RAMAN RESEARCH INSTITUTE
BANGALORE-560 080

ANNUAL REPORT 1984-85

Introduction

The Raman Research Institute founded by Prof. C.V. Raman in the late forties was reorganised, after his death in 1970, as a national Institute for research in basic science and it has been receiving generous grants from the Department of Science and Technology of the Government of India since 1972. The main fields of research are Astronomy and Astrophysics, and Liquid Crystals.

1. Astronomy and Astrophysics

Astronomy which is one of the oldest sciences is concerned with the study of heavenly bodies by investigating the radiation received on earth from them. Optical astronomy deals with the "visible" part (wavelength 3000 Angstroms to 6500 Angstroms, 1 Angstrom = 10^{-8} centimeter) of the electromagnetic spectrum. Radio Astronomy, which had its beginnings in 1932 also deals with the study of these heavenly bodies, but the radiation received by radio telescopes on earth is in the radio wavelength part (30 meters to 1 millimeter) of the same electromagnetic spectrum. The lower and upper limits in wavelength of the radio spectrum are set by the earth's atmosphere and ionosphere respectively. In spite of these limitations, the radio window is very wide (30,000 to 1 compared to the 2:1 wavelength ratio in the visible part) and studies within it over the years have yielded information leading to many exciting discoveries such as the 3°K cosmic background radiation, quasars, pulsars, etc.

The Raman Research Institute has observational programmes in Radio Astronomy extending over most of the avaiable radio spectrum. It has set-up a Decameterwave Radio Telescope at Gauribidanur jointly with the Indian Institute of Astrophysics. Operating at a wavelength of 10 meters, it is among the largest telescopes in the world and is being used to study the radio emission from various types of celestial objects such as the Sun, Jupiter, radio sources of various kinds in our Galaxy, and external Galaxies. Moving to somewhat shorter wavelengths, members of the Institute use the Ooty Radio Telescope operated by the Tata Institute of Fundamental Research, Bombay. This instrument operates at a wavelength of approximately 1 meter and is used for carrying out observations of pulsars, and nebulae of various kinds in the Galaxy.

During the past two decades, millimeterwave astronomy has assumed great importance because of the discovery of numerous molecules (combinations of Hydrogen, Carbon, Nitrogen, Oxygen, Silicon, etc. atoms) by their emitted line radiations in the shortest wavelength region of the radio spectrum. These molecules are generally found in dense molecular clouds in our own and other Galaxies where star formation is thought to be taking place. The Raman Research

Institute has set-up two millimeterwave telescopes of diameters 1.5 and 10.4 meters, which are used for the study of these radiations.

In addition, the Institute has theoretical research programmes in many branches of Astrophysics like Pulsars, Supernova Remnants, the interstellar medium, Galaxies and several aspects of General Relativity and Gravitation.

2. Liquid Crystals

Liquid Crystals are states of matter intermediate between the liquid crystalline states. Many organic compounds whose molecules have pronounced shape anistropy exhibit such phases. The unique combination of fluidity and anisotropic properties of liquid crystals has led to many applications of these materials. The Liquid Crystals Laboratory of the Raman Research Institute has contributed significantly to the development of the field over the past decade.

The laboratory has been organised to undertake studies on most of the fundamental properties of liquid crystals. Theoretical and experimental work on liquid crystals is continuing along the lines indicated in the reports of previous years.

A somewhat more technical account of the work carried out in the past year is given in the following:

ASTRONOMY AND ASTROPHYSICS

1. *Millimeter Wave Astronomy* The most significant achievement in the past year was the completion of the 10.4 meter diameter mm-wave telescope. Some of the major operations involved in the last stages and carried out during the year are mentioned below.

The final high precision cutting of the honey comb panels and epoxy bonding of the reflecting skin on each panel was carried out. They were assembled on the back-up structure, and the surface measured. Then they were disassembled and reassembled and followed by remeasurement of the surface. A final surface accuracy of about 55 microns r.m.s. was obtained, together with the confidence that disassembly in the shop and reassembly on the mount would not introduce any additional inaccuracies.

The mount and yoke of the 10.4 meter mm-wave telescope were transported from the National Aeronautical Laboratory and installed on the pedestal at the Raman Research Institute. The back-up structure was assembled on the mount (in situ) using scaffolding specially built for the purpose. The reflector panels were then mounted at their appropriate locations to form the parabolic primary mirror, and the structure was carefully balanced by addition of appropriate weights on the counter-weight arms. A quadripod required to provide support for the secondary mirror, was constructed and mounted on the primary mirror. A 600 mm diameter hyperbolic secondary mirror was fabricated using a novel design technique based on honeycomb structure. A remotely controlled electrical drive mechanism was installed for the precise adjustment of the secondary mirror position. The azimuth and the elevation encoders were installed and the drive system tested out using specially developed software for the computer control of the telescope.

