# RAMAN RESEARCH INSTITUTE
## BANGALORE-560 080

# ANNUAL REPORT 1985-86

### 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 available 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. ) 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 Astropohysics 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 exihibit 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:* Pointing and calibration checks of the 10.4 millimeter wave Radio Telescope were continued during this year also. Pointing accuracy of better than $\pm 10$ arc seconds was estimated utilizing the 22 GHz receiver at the Cassegrain focus by observing the super-strong (flaring) water-vapour maser-line in the Orion Nebula. A room-temperature 86 GHz low-noise receiver was installed at the bent-Cassegrain focus (Receiver Cabin) of the telescope. This receiver was used to observe the strong SiO maser line at 86.243 GHz from a number of Galactic sources like OMC-1, VYCMa, $WH_{ya}$ etc. A systematic observational search program has been started to find new SiO maser sources in the southern Galatic plane which is not accessible to most millimeter wave telescopes as these are located at Northern latitudes in Europe and America.

Considerable software development was carried out during the year to completely automatize the operation of the telescope. An integrated telescope control program now enables the observer to map a region of the sky almost entirely without user intervention. In addition, a highly versatile spectral-line analysis program has been installed for on-line analysis of the incoming data. A high resolution 1760-channel Acousto-optical spectrometer was installed and integrated with the system.

The 1.5m millimeter wave telescope was also utilized for a variety of observational experiments during the year. 12CO (115.271 GHz) and 13CO (110.201 GHz) lines were observed from the star-forming region Ori-A to test the sensitivity of the receiving system. This telescope is now being geared up to start a survey of the Southern Milky Way Galaxy using the widespread CO molecule.

Development of ultra-low-noise cooled receivers (mixers) is continuing. DSB Mixer noise-temperatures of less than 80K over the frequency range 85-115 GHz were achierved using newly acquired better quality Schottky diode chips (1H16 fabricated at University of Virginia, U.S.A.). This should enable the realization of cooled receivers with DSB receiver noise-temperatures around 100-150K (a factor of four improvement over the existing 86 GHz room-temperature receiver with DSB noise-temperature of about 500K).

Gunn oscillator development was also continued during the year. 5-10mW CW power output was achieved in the frequency range 100-110 GHz using commercially available packaged GaAs Gunn diodes. These oscillators will be used as reliable and compact solid-state local oscillator sources for the low-noise receivers being developed for the W-band (75-110 GHz).

*2. Decameter Wave Astronomy:* Observations of the Galactic H II regions in continuum absorption at 35 MHz are continued. Analysis of the data obtained on the Scutum Ring and several other H II regions is in progress. Observations were made on several pulsars using a swept frequency Local Oscillator system at 35 MHz. The data is being analysed to study the fine structure of pulse profiles, interstellar scattering, etc.

The solar radio maps made with the decameter wave radio telescope during the exceptionally quiet period, August 6-30, 1983, were used to study the brightness temperature variations of the quiet Sun. On these days the position of the centroid of the radio maps agreed quite closely with the center of the optical Sun indicating that there is little or no contribution from active regions. During this period the brightness temperature varied from 200,000K to 800,000K. We were able to explain these variations on the basis of electron temperature variations of the outer corona.

The data obtained on the total flux of the Sun at four low frequencies, i.e., 65, 55, 45 and 35 MHz, with the broadband antenna system were used to compute the daily values of spectral index for about 45 days during the period May-September, 1985. The spectral index varied over the range 0.76 to 4.10. These variations are explained on the basis of large non-thermal contribution from bright regions and also the existence of low temperature regions in the outer corona.

A compound interferometer of high angular resolving power has been constructed at Gauribidanur using the E-W arm of the existing "T" antenna. The instrument produces a fan beam of 3' E-W by 15° N-S at 35 MHz. It is capable of measuring the one dimensional structure of bright regions on the Sun and also some galactic and extragalactic sources.

## ASTROPHYSICS

*1. Foundations of Physics:* A problem related to the Gibbs Paradox, namely, 'disappearance of mixing entropy' was formulated and solved in its full generality for an arbitrary number of gases and an arbitrary number of metastable states. Some related problems are being looked into.

