. Rana Memorial Trophy) was won by Jnana Prabodhini Prashala for the second time in a row. While the winning schools get to keep the trophies for the year, the individual winners were awarded prizes (book tokens) as well. J.V. Narlikar gave away the prizes.

b) Open Day for the Public

An unseasonably hot sun could not deter any of the 6000 visitors from visiting IUCAA as it was open to the general public on February 28 from 11 a.m. to 6 p.m. This was followed by sky viewing till midnight, attended by more than a thousand enthusiasts.

Many of the academic members (including students and visitors) of IUCAA were present during the day to discuss their research with the open day visitors; many of them had put up posters showing exciting results from their area of research. In the Instrumentation Laboratory, one could witness the current status of their automated telescope and low-cost photometer

The visitors were shown demonstrations on image processing at IUCAA, and the facilities on the Internet.



Scientists at IUCAA presented exciting ares in their field of research to the visiting public all day long on the Open Day.

projects, plus various demonstrations involving lasers and CCD cameras. The staff of the Computer Centre and a few students provided demonstrations of the working of the internet, and of samples of the Astronomical Data Centre at IUCAA, and of the image processing research that is carried out at IUCAA.

Almost all visitors spent a considerable time with the interactive outdoor exhibits in the IUCAA Science Park. Two series of half-hour lectures (in English, Hindi and Marathi) were given by IUCAA scientists to capacity audiences all through the day in parallel at two different locations. The lecturers found themselves surrounded by members of the audience with questions for long times outside the lecture halls. Video films on astronomy and space programmes were also shown at yet another location. The library's display included an account of C.V. Raman's work, which is commemorated by the National Science Day each year.

From 7 in the evening till midnight, hundreds of visitors viewed features of the almost full moon, and other objects of astronomical interest, like the Orion nebula, through the six and eight-inch telescopes set up by IUCAA members led by Arvind Paranjpye, with the help of members of the Jyotirvidya Parisanstha, Pune. Almost all the telescopes used had been made by various amateur astronomers at IUCAA as part of our year-long mirror-grinding and telescope making workshop.

(III) Programmes for School Students

a) Summer Programme

Every year IUCAA conducts a summer programme for the school students from class eighth to tenth. The schools in and around Pune are asked to send two motivated students to participate in this programme. About 75 schools responded and around 150 students attended the summer programme. This year the programme started on April 13 and ended on May 22. Every student was assigned to one of the IUCAA members. Each student spent a week, doing their projects and assignments. Some of them made models of the solar system, sun dials, measured period of rotation of the Earth by the Foucault Pendulum; some of them calculated radiation from the sun, distance between stars, etc. The instructions were given in Marathi, English and Hindi.

b) The Science Project Competition

For the first time this year, IUCAA organized an inter-school Science Project Competition with the active collaboration of the Jnana Prabodhini Foundation. It had started in August last year with a workshop on research projects that students could undertake, which was attended by over 100 high school science

The finalists of the inter-school Science projects competition faced the crowd on the National Science Day

teachers from the Pune area. Schools had then been asked for plans of projects that a team of three students may undertake, from which 25 had been selected for the final round. Three months later, on January 30, 1999, these teams had given 15-minute seminars to the judges on their projects. On February 27 and 28, during the National Science Day celebrations, they had set up their displays on the IUCAA grounds, where judges graded them on their ability to explain their work to the public.

The prize for the best project went to the three-girls team from K.S. Sunderbai Rathi Prashala for their model of *"The human eye and some of its defects"*. The second and third prizes were won by the teams from Kendriya Vidyalaya, CME (*"The effect of naturally occurring substances on acid-base titrations"*) and Shri Fattechand Jain Vidyalaya (*"The amount of water needed for different house plants"*) respectively.

c) Astronomy Olympiad Training Camp 1998

IUCAA hosted the training camp for the Indian team who participated in the 3rd International Astronomy Olympiad for school students held in October 1998 at Nizhnij Arkhyz, Russia. Since, this was the first year of India's participation in the Olympiad, the students had been chosen on a trial basis from the cities of Lucknow and Pune by the Astronomical Society of India. Somak Raychaudhury and Jyotsna Vijapurkar took part in the training process, with J.E.S. Singh from Lucknow and Pradeep Gothoskar of NCRA, Pune. Several other members of IUCAA and NCRA gave lectures to the students over a period of two weeks, before the team departed for Russia. All four members of the team won medals (one gold, three bronze) and ranked overall second in the international competition.

d) Lecture Demonstrations

This programme was instituted for conveying the excitement of doing science to secondary school and junior college students. The following lecture demonstrations were conducted during the period under review:

For secondary school students

A.W. Joshi (Department of Physics, University of Pune)

What is there in our Solar System? (in Marathi & English), August 22.

S. Karbelkar (College of Engineering, Akola)

The 1998 Nobel Prize in Physics: Fractional Quantum Hall Effect (in Marathi & English), November 28.

A.K. Kembhavi

The Hubble Space Telescope (in Marathi & English), September 26.

J.V. Narlikar

The strange effects of gravity (in Marathi & English), July 11.

T. Padmanabhan

Snakes, Swings and Curious designs, July 25.

Somak Raychaudhury

Orbits of planets and satellites, January 30.

J. Vijapurkar

A Comet's tale, January 9.

Y.R. Waghmare (formerly from I.I.T., Kanpur)

Atomic nucleus: *A world of wonders*, January 17.

For junior college students

A. Bhagwat

Why are some nuclei radioactive?, December 12.

J.V. Narlikar

Use of Physics in Astronomy, August 8.

R. Nityananda (Raman Research Institute, Bangalore)

Journey into light, September 12.

R. Srianand

Understanding the cosmos through light, October 10.

S. Sridhar

Our galaxy, February 13.

(IV) Programmes for amateur astronomers

a) Observing meteor showers

During the past year, IUCAA has been able to assemble a very active observers group with amateur astronomers in Pune area, and organizing trips to some darker suburbs of Pune to observe meteor showers.