Pointing tests of the telescope were carried out using first a small optical telescope mounted near the centre of the parabolic dish, to look at stars. Subsequently, an all solid-state receiver operating at 22 GHZ, built and tested in the laboratory, was used to check the pointing accuracy of the telescope by observing strong water vapour maser sources in the sky whose positions are known very accurately. Most of the critical components used in the receiver like the corrugated feed-horn, the phase locked Gunn local oscillator, directional coupler, etc., were developed at the Institute. The receiver has a DSB noise temperature of less than 500K and is tunable from 20 to 24 GHz.

This brings to a close the project phase of the mm-wave telescope. Tests of various kinds will, however, be continued for some months to assess the performance of the instrument. In particular, it is planned to carry out holographic measurements of the surface using the super strong (approx. 2 million Jy) maser source in the Orion nebula which happens to be flaring now, and/or a Japanese satellite operating at 19 GHz. In any case it is hoped that regular astronomical observations can be started during the coming good season (winter 85-86).

Regular mm-wave observations will also be carried out with the 1.5 meter telescope. This telescope has also gone through the pointing and control system testing phase and will now be used to do survey work at a wavelength of 2.6 mm. The telescope is coupled through a novel beam-bending quasi-optical system to a 75-115 GHz band room temperature low-noise receiver developed earlier, and a 256-channel filter bank spectrometer controlled by an LSI 11/23 computer which also drives the telescope.

An ultra low-noise mixer for the 75-115 GHz band operating at 30K ambient temperature inside a cryogenic dewer has been developed. Mixer noise temperature (DSB) of about 100K was measured over the frequency range 80-110 GHz. This mixer will be used in the next generation of 75-115 GHz band cooled receivers which are presently under development.

Much progress has been made in the development of solid state frequency doublers to replace the expensive and short-lived klystrons normally used as local oscillators in mm-wave receivers. Changes in mount design and better quality varactor diodes now provide more than 7 mW output power over the frequency range 110-115 GHz for only 50 mW fundamental frequency input, implying a conversion efficiency of about 15%.

The 75-115 GHz receiver and computer controlled filter bank mentioned above were used to measure the ozone over Bangalore by observing its rotational transition at 110.836 GHz. Apart from providing a good check on the overall sensitivity of the complete receiving system, this and subsequent measurements to be carried out periodically will be used in an international study of the Ozone distribution above the earth. Our receiving system is now one of a global network of receivers in various countries primarily used for Astronomy, but also providing measurements of the Ozone for this long term study.

2. *Decameter Wave Astronomy:* In the past year there have been a number of significant achievements in observational decameter wave astronomy. The

most important of these was the detection of carbon recombination lines with principal quantum numbers 574 α and 575 α in the direction of Cas A. These are the first spectral line observations made with the Gauribidanur telescope and they were made using a 128 channel auto-correlation receiver. These observations followed closely the observation of a whole series of recombination lines with principal quantum number of 456 <n> 635 made by a member of the Institute using the 300 foot telescope of the US National Radio Astronomy Observatory at Green Bank. The recombination lines showed a striking four fold increase in width towards the lower frequencies (~26 MHz) caused by collision or radiation broadening. These lines represent the highest excited states yet detected in interstellar gas and the observations represent an important extension of earlier and pioneering work carried out by Soviet astronomers.

Equally significant progress has been made in the very difficult exercise of observing pulsars at such a low frequency. Refinements in techniques, both in hardware and software, have resulted in the detection of several pulsars and an on-going programme of their detailed study. This study will provide new insight into the poorly understood phenomenon of the scattering of pulsar radiation by the interstellar medium.

A third and very significant achievement is the operation of the Gauribidanur array as an image forming instrument using aperture synthesis techniques. The first maps thus produced are of the regions around the galactic centre, W51, the Cygnus loop, the Rosette nebula and a few other regions in the galactic plane. Each map has an extent of 15° (RA) and 10° declination with a resolution 26′ × 40′ sec ZA. The absolute amplitude information normally lost in a one-bit correlator system, such as ours, is recovered using a novel, but simple, hardware scheme. A more advanced system which would enable one to map a 100° stretch in ZA in a single observation schedule is presently under development.

More observations of galactic HII regions in continuum absorption have been made. Very marked non-thermal emission from the eastern part of the giant HII region complex W 51 was detected. Analysis of the observations made on this and several other HII regions, like the Scutum ring, is in progress.

Observations of the interplanetary scintillation of several small diameter radio sources to study the low frequency structure of the sources and also to monitor the velocity and density structure of the solar wind are being continued.