*2. Astronomical Image Processing:* A review article covering the application of the maximum entropy method to image reconstruction was completed in collaboration with R. Narayan (Steward Observatory). A study of the foundations of the maximum entropy principle of inference revealed that there is a hidden assumption in the widely accepted proof that-plnp is the only possible entropy function.

*3. Filaments, Galaxy Clustering and Human Perception:* The Minimal Spanning Tree (MST), A graph theoretical technique for assessing intrinsic patterns in point data sets has been used to study filamentry structure in the large scale distribution of galaxies in the Universe. Factors which appear to dominate the process of pattern recognition by the human eye with special reference to the question of whether significant filamentary or cellular structure exists in the large scale distribution of galaxies was investigated. A number of examples were given which demonstrate the role played by nearest neighbour distances, orientations, visual inertia, local point densities and point sizes in biasing pattern recognition by the eye.

*4. Pulsars and Supernovae:* From earlier work it was concluded that the majority of pulsars must be born as slow rotators. This suggests that angular momentum and rotational energy must have been extracted during or after the core collapse. The feasibility of obtaining supernova explosions by means of extraction of rotational energy of neutron stars through magnetic coupling to stellar envelopes is being examined.

The recent discovery of several pulsars in binary systems has generated immense interest in the origin and evolution of these systems, and especially of the neutron stars in them. Present data seems to indicate that the magnetic fields of neutron stars do not decay below a certain minimum value.

An analysis of the effects of supernova explosions on binary systems in which they occur has been completed. Analogous to its application to velocities of single pulsars, work on its application to binary pulsars is in progress. Detailed implications of this work for stellar evolution leading to production of neutron stars is under study.

*5. Radio Recombination Lines:* The 325 MHz observations of H272 a radio recombination line towards the Galactic Centre were analysed and strong constraints were obtained on the properties of the line-of-sight gas in this direction.

*6. The gravitational pole:* An exact analogy between rotation in stationary spacetimes and magnetic fields is demonstrated based on a natural decomposition of spacetime into space and time in the spirit of Kaluza-Klein theories. This framework is then used to discuss the gravitational counterpart of the Dirac monopole. A general argument is given to show that gravitational monopoles violate causality.

*7. Exact solutions for Spacetimes:* The field equations for perfect fluid spacetimes with local rotational symmetry in which the Dirac equation separates were studied. For vacuum and dust cases all possible exact solutions were exhibited. Solutions were also obtained for radiation, a stiff fluid and a fluid with negative pressure.

The Dirac equation in a Kasner spacetime with two equivalent directions was also studied. It is shown that these in general are more complicated than the special case which represents a flat spacetime in Rindler like co-ordinates.

*8. Instabilities in General Relativity:* When Einstein's equations are supplemented by symmetry conditions, linearisation instabilities can occur that are not present in either of the two sets of equations. The general conditions for this joint instability were investigated. An illustrative example was given where both the Einstein equations and the flatness condition have more linearised solutions than exact solutions. In a minisuperspace model the geometrical reason for these instabilities was demonstrated.

## LIQUID CRYSTALS

A very brief summary of some of the more important results is given below.

The interesting observation has been made for the first time that, under certain circumstances, the nematic-isotropic interface is not a flat surface, but consists of hills and valleys (or cusps and dips) arranged to form a regular lattice-like network of singular points. Such a possibility was, in fact, envisaged by de Gennes in 1970: the surface may get distorted when the director orientation in the bulk is made to conflict with that at the surface by the application of a suitable magnetic field. The present experiments have demonstrated this effect even without a magnetic field. The materials were chosen in which the director makes an oblique angle at the interface, and the bottom plate was treated to give homeotropic alignment. Spectacular photographs of the structure of the interface have been published.

The structure and properties of various topological defects that can occur in ferroelectric smectic C* liquid crystals have been investigated. It has been shown that smectic C* can have new types of defects, called dispirations, that have the features of both dislocations and disclinations in them. The polarization field associated with disclinations, the effect of incommensuration on the structure of dispirations, some interesting situations in the interaction between dispirations and disclinations and between dispirations themselves have been discussed in detail. The properties of cholesteric type disclinations and a possible model for the core structure of a wedge disclination have also been studied.