The method of observations adopted was based on the suggestion by the International Meteor Organization (IMO). The first observations were taken on January 3, 1998 of Quadrantids, and promptly sent to the IMO. Observations of other showers followed.

Detailed preparations were made to observe the Leonids starting November 15 to November 20. Four women and 18 men formed the core group of observers, coordinated by Arvind Paranjpye. The observations were made from the GMRT site at Khodad, 80 km from Pune. As a result, out of about 217 contributions accepted by the IMO for their report on the Leonid showers seen all over the world (corresponding to 585 hours of observing time), 12 observations were from this group, amounting to 35 hours of observing.

The Leonids merely provided the beginning of these activities. In future, IUCAA plans to monitor not only all the major meteor showers but also the minor showers and expand into the photographic observations of the meteor showers. The Association of Indian Meteor Observers (AIMO), affiliated to the IMO, has been formed, with its coordination being done from IUCAA.

b) Making small telescopes for schools and amateur organizations

The workshop for training enthusiastic amateurs in the grinding and polishing of 6-8 inch mirrors and building telescopes for the use of their respective institutions is now a year-round activity. Arvind Paranjpye and Vinaya Kulkarni have been assisting visiting amateurs in making such telescopes at an average rate of five per month. There has been an overwhelming response from the community of local amateur astronomers and telescope makers for this activity.

(V) Programmes for the general public

Apart from the open house activities on the National Science Day (described above) which is open to all, IUCAA has several other programmes for the general public. Every month, on the evening of fourth Friday, Arvind Paranjpye helps all visitors look at the night sky using binoculars and small telescopes. On some other nights, along with members of the local amateur organization, the Jyotirvidya Parisanstha, he has been organizing sky-viewing exercises for various local schools and other organisations.

The Tenth IUCAA Foundation Day Lecture

Proxy Records of the Galactic Travels of the Solar System

by

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Abstract

This discourse sets out to ask one question: Can we find any proxy records of travels of solar system through the galactic matter, a very patchy medium containing a wide range of objects, galactic arms, clouds, stars and gaseous stellar systems? Proxy records are created by the energetic radiations which are both of galactic and solar system origin. The radiations accelerated within the solar system are both of solar system and interstellar matter composition. Since their energy spectra and compositions depend sensitively on their origins, their characteristic signatures in the proxy records can be identified. Therefore, the answer to the above question is, in principle, yes, but it would depend sensitively on two related questions: (i) how far back in time can we find the proxy records?, and (ii) what were the environments of the solar system during this time?

An enquiry through these questions takes us to several other interesting questions such as the mechanisms of acceleration and propagation of energetic corpuscular radiation in the galaxy and within the solar system; temporal variations in the activity of Sun; and the size of the heliosphere (the region within which the solar system plasma is confined), as it continually evolves during its encounters with the interstellar plasma.

In the past, several researchers have indicated potential dramatic effects on the terrestrial climate of changes in the solar system environment. Independently, one would also expect changes in the intensity, energy spectra and composition of corpuscular radiations incident on the earth and planets, and it seems fruitful to explore proxy records created by these radiations. An important point to realize here is the fact that as our understanding of the radiations in the solar system improves, so does our capability to look for prehistoric proxy records. Their search can be fruitfully directed only by appropriate models for the acceleration and propagation of radiations. Looking for proxy records at random is not generally expected to yield any useful results! If such investigations are carried out using theory and experiment in a coupled interactive manner, we stand to learn a great deal about the evolutionary history of the solar system environment.

1. Introduction

The structure and composition of the interstellar matter (ISM) has always been a fascinating topic of study for astronomers and astrophysicists. The solar system continually receives matter and radiations from the galaxy. As our understanding of the astrophysical and terrestrial processes improves, new theories have increasingly been advanced in recent decades, which anticipate dramatic changes in terrestrial climate due to interaction of the solar system with the galactic matter (Clube and Napier, 1986, 1996). And in fact, one often sees a tendency for scientists to attribute such interactions as being the reason for difficult to explain, well-documented records of abrupt climatic changes in the past. The main point here is that the questions relating to solar system interaction with matter in the galaxy have now become relevant even to geophysicists and climatologists (Rampino and Sothers, 1986; Clube and Napier, 1986; Clube, et al, 1996).

The solar system receives matter at both microscopic and macroscopic level, none of which can, however, contribute in any significant way to the mass of the solar system. But as we shall see shortly, they do play very important roles, either as means of learning about our galaxy (and the universe), and also possibly by modifying the terrestrial climate.

At the Earth we receive a number of radiations, from within the solar system, and from the galaxy. In fact, our very knowledge of the solar system and our galaxy owes itself to these radiations; there are two important classes of radiation:

Radiation: Electromagnetic
Carrier Particle: Photon (γ) (mass = 0)
Remarks: Gamma-rays, X-rays, UV, optical, infrared, radiowaves. Energy range > 15 orders of magnitude.

Radiation: Charged particles [Cosmic radiation]
Carrier Particle: Common nuclei and electrons (mass > m_e)
Remarks: Energy range > 15 orders of magnitude. Reveals information on their acceleration and propagation environments, and leaves imprint on matter.

These radiations arise from matter of different compositions, subjected to different physical conditions, and are, therefore, a testimony to their origin. The second radiation, namely the corpuscular radiation, has an unique feature in that, it changes the composition of matter with which it interacts. *Thus, matter and radiation have strong affinity: they are each other's creators.* Furthermore, since the corpuscular radiation changes matter composition, this imprint serves as a proxy record of the evolutionary history of matter. On the Earth, the cosmic radiation produces a large number of stable and radioactive nuclei which are used as tools (tracers) to delineate the history of transport/mixing of matter in the atmosphere/oceans and the lithosphere (cf. Lal and Peters, 1967). The radioactive isotope ^{14}C (half-life = 5730 y) serves as a clock for determining the time of formation of organic matter and its removal from the carbon cycle. Radionuclides produced in meteorites and on the moon serve as tracers for determining their evolutionary histories and history of cosmic radiation (Honda and Arnold, 1967; Lal, 1972, 1974).