Low frequency flux densities of about sixteen radio sources identified with clusters of galaxies have been measured. Preliminary results show that many of these sources have steep spectra.

Observations on the continuum radio emission from the sun during quiet periods were continued. The variations observed are not correlated with those at centimetric wavelengths and the observed minimum brightness temperatures cannot be explained on the basis of the usually accepted density models and an isothermal corona at a million degrees K. To determine the low frequency radio spectrum of the quiet sun, and its variations, daily total flux measurements at 35 MHz, 45 MHz, 55 MHz and 65 MHz are being made using the broadband

array. This array is also being used for high time and frequency resolution observations of the radio bursts from the sun.

THEORETICAL PHYSICS AND ASTROPHYSICS

1. *Supernova Remnants and Pulsars* A detailed study of the evolution and statistics of supernova remnants powered by pulsars shows that the majority of pulsars may be born spinning rather slowly (initial period approx. 100 ms). The role of pulsars in very young supernova remnants (the recently discovered radio supernovae) has also been investigated. Preliminary results suggest that unless the pulsar is a very rapidly spinning one ($P_0 < 10$ ms), it is unlikely to be the important source for either relativistic particles or the magnetic field.

An analysis of observed pulsar proper motions has led to the conclusion that all pulsars are most likely born in binary systems. The disruption of these systems results in the observed pulsar velocities, which also indicate that most pulsar progenitors have masses in the range 4 to 8 M just prior to the supernova explosion that disrupts the system. In another study, recent proposals invoking the growth of pulsar magnetic fields after pulsars are born was demonstrated to be irreconcilable with the data on the Crab pulsar.

2. *Galaxies.* A project investigating the cause of the small scatter in the luminosities of the brightest galaxies in clusters and groups using extreme value theory has been completed. The conclusion is that the first ranked members of clusters must be a class of special objects, whereas first ranked group members are the tail-end of the statistical distribution of galaxies. Model clusters, selected from n-body simulations of clustering have been used to determine the accuracy of virial methods for mass determination. It was found that a large degree of scatter is inherent in the virial method. Since observed clusters are subject to additional sources of error relative to model clusters, it is argued that their M/L ratios are uncertain by at least a factor of three.

Minimal Spanning Trees (MST) is a graph theoretical technique for assessing intrinsic patterns in point data sets. This construction enables the skeletal pattern of clustering to be singled out in a quantitative fashion and differs from other statistics applied to these data sets. This technique has been described and applied to two and three-dimensional distributions of galaxies, and also to comparable random samples and numerical simulations of clustering. It has been demonstrated how statistics and standard errors can be associated with parameters of single data sets using bootstrap resampling methods. These techniques allow significance levels to be associated with any parameter derived from a data set and measure the robustness of the data set to various known and unknown errors and biases. The method has been applied to the two point angular correlation function of the Zwicky 14th mag catalogue of galaxies. Various consequences of these results and further applications of the method have been investigated.

3. *Gravitational Lensing.* Existing theoretical models of the gravitational lensing process are usually confined to very symmetric mass distributions. The calculation of the time delay between the different images in the usual formulation is not

physically transparent. An alternative formalism, based on Fermat's principle of least time, has been worked out. It involves just a single scalar function which combines geometrical and gravitational time delays in a natural way. The general, topological features of lensing by unsymmetrical mass distributions are brought out. This approach is also well suited for the inversion problem in which one attempts to model the mass distribution starting from the image geometry.

4. *Relativistic Electrons in Magnetic Fields.* Relativistic electrons in magnetic fields are often of importance in astrophysics. Work has been done on the solution of the Dirac equation in a constant magnetic field. It turns out that this problem can be solved by operator methods, which borrow ideas from particle physics, like supersymmetry. In quantum treatments of synchrotron radiation, it is usually the square of the Dirac Hamiltonian which is diagonalized. A purely algebraic procedure for diagonalizing the Hamiltonian itself has been worked out. This procedure is also interesting as a simple illustration of the algebra of super symmetry. Other problems (also related to Astrophysical situations) are under investigation.

5. *General Relativity.* Phenomena where general relativistic effects are important in the context of neutron stars have been reviewed. This includes mass, compactness and redshift computations, radial and quadrupole oscillations as well as general relativistic aspects of rotation for rapidly rotating neutron stars. The geometrical characteristics of perfect fluid spacetimes with local rotational symmetry in which the Dirac equation was earlier separated have been examined. These spacetimes fall into three classes characterized as follows: (1) the fluid world lines have only non-vanishing acceleration, (2) the fluid lines are geodesic with non-zero expansion and shear (3) spacetimes with shear that expand in only two directions.