As mentioned in the previous year's report, the nematic-smectic A-smectic C (NAC) muilticritical point in a single component system was observed for the first time in this laboratory. High resolution P-T studies established that the topology of the phase diagram in the vicinity of this point is universal, the critical exponents for the phase boundaries being identical with those obtained by Johnson et al for the phase diagrams near the NAC point in several binary mixtures. In the course of our studies we discovered another type of multicritical point, viz., the re-entrant nematic-smectic A-smectic C (RN-A-C) but the topology was found to be distinctly different. Recent studies have shown that this is due to the remoteness of the nematic-isotropic (NI) transition point in the temperature scale relative to the RN-A-C point. By selecting suitable systems in which the NI transition temperature is close to the RN-A-C point, it has been shown that

the topology of the phase diagram does, in fact, conform to the same universality class. A possible explanation of this is that when the NI transition is far away, the Brazovskii fluctuations are so weak that the critical region becomes experimentally inaccessible. By 'tuning' the Brazovskii fluctuations the RN-A-C point also falls in the same universality class.

A new type of phase diagram has been found in which two types of nematics, one composed of rod-like molecules and the other of disc-like molecules, can co-exist. The observed behaviour is in broad agreement with the predictions of the theory of Palffy-Muhoray et al. Further studies, including detailed measurements of the thermodynamic properties are under way.

A multitraced LCD oscilloscope screen (10 cm × 10 cm and just a few millimetres thick) has been designed and constructed. It runs on a battery and consumes typically about 1 microwatt/cm$^2$ In contrast the conventional Cathode Ray Tube with a 10 cm × 10 cm screen is about 30 cm long and requires a sizeable H.V. power supply and consumes 10 5 or 10 6 times more power.

*Advanced training in research is being offered to the following teachers from other organisations.*

| Name | Topic of study | |
|---|---|---|
| S. Somasekhara<br>Vijaya College<br>Hospet | Experimental studies of Phase diagrams of liquid crystals | UGC Faculty Improvement Programme |
| C. Nagabhushana<br>Veerashaiva College<br>Bellary | Experimental studies the dielectric properties of liquid crystals | |
| Ph.D. (Awarded/submitted) | | |
| B.S. Srikanta | Experimental studies on some liquid crystalline compounds exhibiting smectic order.<br>University of Mysore. | Awarded |
| S. Krishna Prasad | High pressure studies of liquid crystalline transitions.<br>University of Mysore | Reports awaited |
| N. Udaya Shankar | Application of digital techniques to radio astronomy measurements<br>Bangalore University | Reports awaited |

## 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 given in Annexure I (Page12 ).

## Conferences/Seminars and Meetings

The staff of the Institute visited various institutions in India and abroad and attended conferences and presented papers. In addition, 36 lectures were given by them elsewhere.

A large number of scientific, technical and administrative staff of the Institute took part in organizing and running the XIX General Assembly of the International Astronomical Union held at New Delhi during November 19-28, 1985.

Two major International Conferences were organized during the year under the Chairmanship of Prof. S. Chandrasekhar:

1. Conference on Science and Technology Education and Future Human Needs, Bangalore, August 6-14, 1985 jointly sponsored by the International Council of Scientific Unions in cooperation with the United Nations University, UNESCO etc.
2. Second Asia Pacific Physics Conference, Bangalore, January 13-17, 1986.

## Colloquia

The scientists of the Institute and the visiting scientists both from within and outside the country gave 21 colloquia at the Institute on different topics during the year.

## Journal Club Meeting

Ten meetings were held on various topics related to the 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

Six hundred and eighty new books were added to the library during the year. This brings the total book collection to 14,721. The library is presently subscribing to one hundred and forty nine current periodicals and has 17,507 bound volumes.

## General

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

| | | |
|---|---|---|
| Recurring: | Non-Plan | Rs. 32.00 lakhs |
| | Plan | Rs. 70.00 lakhs |
| Non-Recurring: | Plan | Rs. 38.00 lakhs |
| | | Rs. 140.00 lakhs |

The Audited Statements of Account with the auditor's report are given in pages 17 to 30.

## STAFF

On being invited by the Council Prof. S. Ramaseshan joined RRI on 30th October, 1985 as Distinguished Professor Emeritus for a period of 5 years. Prof. Ramaseshan – a very distinguished Crystallographer and Materials Scientist with very active and wide ranging scientific interests – has been associated with RRI since the days of Prof. C. V. Raman and his presence on campus will contribute significantly to the intellectual work and atmosphere of the Institute.