In this discourse, we explore a new plausible application of the corpuscular radiation, for determining the environment of the Sun in the past as it travels through the ISM in its galactic journey. We discuss below the type of charged particle radiations in the solar system, and the radiation which could possibly serve as an indicator of ISM conditions, especially during periods of enhanced ISM densities. This thought journey through the ISM raises several interesting questions, which are briefly discussed. Reference is made to Lal, Vahia and Goswami (1999) for the expected temporal variations in the heliosphere and the solar system corpuscular radiations with changing ISM environment.

2. Energetic corpuscular radiation in the solar system

We live in a radiation-dominated universe. Besides the two radiations mentioned above, the electromagnetic and the corpuscular radiation, we also have a neutrino sea comprised of neutrinos of finite mass, presumably less than 50 electron mass. There are many sources of corpuscular radiations, because wherever electromagnetic fields exist (common in astrophysical environments), ionised particles can get accelerated to KeV-MeV and higher energies. The solar system is populated by a range of galactic and solar origin particles (Table 1), accelerated under very different conditions, outside the galaxy, by the Sun, and within the heliosphere.

With the exception of the galactic cosmic rays (GCR), which are accelerated (primarily) in our galaxy, other radiations in Table 1 are accelerated either by the Sun (solar cosmic radiation, termed SCR), or accelerated by electromagnetic processes within the heliosphere.

The anomalous cosmic radiation (ACR) has a rather unique origin, considering that it represents acceleration of interstellar neutrals which come in through the heliopause, are ionised near the Sun by solar UV-radiation, are carried back to the heliopause with the solar wind, and finally accelerated at the termination shock (in outer heliosphere, Fig. 1a) in irregular magnetic fields (Fig. 1b). It is composed of elements with large first ionisation potentials. The anomalous component of cosmic radiation is called anomalous because of anomalous flux increases in the low energy spectra of He (< 50 MeV/n), O and N (< 20 MeV/n). It was first discovered in 1972 (see Klecker, 1995, and Biswas, 1996 for reviews), studied in detail in the Anuradha experiment in Spacelab-3 (Biswas, et al, 1993), and in a number of spacecraft missions designed to study the low energy radiations in the inner and outer heliosphere (Voyager and Sampex missions). For observations on ACR fluxes, reference is made to these papers and to Cummings and Stone (1996), Stone, et al (1996) and Mewaldt, et al (1993, 1996).

In Fig. 2a, we show the measured energy spectra of ACR ions during 1987 solar minimum, and in Fig. 3a, the temporal variations in ACR fluxes of 8-27 MeV/n oxygen ions in the past three decades. The high degree of modulation of ACR fluxes by Sun, relative to GCR flux, is apparent. The ACR particles get trapped in a belt imbedded in the inner Van Allen belt (Fig. 3b).

Fig. 2b shows the differential kinetic energy spectra of SCR and GCR protons. The GCR flux is modulated by solar plasma and, therefore, shows an 11-year modulation cycle. Both SCR and GCR contain heavier nuclei, but protons are the most abundant component.

3. The proxy record of corpuscular radiation in solar system objects

Some of the radiations listed in Table 1 have energies well in excess of the nucleon binding energies in nuclei, and, therefore, can cause fragmentation of target nuclei. New nuclei not present earlier in the target are thus produced, some radioactive, some stable. In the last four decades, extensive studies have been carried out on the nuclear effects of cosmic radiation in extra-terrestrial and terrestrial materials to study evolutionary histories of the meteorites, lunar regolith, cosmic dust and the principal terrestrial reservoirs, the atmosphere, oceans, cryosphere and the lithosphere (cf. Honda and Arnold, 1967; Lal and Peters, 1967; Lal, 1991; Nishiizumi, et al, 1993).

Meteoritic evidence has thus far pointed to an essentially galactic constant cosmic ray intensity for the past ~1 by (Arnold, et al, 1961; Lal, 1972). Lunar samples have provided information on time-averaged SCR fluxes, averaged over half-lives of different nuclides, ^{14}C, ^{10}Be, ^{26}Al and ^{53}Mn (cf. Reedy, 1999; Goswami, et al, 1988; Lal, 1972). Long term averaged galactic cosmic ray heavy nuclei composition and energy spectra have also been determined using meteorites and lunar samples (cf. Lal, 1972, 1974).

Freshly fallen meteorites have been used to obtain recent time-integrated galactic cosmic ray fluxes, integrating over short time periods (using ^{44}Ti, half-life 66 y) until the end of epochs representing different phases in solar activity (Bonino et al, 1995). This method yielded very valuable information on the nature of solar modulation of GCR proton flux, > 1 GeV kinetic energy. Besides, nuclear tracks produced in silicate crystals due to solid-state damage by Fe-group and heavy nuclei have been studied in lunar and meteoritic minerals, for both SCR and GCR particles (cf. Lal, 1972).

Records of ^{10}Be in polar ice have shown that during the past 100 ky there were presumably two episodes around 30-40 ky and 50-60 ky when the ^{10}Be concentrations were elevated considerably (Raisbeck, et al, 1987). This may suggest a higher cosmic ray flux during those periods. This increase has in fact been attributed by some to the supernova (Sonnett, et al, 1987) which resulted in the Geminga pulsar (Gehrels and Chen, 1993).

We will not go here into any details of the various proxy record studies, and also not discuss other possible explanations for the increased ^{10}Be concentration in polar ice. But we wish to point out the existence of such records, and also highlight the fact that there exist two types of records, e.g., the meteoric record which integrates the effects of cosmic ray bombardment, and the other, a differential time record found in sediments. The former obviously resembles a low pass filter, where any high-frequency (i.e., short-lived) changes in cosmic ray flux would be heavily damped. The ^{10}Be record in ice in fact constitutes a high pass filter, which should sensitively record short-term changes in cosmic ray flux.

An interesting feature of the proxy records is that one can design an experiment if one knows what to look for. Then the appropriate recording material can be chosen. For studying ISM induced changes in the solar system corpuscular radiations, an appropriate target could be lunar regolith deposited by cratering, estimated to be in the range of ~ (3-7) mm/my. Nuclear tracks have been studied in several lunar drill cores, and large variations in track densities were observed during the past 500 my (Goswami and Lal, 1978). Although, we are presently limited to the Earth and Moon, such differential records may also become available from solar system planets in the future!