Accretion of charged matter onto a Kerr black hole immersed in a dipole magnetic field has been analysed. For motion in the equatorial plane one obtains the Keplerian angular momentum distribution, marginally stable and bound orbits and efficiency as functions of black hole parameters. For hydrodynamical accretion, the effects of the magnetic field are much smaller than for test particles.

The Killing-Yano tensor admitted by the Kerr spacetime was studied in order to define the angular momentum of particles following geodesics. Similarities between the properties of angular momentum in flat space time and in the Kerr metric were investigated. The implications of the existence of Killing-Yano tensors in three dimensions were elucidated.

LIQUID CRYSTALS

Theoretical and experimental studies on liquid crystals are being pursued along the lines indicated in previous reports and several articles and papers have been published during the current year. A very brief summary of some of the more important results is given below.

Multi-critical points in liquid crystalline systems has attracted considerable

attention in recent years. The nematic-smectic A-smectic C or NAC multi-critical point was first observed by Johnson et al and independently by Sigaud et al in the temperature concentration diagram of binary mixtures. Subsequently very detailed high resolution studies were carried out by Johnson et al on a number of mixtures and it was concluded that the topology of the phase diagram in the vicinity of the NAC point is universal. Clearly there was a need to find a NAC point in a pure compound to eliminate effects due to critical-concentration fluctuations, and therefore for some time now, we have been carrying out a search for multi-critical points in the pressure-temperature diagram of single component systems.

Another new type of multi-critical point was discovered, viz., the reentrant nematic-smectic A-smectic C (RNAC) point, the topology of which was different from that of the NAC point, but the NAC point itself remained elusive. However, very recently, a compound was found which showed this point, and high resolution P-T studies (undoubtedly the most accurate P-T studies reported to date) were carried out and the remarkable result was established that the topology of the phase diagram is indeed universal. The critical indices for the NA, AC, NC phase boundaries for the pure compound were identical, with experimental limits, with those obtained by Johnson and co-workers in binary systems. Further investigations are under way.

The occurrence of polymorphic forms of smectic A is a problem of fundamental interest. Detailed dielectric, X-ray and high pressure density measurements have been made of the different types of A-A transitions with a view to elucidating the precise structural changes accompanying them. Two important discoveries were made during the course of this study, discoveries that have profound implications in condensed matter physics: (1) A new kind of A-A transition from a temperature dependent partially bilayer structure to a temperature independent partially bilayer structure, and (2) an entirely new type of smectic A with two incommensurate periodicities.

Interesting results have been obtained in the hydrodynamics of cholesterics and smectics in certain unusual situations and in the continuum mechanics of biaxial nematics.

The work on multiplexed liquid crystal displays has been progressing satisfactorily. New materials with suitable electro-optic characteristics have been prepared, new addressing techniques have been developed and a working model of a large area ($4'' \times 4''$) 64×64 dot matrix display has been fabricated. This is the first step towards making LCDs for computer terminals, sophisticated calculators, etc.

Advanced training in research is being offered to the following teachers from other organisations:-

Name	Topic of study	
C. Nagabhushana Veerashaiva College Bellary	Experimental studies on the Dielectric properties of Liquid Crystals.	UGC Faculty Improvement Programme
S. Somasekhara Vijaya College Hospet	Experimental studies of phase diagrams of Liquid Crystals.	

Ph.D. (Awarded)

D.K. Ravindra	Digital correlation receiver for Gauribidanur Decameter Wave Radio Telescope, Indian Institute of Science.
S. Krishnaswamy	Studies on the surface properties of liquid crystals, Mysore University
K.R. Anantharamaiah	A study of radio recombination lines from the galactic plane at 325 MHz, Bangalore University.
R.S. Arora	Solid-state local oscillator systems for millimeter wave radio astronomy receivers, Indian Institute of Science, Bangalore.

Ph.D. (Submitted)

M. Vivekanand	Theoretical and Observational investigations of pulsar properties, Bangalore University.
B.S. Srikanta	Experimental studies on some Liquid Crystalline Compounds exhibiting Smectic order, Mysore University.

Publications

The research work done by the staff of the Institute has been published in a number of journals. A list of publications that have already appeared and those submitted and in press is at pages 12 to 17.

Conferences/Seminars and Meetings

The staff of the Institute visited various institutions in India and abroad and attended 22 conferences and presented papers. In addition, 100 lectures were given by them elsewhere.

As a part of the Golden Jubilee Celebrations of the Indian Academy of Sciences, a five day workshop on Supernovae, their Progenitors and Remnants was held at the Institute during October 29 to November 2. A number of scientists participated in the workshop.