It is with deep regret that we record the demise on 14th April 1986 of Shri K.T. Balakrishnan who served the Institute in an exceptional way for 33 years. having joined it early in its history in 1953, he was closely associated with Prof. Raman who depended heavily on Balakrishnan's versatility for the setting up on every apparatus needed for his experiments. In the subsequent years after the Institute's reorganisation, Balakrishnan continued to be a pillar of strength leaned on by everyone at the Institute. His technical resourcefulness, and willingness to help, earned him a unique place in the minds and hearts of all those who knew him, not only at the Institute, but from all over the city.

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. Ramaseshan
4. S. Krishnan
5. N.V.G. Sarma
6. S. Krishna
7. C.V. Vishveshwara
8. N.V. Madhusudhana
9. A. Krishnan**
10. G. Srinivasan
11. R. Shashidhar
12. G.S. Ranganath
13. A.C. Kunwar
14. V. Surendranath+
15. Rajendra Bhandari
16. C.S. Shukre
17. Rajaram Nityananda
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. Rumckmongathan
36. P.A. Johnson
37. B.V. Nataraja
38. G. Sarabagopalan
39. R. Ganesan
40. H. Subramoniam
41. Antony Joseph
42. G. Rengarajan
43. K.S. Dwarakanath
44. A. Deshpande
45. S. Chanthrasekharan
46. K. Chandrasekhara
47. P.G. Ananthasubramaniam
48. K. Sukumaran
49. R. Vijayalakshmi
50. P.S. Ramkumar *
51. V. Suresh Rao *
52. V. Lakshminarayan
53. Mohd. Ateequlla
54. M.N. Ramanuja
55. B.R. Ratna
56. B.R. Iyer
57. M. Vivekanand
58. T.S. Ravishankar
59. G. Jayakumar
60. C. Ramachandra Rao
61. N. Jayaprakash
62. Joseph Samuel
63. Suketu P. Bhavasar
64. C.J. Pasupathi

*Visiting Positions*
1. G.S.R. Subba Rao
2. Anand Kumar

*Consultant Physicians*
1. A.R. Pai
2. M.R. Baliga

*Research Fellows*
1. S. Krishna Prasad
2. R. Pratibha
3. V.N. Raja
4. V.A. Raghunathan
5. S. Ramesha
6. K. Usha *
7. Geetha G. Nair *
8. G.B. Shivakumar

*Joint Astronomy Programme*
1. D. Bhattacharya
2. S. Karbelkar
3. S. Sridhar *
4. Nimesh Patel *

*Resignations*
1. Ramesh Narayan
2. Elizabeth Vincent
3. K.R. Sumathy
4. Imthyaz Ahmed Khan

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| + | On leave with Kent State University, Ohio, USA. |
| ++ | On leave at the Dowell Schlumberger, France |
| +++ | On leave with the National Radio Astronomy Observatory, VLA Site, Socorro, New Mexico, USA. |
| ** | Deputation completed in January, 1986. |

## LIST OF VISITORS

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|---|---|
| Dr. G.S. Bisnovatyi-Kogan & V.I. Slysh<br>Space Research Institute<br>The USSR Academy of Sciences<br>Moscow, USSR | March 12 –<br>April 15, 1985 |
| Dr. P.C. Vaidya<br>Department of Mathematics<br>Gujarat University<br>Ahmedabad | June 3-4, 1985 |
| Dr. A.K. Raychudhuri<br>Department of Physics<br>Presidency College<br>CALCUTTA | June 3-8, 1985 |
| Dr. Arvind Borde<br>Syracuse University<br>Syracuse, USA | July 1-4, 1985 |
| Dr. W. M. Goss<br>Kapteyn Astronomical Institute<br>Groningen<br>THE NETHERLANDS | July 2-29, 1985 |
| Dr. Paul J. Wiita<br>University of Pennsylvania<br>Philadelphia<br>USA | July 19-31, 1985<br>August 12-18, 1985 |
| Dr. Varun Sahni<br>Moscow State University<br>Moscow, USSR | August 13-17, 1985 |
| Dr. Ramesh Narayan<br>Dept. of Theoretical Astrophysics<br>California Inst. of Technology<br>Pasadena, California | October 15 –<br>November 15, 1985 |
| Dr. A.V. Tutukov<br>Astronomical Council<br>The USSR Academy of Sciences<br>Moscow<br>USSR | November 3-16, 1985 |
| Dr. M. Ruderman<br>Dept. of Physics<br>Columbia University<br>New York, USA | November 7-16, 1985 |
| Dr. R.A. Windhorst<br>Mt. Wilson & Las Companas Obs.<br>Pasadena, USA | November 12-16, 1985 |