The most prominent nuclear effects of the GCR and SCR are produced by primary protons. Consequently, most studies to date have been confined to the protons in the case of SCR, and to the nucleonic cascades produced by energetic protons in the targets by the GCR. (A special case is that of ^{59}Ni, half-life = 7.5 x 10^4 y, in iron meteorites, which cannot be produced by protons from iron; it can be produced only by nuclear interactions of alpha particles and heavier nuclei. Limited data on cosmogenic ^{59}Ni are available.) The ACR radiation, by virtue of its unique composition, now provides an opportunity to study nuclear interactions produced by He, N, O, Ne nuclei in the 10-50 MeV/n energy interval (see Fig. 2a). Because of their average lower energies, an appreciable fraction of ions would also be brought to rest in the matrix by ionisation, offering the possibility of measurement of the ACR composition for ions of energies below 10-20 MeV/n from observations in proxy records. Higher energy ions would produce nuclear spallation favoring production of nuclei heavier than the target, which is not the case for the commonly studied proxy record due to protons.

4. Solar system travels through the ISM: present and past

Our galaxy is a highly evolved spiral with about 10% of its mass in diffuse gas; the rest is in stars. The Sun is located ~8 kpc from the galactic centre, slightly above the galactic plane, and is moving through space at 16.5 kms^{-1}, with respect to the local standard of rest. Information about the local interstellar medium (LISM) is obtained in several ways. Valuable information about the structure and dynamics of the LISM has recently been obtained from data obtained from two recent spacecraft missions, ROSAT and ULYSSES. For reviews, see Bash (1986), Frisch and York (1986) and Egger, et al (1996). Based on the information from the X-ray data from ROSAT, and extreme ultraviolet data from earlier spacecrafts, the structure and dynamics and associations of the LISM (local bubble, superbubble shells, molecular clouds, etc.) have been investigated in detail (cf. Breitschwerdt, et al, 1996; Egger, et al, 1996).

Figure 4 shows a cartoon of the local morphology of matter surrounding the Sun (Breitschwerdt, et al, 1996); see also Lallement et al (1993) for streaming of interstellar ions into the solar system. We are presently in a local hot bubble whose characteristics are given below, along with that for the local interstellar medium (Egger, et al, 1996).

	Local hot bubble	Local interstellar medium
Density	0.005 cm^{-3}	0.07 cm^{-3}
Temperature	10^6 °K	7000 °K
Pressure	1.4 x 10^{-12} ergs cm^{-3}	7 x 10^{-14} ergs cm^{-3}

The present position of the heliopause has been determined to be at about 100 AU, based on observations of ACR (Stone, et al, 1996). This is in general agreement with theoretical expectation (Egger, et al, 1996). The solar wind pressure, P_{sw} (ergs cm^{-3}), at distance r (in AU), from the Sun is given by:

$$P_{sw} = \rho v^2_{sw} \sim 2 \times 10^{-8} r^{-2} \qquad (1)$$

where v_{sw} is the solar wind velocity (~400 kms^{-1} at 1 AU), and ρ is the solar wind ion density at 1 AU.

The ram pressure of the local interstellar medium with corresponding values for ñ and v (= 25 km/sec) in equation (1), is about 10^{-12} ergs cm^{-3}, which yields a value of about 130 AU for the heliopause. Alternate calculations of solar wind shock strength, considering solar wind and interstellar matter density and temperature (Lal, et al, 1999), yield approximately similar values as the presently inferred distance of heliopause.

5. Expected effects of ISM on cosmic radiation fluxes in the heliosphere

There are several obvious interesting expectations : They arise directly in part due to a change in the heliopause distance, and in part due to the change in the ACR fluxes.

a) Heliopause distance

We estimated the heliopause distances for a range of densities and temperatures as generally adopted for galactic arms and clouds (Lal, et al, 1999). The heliopause distances vary in a very significant manner (Table 2), as would be expected. The numbers used in Table 2 for densities and temperatures are not critical; the calculations are purely exemplary.

Undoubtedly, calculations presented in Table 2 cannot be expected to be realistic for high densities of ISM which lead to heliopause distances of < 1 AU. But they do indicate that under such conditions (ISM densities > 100 cm^{-3}), the heliosphere would be a small entity with Sun in close proximity (in space) to the interstellar particles and magnetic fields. Increased GCR fluxes close to the interstellar GCR value (cf. Jokipii and Marti, 1986) may then be expected!

b) ACR fluxes

A direct consequence of higher ISM densities (than at present) would be greater flux of ISM neutrals in the heliosphere. Consequently, if the streaming velocity of ISM in the solar system remains unchanged, the ACR flux would be expected to be increased, proportional to ISM density. Appreciable increases in ACR fluxes would be observed for ISM densities exceeding the present value of 5×10^{-3} cm^{-3} for the local bubble, following the apparent scaling in Table 2. The ACR energy spectra would not be expected to change significantly. The ACR fluxes would be expected to be several orders of magnitude higher than those observed presently, for the case of encounters with molecular clouds. Astrophysical data should allow reasonable predictions of traversal of solar system through molecular clouds (cf. Scoville and Sanders, 1986).

6. Discussion and conclusions

We have seen in the preceding that the field of solar system radiations, the heliosphere and its evolutionary history as dictated by the ISM environment is a rich topic full of unknowns, but it is an area where enough is known to make some useful models at the present time. Among the various corpuscular radiations in the solar system (Table 1), excluding the galactic cosmic radiation (GCR), the so-called anomalous cosmic radiation (ACR) is now believed to be the only radiation representing interstellar matter just outside the heliopause. The local ISM is finally, after an arduous history within the heliosphere, accelerated at the heliopause and propagated back as ACR into the heliosphere (Fig. 1b). The ACR is also trapped in the inner Van Allen Belt of the Earth (Fig. 3b). We discuss that although its flux in the solar system is small compared with the GCR and SCR fluxes, in the past—when ISM densities were higher than today—the ACR flux would have been correspondingly larger. These episodes would be recorded in solar system matter by their nuclear interactions, and would relate to ISM conditions if we do accept the present model for acceleration of ACR. Note that Lal, et al (1999) have considered other non-ISM sources for ACR; if these prove to be important, the ACR may be a mixture of ISM and solar origin particles.