Colloquia

During the year the scientists of the institute and the visiting scientists, both from within and outside the country, gave 15 colloquia at the Institute on different topics.

Journal Club Meetings

As in the past three years, the activities of the journal club continued during this year. Fifteen meetings were held on various topics relating to scientific activities at the Institute.

Visiting Scientists

A number of scientists from institutions within the country and outside visited the Institute during the year. Their names are listed following those of the scientific and technical staff of the Institute given towards the end of the report.

Library

During the year 613 new books were added to the library bringing the total book collection to 14,033. The library is presently subscribing to 152 scientific and technical journals and has 16,568 bound volumes of periodicals.

A revised catalogue of "Scientific and Technical journals received by Air Mail in Bangalore libraries" was brought out.

General

I. The following grants were received from the Department of Science and Technology during the year.

Recurring	Non-Plan	Rs. 29.70 lakhs
Recurring	Plan	Rs 42.30 lakhs
Non-Recurring	Plan	Rs. 47.00 lakhs

II. The audited statements of account for 1984-85 with the Auditor's Report thereon are at pages 19 to 35.

STAFF

The Scientific and Technical Staff of the Institute is given below: Additions during the year are marked with an asterisk.

1. V. Radhakrishnan
2. S. Chandrasekhar
3. S. Krishnan
4. N.V.G. Sarma
5. S. Krishna*
6. C.V. Vishveshwara
7. N.V. Madhusudana
8. A. Krishnan
9. G. Srinivasan
10. R. Shashidhar
11. G.S. Ranganath
12. A.C. Kunwar+
13. V. Surendranath++
14. Rajendra Bhandari
15. C.S. Shukre
16. Rajaram Nityananda

17. Ramesh Narayan+++
18. U. Devappa Kini
19. K.A. Suresh
20. B.K. Sadashiva
21. K.T. Balakrishnan
22. D.K. Ravindra
23. R.S. Arora
24. K.R. Anantharamaiah
25. Jayanthi Ramachandran
26. M.O. Modgekar
27. M.R. Subramanyam
28. P.N. Ramachandra
29. R. Nandakumar
30. T. Ramachandran
31. K. Subramanya
32. K. Smiles Mascarenhas
33. N. Udaya Shankar
34. M. Selvamani
35. T.N. Ruckmongathan
36. P.A. Johnson
37. B.V. Nataraja
38. G. Sarabagopalan
39. R. Ganesan
40. H. Subramoniam
41. Anthony Joseph
42. G. Rengarajan
43. K.S. Dwarakanath
44. A. Deshpande
45. S. Chandrasekharan
46. K. Chandrasekhara
47. P.G. Ananthasubramaniam
48. K. Sukumaran
49. R. Vijayalakshmi
50. Elizabeth Vincent
51. V. Lakshminarayan
52. Mohd. Ateequlla
53. M.N. Ramanuja
54. B.R. Ratna
55. B.R. Iyer
56. M. Vivekanand
57. T.S. Ravishankar
58. G. Jayakumar
59. C.J. Pasupathi
60. C. Ramachandra Rao
61. N. Jayaprakash
62. Suketu P. Bhavsar
63. Joseph Samuel

Visiting Positions

1. S. Ramaseshan
2. G.S.R. Subba Rao

Medical Consultant

Dr. A.R. Pai

Research Fellows

1. S. Krishna Prasad
2. R. Pratibha
3. K.R. Sumathy
4. V.N. Raja
5. V.A. Raghunathan
6. S. Ramesha*
7. Imthyaz Ahmed Khan*
8. D. Bhattacharya++++
9. S. Karbelkar++++

Resignations

1. K. Srinivasa Prasad
2. C.L. Khetrapal

Retirement

J. Padmanabhan

\+ On leave with School of Chemical Sciences, University of Illinois, Urbana, Champaign, Illinois, U.S.A.

++ On leave with Kent State University, Ohio, U.S.A.

+++ On leave with Theoretical Astrophysics Group, California Institute of Technology, Pasadena, U.S.A.