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|---|---|
| Dr. D. Morris<br>IRAM<br>Grenoble<br>FRANCE | November 28 –<br>December 31, 1985 |
| Dr. J.E. Baldwin<br>Cavendish Laboratory<br>Cambridge, UK | December 6-14, 1985 |
| Dr. Martin Rees<br>Institute of Astronomy<br>Cambridge, UK | December 6-9, 1985 |
| Dr. J.A. Roberts<br>CSIRO Div. of Radiophysics<br>Epping, Sydney<br>AUSTRALIA | December 14-16, 1985 |
| Dr. J. Faulkner<br>University of California<br>Santa Cruz, USA | December 14-16, 1985 |
| Dr. I.D. Novikov<br>& Dr. V. Kostenko<br>Space Research Institute<br>The USSR Academy of Sciences<br>Moscow, USSR | December 16-28, 1985 |
| Sir Hermann Bondi<br>Master, Churchill College<br>Cambridge, UK | December 20-28, 1985 |
| Dr. Gareth Hunt<br>NRAO, VLA Site<br>Socorro, New Mexico<br>USA | January 4-25, 1986 |
| Dr. R. Penrose<br>University of Oxford<br>Oxford, UK | January 16-17, 1986 |
| Dr. A. Kuzmin<br>Lebedev Physical Institute<br>Moscow, USSR | February 5-8, 1986 |
| Dr. M. Dodson<br>Dept. of Mathematics<br>University of York<br>York, UK | February 24 –<br>March 7, 1986 |
| Dr. S. Kichenassamy<br>Institut Henri Poincare<br>Paris, FRANCE | February 27 –<br>March 7, 1986 |

## PUBLICATIONS

## ANNEXURE I

1. The Quantum Measurement Problem and Selection of Classical States. (R. Bhandari) – Pramana **25,** 377 (1985).

2. On the Axiomatic approach to the Maximum Entropy Principle of Inference. (S.N. Karbelkar) – Pramana **26,** 301 (1986).

3. Minimal Spanning Trees, Filaments and Galaxy Clustering. (S. Bhavsar, J.D. Barrow and D.H. Sonada) – Mon. Not. Roy. Ast. Soc. **216,** 17 (1985).

4. On Pulsar – SNR Associations. (G. Srinivasan) – Supernovae, their Progenitors and Remnants, eds. G. Srinivasan and V. Radhakrishnan, Indian Academy of Sciences, Bangalore, p. 105 (1985).

5. How often are Remnants like Crab Nebula born? (K.S. Dwarakanath and G. Srinivasan) – Supernovae, their Progenitors and Remnants, eds. G. Srinivasan and V. Radhakrishnan, Indian Academy of Sciencies, Bangalore, p. 97 (1985).

6. On the Nature of Supernova Remnant 0540-69.3 in the Large Magellanic Cloud. (D. Bhattacharya and G. Srinivasan) – Supernovae, their Progenitors and Remnants, eds. G. Srinivasan and V. Radhakrishnan, Indian Academy of Sciences, Bangalore, p. 119 (1985).

7. On the implications of the recently discovered 5 Millisecond Binary Pulsar 1855+09. (D. Bhattacharya and G. Srinivasan) – Cur. Sci. **55,** 327 (1986).

8. Has the Crab Pulsar magnetic field grown after its birth? (D. Bhattacharya and C.S. Shukre) – J. Astrophy. Astron. **6,** 233 (1985)

9. On the meaning of Pulsar Velocities. (V. Radhakrishnan and C.S. Shukre) – Supernovae, their Progenitors and Remnants, eds. G. Srinivasan and V. Radhakrishnan, Indian Academy of Sciences, Bangalore, p. 155 (1985)

10. Observations of Ortho and Para Thio Formaldehyde. (F.F. Gardner, B. Hoglund, C.S. Shukre, A.A. Stark and T.L. Wilson) – Astron. Astrophys. **146,** 303 (1985)

11. The Pulsar Velocities and their Binary Origins. (V. Radhakrishnan, C.S. Shukre) – Astrophy. Space Sci. **118,** 329 (1986) – (invited review in the Proceedings of the III Asian-Pacific Regional Meeting of the IAU, Kyoto, 30th September to 5th October, 1984).