Today, a great variety of nuclear records are found in meteorites, in lunar samples, and on the Earth. The long term average energy spectra of protons of energies > 10 MeV have been deduced from such records (Fig. 3b). In terms of our present day knowledge, before we considered ACR as a radiation whose imprints would be observable in the proxy materials, we have ascribed them to SCR and GCR particles. The ACR record would be found in samples where SCR records are found, and we have to look for them using conventional radiochemical and mass spectrometric methods. But this search has to be guided by astrophysical data and models.

Unfortunately, or what may be the *raison d'être* for the human civilization as we know it, the solar system is now and has been travelling through a very low density ISM environment, and has been in it for periods of the order of 10 my, which we can fairly well comment on (Egger, et al, 1996; Breitschwerdt, et al, 1996). The passage of the solar system through a molecular cloud (MC) would have two direct consequences:

i) a dramatic shrinkage of the heliosphere,
ii) a dramatic increase in the ACR flux in the solar system.

Our experience with solar system environment is limited to small changes in solar activity and in cosmic radiation fluxes. But under extreme conditions such as is expected in encounters with molecular clouds, it is difficult to predict the evolution of geophysical and climatic conditions on the Earth. Today, we realise that appreciable changes do occur in climate with small changes in solar activity and geophysical parameters (cf. Tinsley, 1994; Muller and MacDonald, 1996). In "extreme situations", the coupled interactions between solar wind, interplanetary radiations, and the Earth's atmosphere and the magnetosphere could lead to several consequences, yet difficult to model meaningfully, which would generally be expected to throw the Earth's climate in a spin. A similarly complex situation would arise when the Earth's magnetic field becomes zero, as believed to have occurred during reversal of Earth's magnetic field.

Fortunately, we are sailing through a low density ISM and will do so for quite some time in the future.

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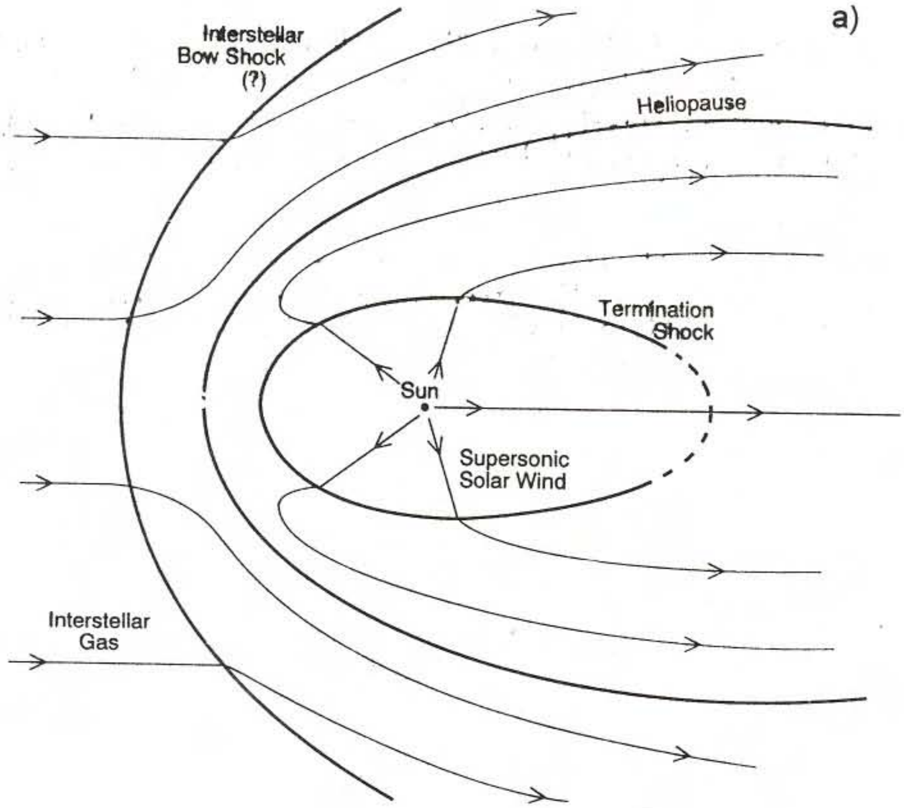
Table 1. Energetic Particle Sources in the Solar System*

Energetic particle population	Typical energy range (KeV/nucleon)	Seed nuclei	Acceleration mechanism
Galactic cosmic rays **(GCR)**	10^3-10^8	Stellar and galactic particles	Supernova remnants, outside of heliosphere
Anomalous cosmic rays **(ACR)**	10^3-10^5	Interstellar neutrals ionized in heliosphere	Termination shock—outer heliosphere
Gradual solar events **(SCR)**	10^0-10^5	Solar wind ions	Interplanetary shocks driven by CMEs—solar wind
Impulsive solar events **(SCR)**	10^0-10^5	Chromospheric particles	Solar flares—at Sun
Corotating events	10^0-10^4	Solar wind ions	Forward/reverse shocks driven by corotating, high-speed streams—beyond ~2 AU
Leaked particles	10^0-10^3	Magnetospheric particles	Planetary magnetospheres
Bow shock particles	10^0-10^2	Solar wind ions	Planetary and cometary bow shocks

*Based on Weissman, et al (1999).