++++ Joint Astronomy Programme

List of Visitors

1.	Dr. R.V. Saraykar Department of Mathematics Nagpur University NAGPUR	April 24-May 5, 1984
2.	Dr. R. Chevalier University of Virginia Department of Astronomy Charlottessville U.S.A.	Oct. 28-Nov. 8, 1984
3.	Dr. V. Trimble Astronomy Programme University of Maryland College Park U.S.A.	Oct. 28-Nov. 10, 1984
4.	Dr. F. Pacini Observatorio Astrofisico de Arcetri Largo Enrico Fermi Firenze, ITALY	Oct. 28-Nov. 6, 1984
5.	Dr. D.H. Clark Space & Astrophysics Division Rutherford Applied Lab. Chilton Oxon, U.K.	Oct. 29-Nov. 2, 1985
6.	Dr. K.W. Weiler National Science Foundation Washington, U.S.A.	Oct. 26-Nov. 8, 1984
7.	Dr. Jacqueline V. Gorkom National Radio Astronomy Observatory New Mexico, U.S.A.	Oct. 20-Nov. 15, 1984
8.	Dr. E.P.J. van den Heuvel Astronomical Institute University of Amsterdam Amsterdam THE NETHERLANDS	Oct. 28-Nov. 6, 1984

PUBLICATIONS

1. The Origin of Pulsar Velocities, in the Proceedings of the Workshop on 'Birth and Evolution of Neutron Stars: Issues Raised by Millisecond Pulsars', 6-8th June, 1984, Green Bank, West Virginia, (V. Radhakrishnan) Eds. S.P. Reynolds and D.R. Stinebring, p 130.
2. Gravitational Lensing by Stars in a Galaxy Halo: Theory of Combined Weak and Strong Scattering. (R. Nityananda and J.P. Ostriker) Journal of Astrophys. and Astr. **5**, 235 (1984).
3. On the Nature of the Supernova Remnant 0540-69.3 in the Large Magellanic Cloud. (G. Srinivasan and D. Bhattacharya) Curr. Sci. **53**, 513 (1984).
4. On the Supernova Remnants produced by Pulsars. (G. Srinivasan, D. Bhattacharya and K.S. Dwarakanath) Journal of Astrophys. and Astr. **5**, 403 (1984).
5. Neutrinos in Gravitational Collapse: Analysis of the Flux Profile. (S.V. Dhurandhar and C.V. Vishveshwara) Pramana **22**, 150 (1984).
6. General Relativity and Gravitational Collapse. (C.V. Vishveshwara). Proceedings of the Workshop on Gravitation and Relativistic Astrophysics., Ed. A.R. Prasanna, J.V. Narlikar and C.V. Vishveshwara (World Scientific/Indian Academy of Sciences) (1984).
7. Leelavathi. (C.V. Vishveshwara) Bulletin of Sciences **1**, 21 (1984).
8. Core Envelope Models of Collapsed Objects. (B.R. Iyer). Proceedings of the Workshop on Gravitation and Relativistic Astrophysics, Ed. A.R. Prasanna, J.V. Narlikar and C.V. Vishveshwara (World Scientific/Indian Academy of Sciences). (1984).
9. Ultracompact ($R < 3M$) Objects in General Relativity (B.R. Iyer, C.V. Vishveshwara and S.V. Dhurandhar) Classical and Quantum Gravity **2**, 219 (1985).
10. A Bootstrap Resampling Analysis of Galaxy Clustering (J.D. Barrow, Suketu P. Bhavsar and D.H. Sonoda) Mon. Not. R. astr. Soc., **210**, 19 (1984).
11. The Virial Masses of Clusters of Galaxies and the Effects of Contamination (J.A. Fernley and Suketu P. Bhavsar) Mon. Not. R. astr. Soc., **210**, 883 (1984).
12. First Ranked Galaxies in Groups and Clusters (Suketu P. Bhavsar and J.D. Barrow) Mon. Not. R. astr. Soc., **213**, 857 (1985).
13. Proceedings of the Workshop on Gravitation and Relativistic Astrophysics, Ahmedabad, 18-20, 1982. Book edited by A.R. Prasanna, J.V. Narlikar and C.V. Vishveshwara.
14. Observations on the continuum emission from the sun at 34.5 MHz (Ch.V. Sastry) Proc. of Indo-US Workshop on Solar terrestrial physics, New Delhi 1984.

15. Observations of the giant HII region complex W 51 at decameter wavelengths (A.A. Deshpande and Ch.V. Sastry) Proc. of the Third Asian Pacific Regional IAU Meeting, Kyoto, Japan, 1984.

16. Observations of pulsars with the Gauribidanur Radio Telescope (A.A. Deshpande, Ch.V. Sastry and V. Radhakrishnan) Proc. of the workshop on low frequency radio astronomy, NRAO, Green Bank, U.S.A., 1984.

17. Radio Physics of the sun: A status report (N. Gopalswamy and Ch.V. Sastry) INSA Publications, New Delhi, 1984.

18. Observations of the Rosette Nebula using the decameter wave radio telescope at Gauribidanur (A.A. Deshpande, R.K. Shevgaonkar and Ch.V. Sastry) Astrophys. and Space Sci. **102,** 21, 1984.

