

**RAMAN RESEARCH INSTITUTE  
BANGALORE 560 080**

**ANNUAL REPORT 1989-90**

**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 setup 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 setup 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 and crystalline states. Many organic compounds whose molecules have pronounced shape anisotropy 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 and a half.

The laboratory has been organised to undertake studies of 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.

### THEORETICAL PHYSICS

*Majorana Fermions:* It is known that in the four dimensional Euclidean space there are no Majorana fermions. A generalisation of the Majorana condition was found which enables one to define "Majorana-like fermions" in Euclidean space. It turns out that an extended supersymmetric Yang-Mills (SSYM) theory constructed out of these fermions becomes an ordinary SSYM or a topological SSYM depending on the choice of the definition of the Majorana-like fermions.

*Maximum Entropy Method:* This technique has recently attracted some interest in the Crystallographic Phase Problems. In this context MEM is viewed as a variational way of obtaining a density map which agrees simultaneously with experimental data, as well as with physical constraints based on a priori knowledge of the characteristics of the density function. For two specific "entropy" functions, the topology of the "entropy surface" in the space of unknown phases was investigated numerically. Multiple extrema were found to be the rule. A hybrid algorithm based on the gradient search and incorporating the simulated annealing philosophy was tried on a heavy atom real structure and showed promising results. The implications of these results for potential numerical algorithms is being explored.

*Geometric Phase and Optics:* The problem of synthesizing general polarization transformers with quarterwave and halfwave plates was pursued further and a five-element combination with several useful properties discovered. For example, it allows the practical realization of an exact analogue of an arbitrary hamiltonian acting on a spin 1/2 system. Using this device, phase changes arising in the evolution of spin 1/2 systems under several different kinds of hamiltonian were simulated in a HP laser interferometer system, thus demonstrating the concept of a 'spin 1/2 interferometer' using light beams. Further applications of this concept are being investigated.

It was found that the method of decomposing arbitrary rotations into desirable ones used in the synthesis of polarization retarders can be applied to the problem of 'zero angular momentum turns' involved in phenomena like the turning of cats spacemen and divers, yielding useful insight.

## GENERAL RELATIVITY AND COSMOLOGY

Geodesic motion in higher dimensional Boulware-Deser black hole spacetime was studied and the results compared with those for higher dimensional Schwarzschild geometry. It was found that for both time-like and null geodesics no suitable bound orbit is possible.

The properties of black hole solutions in higher dimensions are of importance in the study of string theories and the quantum theory of gravity. Motivated by this, a study of scalar perturbations of a Kerr-type black hole in higher dimensions has been initiated.

Previous work on approximating the black hole potential by a patchwork of potentials for which the scattering problem may be exactly solved was continued. The effective potential for the Schwarzschild black hole was approximated by two Eckart potentials and a  $r^{-2}$  potential. The solution was obtained in terms of hypergeometric and confluent hypergeometric functions. Matching the solutions yielded an analytic expression for the reflection coefficient. The results thus obtained agreed well with numerical results.

The Relativistic multipole expansion for electromagnetism and linearized gravity in the region outside a spatially compact supported source has been obtained directly within the STF formalism. The results were compared with those obtained earlier using the Debye potential formalism. The slow motion limit of the mass and spin moments agree with those of Thorne at the first Post Newtonian level.

*Gravitational Radiation:* Starting from the first Post Newtonian expressions for radiative spin moments obtained in linearised gravity, the effects of quadratic non-linear terms were taken into account. A prescription to obtain compact support expressions for the moments was introduced and used to study the spin moments. This completes the discussion of the emission of gravitational waves upto order  $(v/c)^3$  beyond the Einstein-Landau-Lifshitz quadrupole formula.

Massless scalar waves in the Witten Bubble spacetime have been investigated. The time like and angular parts of the separated Klein Gordon equation are written in terms of hyperbolic harmonics characterised by a generalised frequency. The radial equation is cast into the Schrodinger form. The above mathematical formulation has been applied to study the scattering problem, the bound states and the corresponding stability criteria. The results confirm the concept of a bubble wall as a perfectly reflecting expanding sphere.

## LIQUID CRYSTALS

Work is continuing as usual on diverse aspects of the multidisciplinary field of liquid crystals. A brief summary of some of the most significant results is given below.