Table 2. Estimated heliopause distances for different assumed ISM states (Lal, et al, 1999)

ISM Type	Density (cm^{-3})	Temperature (°K)	Estimated heliopause distance (AU)
Inter-arm	5×10^{-4}	5×10^4	800
Bubble	5×10^{-3}	1×10^4	140
Fluff	2×10^{-2}	7×10^3	70
Arm	5×10^{-3}	1×10^5	29
MC	1×10^3	1×10^1	3
GMC	1×10^4	1×10^1	0.1



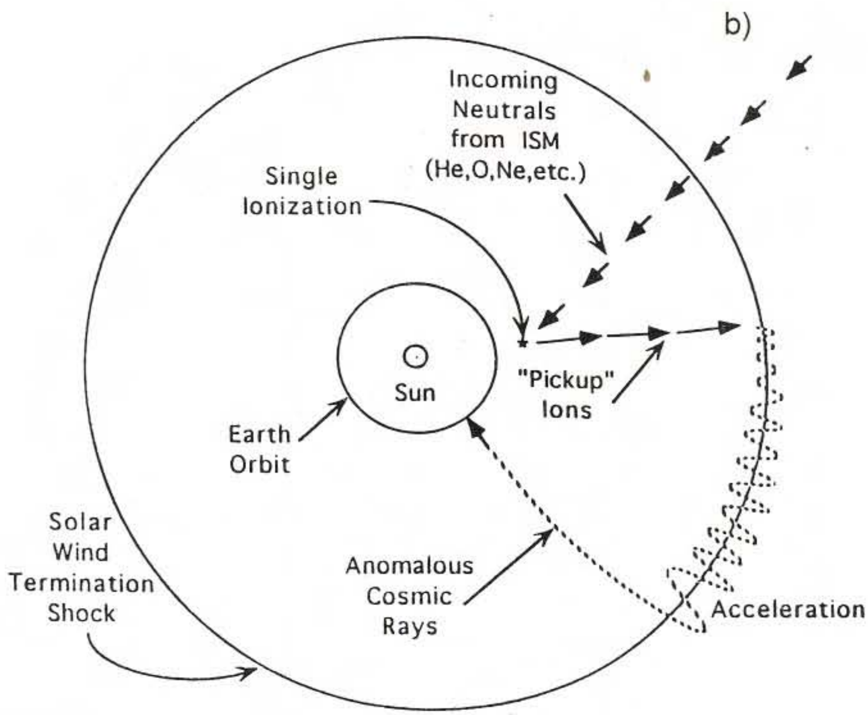


Figure 1. a) Schematic illustration of the interactions of heliosphere with the interstellar plasma. The heliopause is at about 100 AU in the present conditions of ISM (from Weissman, et al, 1999). b) A cartoon of proposed scheme for the acceleration of anomalous cosmic rays in the heliosphere, from interstellar neutrals (from Mewaldt, et al, 1996).

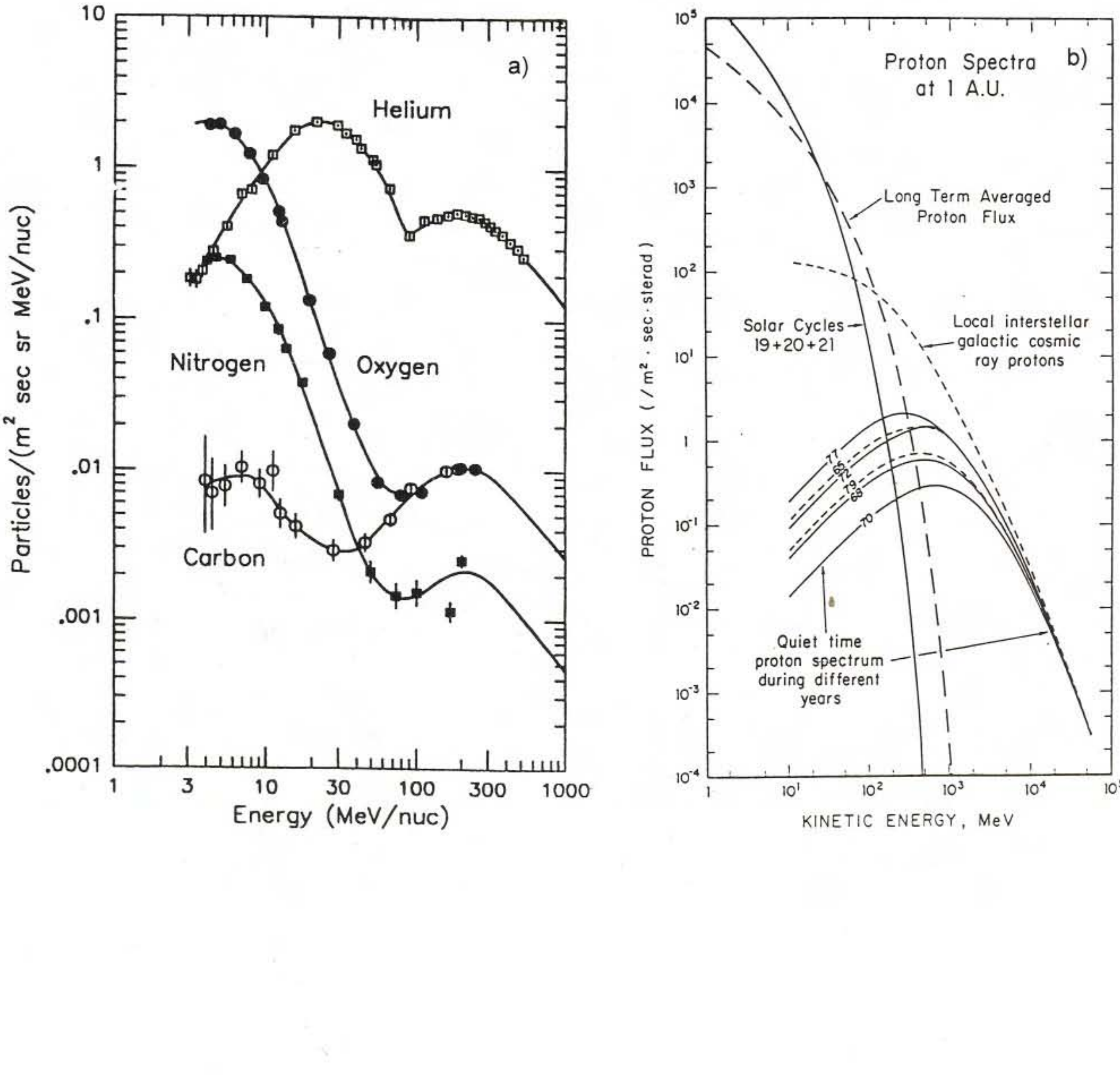
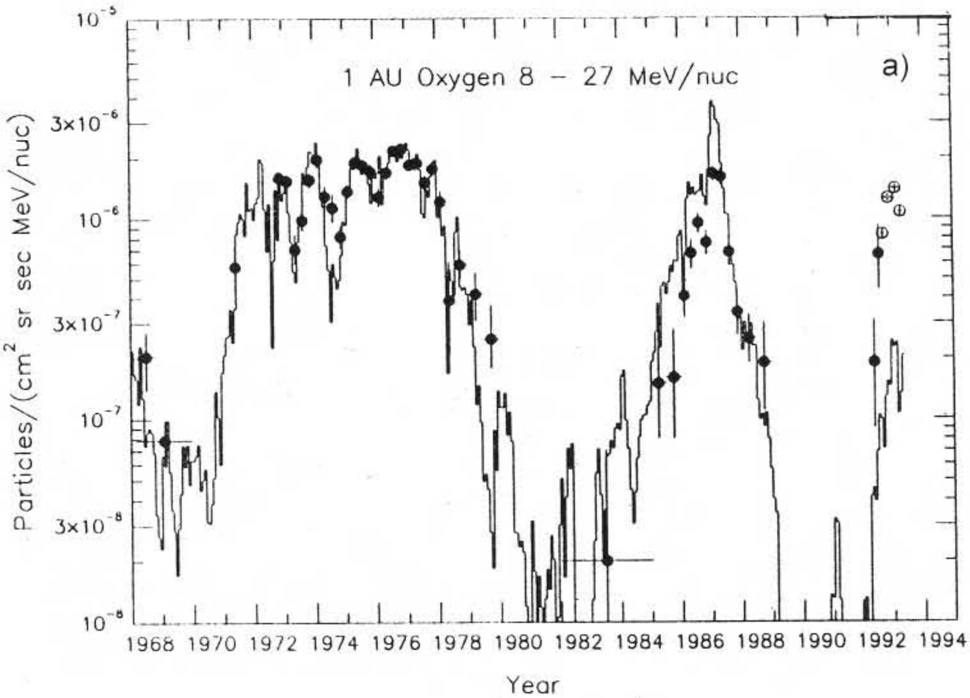