19. Millimeter Wave Gunn Oscillators for low noise receivers (R.S. Arora and N.V.G. Sarma). Proceedings of the National Symposium on Microwave Communication Systems, Madras 1984 p. 86-97.

20. Ultra-Low Noise GaAs FET Amplifiers for L and C Bands (R. Ganesan, K. Smiles Mascarenhas and N.V.G. Sarma) in the Proceedings of the National Symposium on Microwave Communication Systems. Madras, 1984. p. 98-111.

21. Multiple imaging of quasars by galaxies and clusters (R. Narayan, R. Blandford and R. Nityananda) Nature, **310,** 112 (1984).

22. The relevance of the Eddington luminosity in thick accretion discs (R. Nityananda and R. Narayan) in the Proc. of the IAU/COSPAR meeting on advances in high energy astrophysics and cosmology, Rogen, Bulgaria, July 18-22, 1983. Advances in Space Research **3,** 319 (1984).

23. Maximum entropy—flexibility versus fundamentalism (R. Narayan and R. Nityananda) in the Proc. of the IAU/URSI workshop on measurement and processing for indirect imaging, Sydney, Aug.-Sept. 1983, p. 281 (1984).

24. Report on Cambridge Society—TIFR Workshop on galaxy inter-action (Suketu P. Bhavsar and D. Bhattacharya) Bull. of the Astron. Soc. India, **12,** 321 (1984).

25. Rare gas repulsion from compression properties of closed shell ions (Raghurama and R. Narayan) J. Phys. C: Solid State 18, 721.

26. Physics of Liquid Crystals (S. Chandrasekhar)—A course of 10 lectures delivered at ICTP, Trieste, Published in 4 chapters in 'The Physics of Polymers, Liquid Crystals and Low Dimensional Solids'. Eds. N. March and M. Tosi. ICTP, Trieste, Plenum Press, 1985.

27. Some recent studies of liquid crystals; A review (S. Chandrasekhar) Plenary lecture at the 15th IUPAP conference on Statistical Physics, J. Stat. Phys. **34,** 883 (1984).

28. Relation between molecular structure and liquid crystalline properties (S. Chandrasekhar) Plenary lecture at the X International Liquid Crystal Conference, York, July 1984, Mol. Cryst. Liq. Cryst. **124,** 120 (1984).

29. Stable high strength defects in nematic liquid crystals (S. Chandrasekhar) Plenary lecture at the First Asia Pacific Conference, Singapore, 1983 published in Proceedings, World Scientific Publishing Company Pvt. Ltd., (1984), p. 407.

30. High pressure studies of the phase transition in DMPC-water system (R. Shashidhar, B.P. Gaber, S. Krishna Prasad and S. Chandrasekhar) Liquid Crystals and Ordered Fluids, Mol. Cryst. Liq. Cryst. **110,** 153 (1984).

31. Dielectric relaxation studies on two systems exhibiting the induced smectic A phase (B.S. Srikanta and N.V. Madhusudana) Mol. Cryst. Liq. Cryst. **108,** 39 (1984).

32. Comparative X-ray and dielectric studies on some structurally related smectogenic compounds. (N.V. Madhusudana, B.S. Srikanta and M. Subramanya Raj Urs) Mol. Cryst. Liq. Cryst. **108,** 19 (1984).

33. Induction of smectic C phase in binary mixtures of compounds with cyano end groups (N.V. Madhusudana, V.A. Raghunathan and M. Subramanya Raj Urs) Mol. Cryst. Liq. Cryst. **106,** 161 (1984).

34. Weak anchoring energy and pretilt of a nematic liquid crystal (G. Barbero, N.V. Madhusudana and G. Durand)—J. Physique Lett. **45,** L-613, (1984).

35. Optical determination of large distortion surface anchoring torques in a nematic liquid crystal (G. Barbero, N.V. Madhusudana, J.F. Palierne, G. Durand)—Phys. Lett. **103A,** 385 (1984).

36. Anchoring energy of nematic liquid crystals: An analysis of the proposed forms (G. Barbero, N.V. Madhusudana and G. Durand)—Z. Naturforschg. **399,** 1066 (1984).

37. Linear flexo-electro-optic effect in a hybrid aligned nematic liquid crystal cell (N.V. Madhusudana and G. Durand)—J. Physique Lett. **46,** L-195 (1985).

38. Twist instability of a flexoelectric nematic domain in an external field (N.V. Madhusudana, J.F. Palierne, Ph. Martinot-Lagarde and G. Durand)—Phys. Rev. **A30,** 2135 (1984).

39. High pressure studies of liquid crystalline transitions (R. Shashidhar) in 'High Pressure in Science & Technology' Part II, Eds. C. Homan, R.K. Maccrone and E. Whalley, North Holland (1984).