It was mentioned in last year's report that a notable achievement of the laboratory was the prediction and discovery of a biaxial nematic liquid crystal phase in a simple thermotropic system. Since then two other cases of the biaxial nematic phase have been reported, both from Germany. In all three cases the molecule combines the features of the rod and the disc as was predicted here some years ago. Recently, it has been possible to obtain further confirmatory evidence of the biaxial nature of the nematic phase of our compound by X-ray methods. It is well known that the classical uniaxial nematic phase gives rise to two liquid-like X-ray diffraction maxima. In the present case the diffraction pattern consists of three diffuse maxima as would be expected from an orthorhombic fluid.

Theoretical investigations on electrohydrodynamic instabilities in nematic liquid crystals were continued. It has been shown that if the symmetry of the cell is changed by incorporating a small tilt angle of the director at the boundary surfaces, the instability pattern propagates. This mode has been observed by us experimentally.

A simple linearized perturbation theory has been developed to account for electric field induced static modulated structures in nematics. Theoretical calculations are in qualitative agreement with experiment with regard to the threshold, domain size, etc. A rigorous numerical approach has been adopted to study the occurrence of the "stripe phase" above the bend Freedericksz transition in nematics at temperatures close to the smectic A transition. While qualitatively accounting for the experimental observations regarding the domain of existence of the stripe phase, the calculations also indicate the possibility of the occurrence of stripes in certain polymer nematic systems such as the tobacco mosaic virus (TMV).

The influence of a magnetic field on the structure and properties of defects in liquid crystals has been studied theoretically. Interesting new results are predicted in certain situations. For example, a pair of parallel disclination lines in nematics subjected to a magnetic field interacts through a distance-independent force law, which is quite different from the  $1/r$  law of interaction for the field free case. In diamagnetically negative nematics, at high fields, a singular line of strength  $S = +1$  terminates within the body of the material. In the case of smectics, in the field free case, screw dislocations have neither self energy nor do they interact. However, when a field is applied they interact through a  $1/r$  force law; also smectics can exhibit

screw dislocation mediated instabilities. In the case of discotic liquid crystals a  $S = +1$  defect with the columns encircling the disclination line exhibits a structural instability in a magnetic field.

The director configuration in the nematic-nematic co-existence range of mixtures of rod-like and disc-like compounds was investigated. Using these studies, the topological equivalence of point defects of strength  $+1$  and ring defects of strength  $+1/2$  could be demonstrated experimentally.

About forty new ferroelectric liquid crystals have been synthesized. Some of these have fairly low melting points and moderately high value of spontaneous polarisation. A ferroelectric liquid crystal containing a transition metal has also been synthesized. The properties of this class of materials are under investigation.

Although in recent years ferroelectrics have been attracting a great deal of attention, the relationship between molecular structure and physical properties is still not clearly understood. In particular, information about the influence of molecular structure on spontaneous polarisation, response time and rotational viscosity are important from the applications point of view also. In order to study these properties in detail a completely computerised high resolution set up has been constructed. Using this set up experiments have been conducted on four different but structurally related homologous series of compounds synthesised by this laboratory. The results have led to a better understanding of the structure – property relationship.

Several new metal complexes have been prepared and some of them exhibit interesting polymesomorphism. Uniaxial nematic, biaxial nematic, smectic A, smectic C, smectic C\* and smectic E phases have been identified in some of these complexes.

The crystal and molecular structure of a discogen, bis[1,3-di(p-n-decyl-phenyl)propane-1,3-dionato] palladium (II) has been analysed. The sample crystallizes in the triclinic space group  $\bar{P}1$  with one molecule in a unit cell. The crystal structure was solved by direct methods and refined using full matrix least squares procedure. The palladium atom is located at an inversion centre, and the decyl chains are fully extended in an all trans conformation. In the crystal structure, the molecules form a tilted columnar arrangement, each column being surrounded by six others. The crystal molecular structures of other organometallic complexes which form discotic liquid crystals are also being investigated.

In the area of applications, the possibility of lowering the supply voltage requirement without sacrificing the contrast ratio of multiplexed displays by making use of generalised addressing scheme, is being explored.

The Liquid Crystal Laboratory, Raman Research Institute, was recently conferred a unique honour on the occasion of the 900th anniversary celebrations of the University of Bologna, Italy. The laboratory was "awarded a special prize in a world-wide selection of the most distinguished Academic and Scientific Institutions in the world". Professor Chandrasekhar was invited to Bologna to receive the award at a special ceremony held on 9 June 1989. The Laboratory shared this honour with about a

dozen other famous centres which included CERN (Geneva), ICTP (Trieste), the Institut Pasteur (Paris), the Laboratory for Molecular Biology (Cambridge), etc., and about 25 of the world's most renowned Universities.