Figure 2. a) Measured energy spectra of cosmic rays on Voyager 2 at 23 AU during solar minimum in 1987. Note the high fluxes of anomalous cosmic rays below 50 MeV/n; above 100 MeV/n, the spectra are due to galactic cosmic rays (from Mewaldt, et al, 1996). b) Measured differential kinetic energy spectra of galactic cosmic ray (GCR) protons during 1965-1979, theoretically expected spectrum of GCR protons in local interstellar space, and long-term averaged and recent solar flare cosmic ray protons are shown (from Lal, 1988).



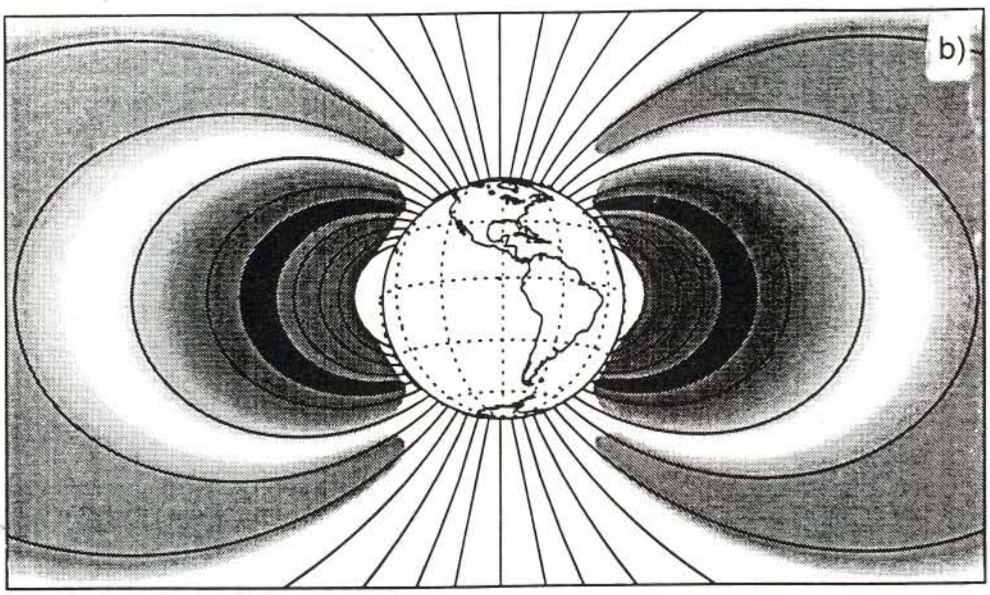


Figure 3. a) Time variation in the observed anomalous cosmic ray oxygen at 1 AU over two solar cycles (data points), shown against scaled Mt. Washington neutron monitor counting rate (from Mewaldt, et al, 1993). b) Cartoon of the radiation belt (dark band) composed of the trapped ACR ions, embedded in the inner Van Allen belt (from Mewaldt, et al, 1996).