12. A search for Compact Sources in Supernova Remnants. (J.H. van Gorkom, R.D. Ekers, K. Johnston, V. Radhakrishnan and C.J. Salter) – Supernovae, their Progenitors and Remnants, eds. G. Srinivasan and V. Radhakrishnan, Indian Academy of Sciences, Bangalore. P.93(1985)

13. Observation of Highly Excited Radio Recombination lines towards Cassiopeia A. (K.R. Anantharamaiah, W.C. Erickson and V. Radhakrishnan), Nature **315,** 647 (1985).

14. A survey of Recombination line emission from the Galactic Plane at 325 MHz. (K.R. Anantharamaiah) – J. Astrophys. Astron. **6,** 177 (1985).

15. Low density ionized gas in the inner Galaxy – Interpretation of Recombination line observations at 325 MHz (K.R. Anantharamaiah) – J. Astrophys. Astron. **6,** 203 (1985).

16. Separability of the Dirac Equation in a class of perfect fluid spacetimes with local rotational symmetry. (B.R. Iyer and C.V. Vishveshwara) – J. Math. Phys. **26,** 1034 (1985).

17. 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 **25,** 135 (1985).

18. General relativistic aspects of Neutron star models. (B.R. Iyer and C.V. Vishveshwara) – 'A Random Walk through General Relativity and Cosmology', eds. N. Dadhich, J. Krishna Rao, J.V. Narlikar and C.V. Vishveshwara, Wiley Eastern (1985).

19. Dirac Equation in Kasner spacetime with local rotational symmetry. (B.R. Iyer) – Phys. Lett. **112A,** 313 (1985).

20. A. Random Walk in Relativity and Cosmology. eds. N. Dadhich, J. Krishna Rao, J.V. Narlikar and C.V. Vishveshwara (Wiley Eastern 1985).

21. Supernovae, their Progenitors and Remnants. eds. G. Srinivasan and V. Radhakrishnan (Indian Academy of Sciences, 1985).

22. Experimental investigations of Millimeter-Wave Gunn Oscillator circuits in circular waveguides. (R.S. Arora and N.V.G. Sarma) – Int. J. Infrared MM Waves **6,** 951 (1985).

23. Observations of the giant HII region complex at Decameter Wavelengths. (A.A. Deshpande and Ch.V. Sastry) – Astron. Astrophys. **160,** 129 (1986).

24. Molecular interactions and dynamics in Liquid Crystals. (S. Chandrasekhar and N.V. Madhusudana) – A review article in topics in Molecular Interactions, eds. W.J. Orville-Thomas, H. Ratajczak and C.N.R. Rao, Elsevier, p. 139 (1985).

25. Pressure studies on two discotic Liquid Crystals. (V.N. Raja, R. Shashidhar, S. Chandrasekhar, R.E. Boehm and D.E. Martire) – Pramana, **25,** L119 (1985).

26. Evidence for two co-existing nematic phases in mixtures of rod-like and disc-like molecules. (R. Pratibha and N.V. Madhusudana) – Mol. Cryst. Liq. Cryst. Lett. **1,** 111 (1985).

27. Enhanced smectic A mesophase in mixtures of two terminally polar compounds. (V.A. Raghunathan, M.S.R. Urs and N.V. Madhusudana) – Mol. Cryst. Liq. Cryst. **131,** 9 (1985).

28. 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. **129,** 137 (1985).

29. Linear flexo-electrooptic effect in a hybrid aligned nematic Liquid Crystal Cell. (N.V. Madhusudana and G. Durand) – J. Phys. Lett. 46, L195 (1985).

30. Experimental studies on a terminally nitro substituted compound with a latent re-entrant nematic phase. (B.R. Ratna, S. Krishna Prasad and R. Shashidhar) – Mol. Cryst. Liq. Cryst. **124,** 21 (1985).

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