40. Nematic-smectic A-smectic C multi-critical point in a single component system (R. Shashidhar, B.R. Ratna and S. Krishna Prasad)—Phys. Rev. Lett. **53,** 2141 (1984).

41. A new kind of A-A transition: Studies on binary mixtures of terminally cyano and nitro substituted compounds. (R. Shashidhar, B.R. Ratna and S. Krishna Prasad) Mol. Cryst. Liq. Cryst. Lett. **102,** 105 (1984).

42. Pressure studies on ferroelectric liquid crystals. (S. Krishna Prasad, B.R. Ratna, R. Shashidhar and V. Surendranath) Ferroelectrics, **58**, 101 (1984).

43. High pressure studies of liquid crystals (R. Shashidhar) in 'Science and Technology at High Pressures', Eds. E.S.R. Gopal, J. Ramakrishna, S.V. Subrahmanyam and S. Mohan, Instruments Society of India (1984).

44. Some interesting situations in the hydrodynamics of smectics and cholesterics (G.S. Ranganath) Mol. Cryst. Liq. Cryst. Lett. **102**, 281 (1984).

45. Some comments on the effect of a lateral substituent on the re-entrant nematic phase (B.K. Sadashiva) Mol. Cryst. Liq. Cryst. **110**, 309 (1984).

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47. Langmuir monolayers of mesomorphic monomers and polymers (K.A. Suresh, A. Blumstein and F. Rondelez) J. Physique **46**, 453 (1985).

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49. Isothermal hydrodynamics of orthorhombic nematics (U.D. Kini) Mol. Cryst. Liq. Cryst. **108**, 71 (1984).

50. Homogeneous instability in the gravity flow of nematic liquid crystals (U.D. Kini) J. de physique **45**, 1875 (1984).

51. Homogeneous instability in shear flow of nematics—Effect of an oblique magnetic field (U.D. Kini) Mol. Cryst. Liq. Cryst. **116**, 1 (1985).

Papers in press

1. "Separability of the Dirac equation in a Class of Perfect Fluid Spacetimes with Local Rotational Symmetry" (B.R. Iyer, C.V. Vishveshwara) J. Math. Phys. 1985.

2. "Accretion onto a Kerr Black hole in the presence of a Dipole Magnetic Field" (B.R. Iyer, C.V. Vishveshwara, P.J. Wiita and J.J. Goldstein) Pramana 1985.

3. "General Relativistic Aspects of Neutron Star Models" (B.R. Iyer and C.V. Vishveshwara) in "A Random Walk in General Relativity and Cosmology", Eds. N. Dadhich, J. Krishna Rao, J.V. Narlikar and C.V. Vishveshwara, Wiley Eastern, 1985.

4. Minimal Spanning Trees, Filaments and Galaxy Clustering (J.D. Barrow, S.P. Bhavsar and D.H. Sonada) Mon. Not. R. ast. Soc. (1985).

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10. Observation of radio recombination lines with principal quantum number $456<n<634$ towards Cassiopeia A (K.R. Anantharamaiah, W.C. Erickson and V. Radhakrishnan) Nature 1985.
11. Molecular interactions and dynamics in liquid crystals. (S. Chandrasekhar and N.V. Madhusudana) Chapter in a book to be published by Elsevier.
12. Observations on a nematic liquid crystal with an oblique orientation of the director at the nematic-isotropic interface. (N.V. Madhusudana and K.R. Sumathy) Mol. Cryst. Liq. Cryst.
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14. Enhanced smectic A mesophase in mixtures of two terminally polar compounds (V.A. Raghunathan, M. Subramanya Raj Urs and N.V. Madhusudana) Mol. Cryst. Liq. Cryst.
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16. A_d-A_d transition in a binary liquid crystal system. (R. Shashidhar, B.R. Ratna and S. Krishna Prasad) Presented at the Tenth International Liquid Crystal Conf., York, July 1984, Mol. Cryst. Liq. Cryst.
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19. Experimental studies on a terminally nitro substituted compound with a latent re-entrant nematic phase (B.R. Ratna and S. Krishna Prasad) Presented at the Tenth International Liquid Crystal Conf., York, July 1984, Mol. Cryst. Liq. Cryst.

20. No re-entrant nematic below smectic A_1. (R. Shashidhar, S. Somasekhar and P.E. Cladis) Presented at the Tenth International Liquid Crystal Conf., York, July 1984, Mol. Cryst. Liq. Cryst. Lett.

21. Experimental studies on a triply re-entrant mesogen. (R. Shashidhar, B.R. Ratna, V. Surendranath, V.N. Raja, S. Krishna Prasad and C. Nagabhushana) J. de Physique Lett.

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