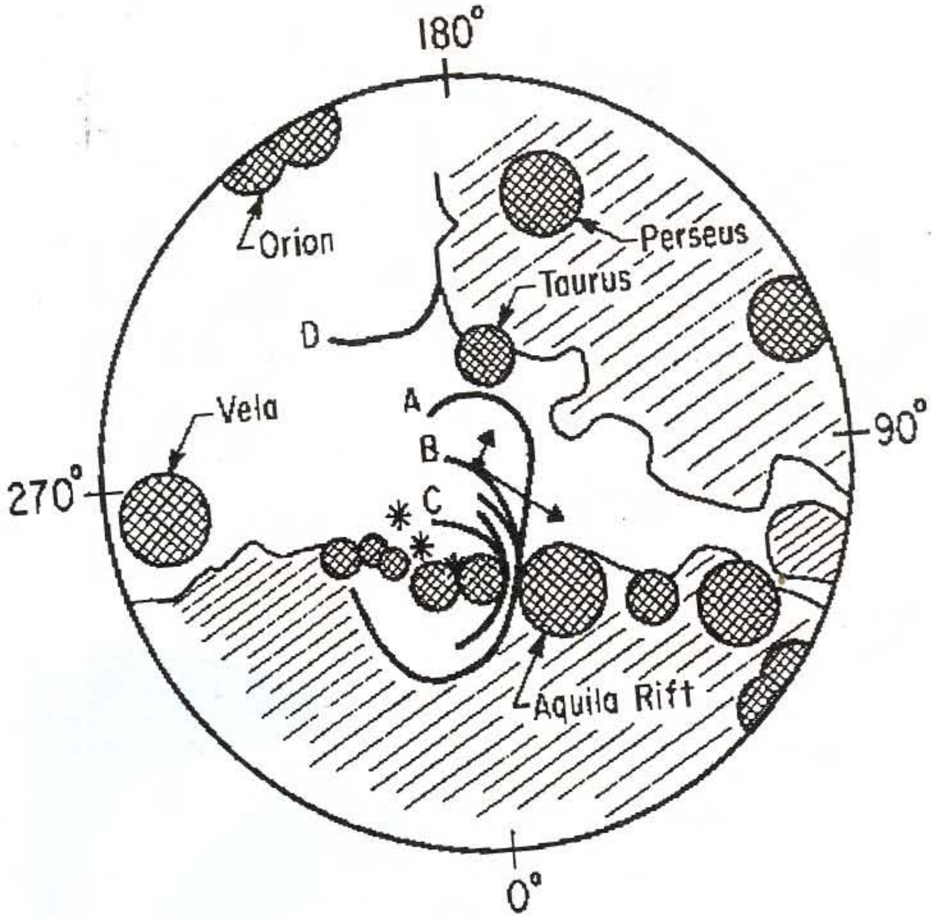


Figure 4. A cartoon showing the position of the Sun in the interstellar medium in the Scorpius-Centaurus Association (SCA). The long arrow on right of B shows the direction of the solar motion, while the short arrow shows the direction of flow of interstellar cloud surrounding the solar system in the local standard of rest. Spiral arm structure is shown by the CO molecular clouds. Superbubble shell fragments due to epochs of star formation in SCA within the past 15 my are also shown. Features A, B, C and D: *A* is the outer boundary of SCA superbubble shell; *B* is 4 my shell fragment around the Sun; *C* is the 250,000 y Loop I supernova remanent shell; *D* is the superbubble shell corresponding to Orion's cloak (from Breitschwerdt,v et al, 1996).

ACRONYMS

AAVSO	:	American Association of Variable Star Observatory
AGB	:	Asymptotic Giant Branch
AGN	:	Active Galactic Nuclei
ASCA	:	Advanced Satellite for Cosmology and Astronomy
ASI	:	Astronomical Society of India
AU	:	Astronomical Unit
BARC	:	Bhabha Atomic Research Centre
BH	:	Black Hole
BLR	:	Broad Line Region
CASS	:	Centre for Astrophysics and Space Sciences
CAT	:	Centre for Advanced Technology
CCD	:	Charge Coupled Device
CMB	:	Cosmic Microwave Background
COBE	:	Cosmic Background Explorer
CSIO	:	Central Science Instruments Organisation
CTS	:	Centre for Theoretical Studies
CWKB	:	Complex Wentzel-Kramers-Brillouin
DSP	:	Digital Signal Processor
EFOSC	:	ESO Faint Object Spectrograph and Camera
ERNET	:	Educational Research Network
ESO	:	European Southern Observatory
FIRST	:	Faint Images of the Radio Sky at Twenty Centimetre
FOS	:	Faint Object Spectrograph
FRW	:	Friedmann - Robertson - Walker
GBD	:	Generalised Brans-Dicke
GR	:	General Relativity
GMRT	:	Giant Metrewave Radio Telescope
HDFS	:	Hubble Deep Field - Source
HST	:	Hubble Space Telescope
IAGRG	:	Indian Association for General Relativity and Gravitation
IIA	:	Indian Institute of Astrophysics
IISc	:	Indian Institute of Science
IIT	:	Indian Institute of Technology
IMPOL	:	Imaging Polarimeter
IPR	:	Institute for Plasma Research
IR	:	Infra - Red
IRAS	:	Infra-Red Astronomy Satellite
ISM	:	Inter Stellar Medium
IUE	:	International Ultraviolet Explorer
JNCASR	:	Jawaharlal Nehru Centre for Advanced Scientific Research
LIGO	:	Laser Interferometric Gravitational Wave Observatory
LISA	:	Laser Interferometric Space Antenna
MACHOS	:	Massive Compact Halo Objects
MHD	:	Magnetohydrodynamics
MRI	:	Mehta Research Institute of Mathematics and Mathematical Physics
NCRA	:	National Centre for Radio Astrophysics
NERIST	:	North Eastern Regional Institute of Science and Technology

PICT	:	Pune Institute of Computer Technology
PRL	:	Physical Research Laboratory
QCD	:	Quantum Chromo Dynamics
QSO	:	Quasi Stellar Object
QSSC	:	Quasi - Steady State Cosmology
RGO	:	Royal Greenwich Observatory
RRI	:	Raman Research Institute
SAC	:	Scientific Advisory Committee
SINP	:	Saha Institute of Nuclear Physics
SNR	:	Signal to Noise Ratio, Supernova Remnant
STIS	:	Space Telescope Imaging Spectrograph
SUSY	:	Super Symmetric
TIFR	:	Tata Institute of Fundamental Research
VLA	:	Very Large Array
VLBA	:	Very Large Baseline Array
VLBI	:	Very Large Baseline Interferometer
VSP	:	Vacation Students' Programme
WKB	:	Wentzel-Kramers-Brillouin

The National Science Day Trophies

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