## ASTRONOMY AND ASTROPHYSICS

*Stellar Dynamics:* The study of the dynamics of oscillating three dimensional collisionless stellar systems (shells, ellipsoids) was continued.

The dynamics of planar systems which are time dependent generalisations of Freeman discs was also investigated. It was found that in the tidal approximation, the distribution function contains ten parameters whose evolution specifies a system of ordinary differential equations. Results were obtained for energy and angular momentum transfer.

*Pulsars:* A novel mechanism was suggested for the underlying physical mechanism responsible for the decay of the magnetic fields of neutron stars. This exploits the fact that both the superconducting protons and the superfluid neutrons in the interior of a magnetised rotating neutron star will be in a *vortex state*. The secular decay of the magnetic field is related to the secular slow down of the neutron star, through a strong interpinning between the vortices in the superconductor and the superfluid. Among many other things, this model is able to explain for the first time why low field neutron stars are almost always in binary systems.

It was pointed out that the fact that the measured mass of the millisecond pulsar PSR 0021-72A in the globular cluster 47 Tucanae is close to the Chandrasekhar mass lends strong support to the possibility that the radiation from pulsars spun up to ultra short periods may be efficient in evaporating the companion. If this is true, then the lifetime of low mass X-ray binaries may be 10 to 100 times smaller than generally believed, alleviating many evolutionary problems concerning the progenitors of millisecond pulsars.

One of the controversial questions in the literature has been whether the spin axis and magnetic axis of pulsars align with age. Using the recently available data on the inclination angles of nearly 150 pulsars it was demonstrated that there is no observational evidence to support the alignment hypothesis.

Effect of limited data length on the estimates of slow intensity fluctuations resulting from refractive effects in the interstellar medium was studied. The results of Monte Carlo simulations indicate that the apparent modulation index reduces if the duration of the observations is not very long compared to the refractive time scale. These computations can be used to estimate the true modulation index given the measured values.

A new observational programme for detailed studies of pulsar radiation at meter wave length using the Ooty radio telescope has been started in collaboration with the TIFR group. The development of appropriate software to enable the acquisition, and on line processing of pulsar data, has been completed. Many important modifications

were made to an available digital correlation receiver to suit pulsar observations, and the new receiver system has been successfully tested.

The design and construction of suitable instrumentation for pulsar searches and observations with the Giant Meter Wavelength Telescope (being built near Pune) is in progress.

*Radio Emission from the Galactic Centre:* Using the Very Large Array radio telescope, a  $2^\circ \times 2^\circ$  wide field around the galactic centre was imaged at 332 MHz with angular resolution ranging from 15" to 100". The images show all the unique features associated with the Galactic center, including the linear filaments, and several long "thread-like" features. Many linear filaments in this region, although non-thermal, show positive spectral index ( $\alpha = +0.3$ ). This may indicate in situ production of relativistic electrons on time scales of less than  $10^4$  years. The orientation of the "threads" and the filaments suggest the presence of a strong poloidal magnetic field in the central 100 pc of the Galaxy.

*Carbon recombination lines towards Cas A:* These were investigated over the frequency range 34-325 MHz, corresponding to transitions in the quantum number range  $n = 578$  to  $n = 272$ . The lines appear in absorption at low frequencies ( $< 150$  MHz) and in emission at high frequencies ( $> 200$  MHz) as expected. In order to determine the origin of these lines, optical depth maps of  $C272\alpha$  (325 MHz) were obtained using the VLA with a resolution of  $\sim 1.5'$ , and compared with those of 21 cm HI and 6 cm  $H_2CO$  absorptions. The recombination line maps are similar to 21 cm HI absorption maps suggesting that the lines originate in warm (50-100K) HI clouds with an electron density  $\sim 0.05 \text{ cm}^{-3}$ . However, the variation of the intensity of the line with frequency is better fit by a model in which the lines originate in cold (15-20K) regions with electron densities  $\sim 0.3 \text{ cm}^{-3}$ . This dilemma is yet to be resolved and further observations near 600 MHz are planned.

*The warm ionized interstellar medium:* A hydrogen recombination line near 145 MHz was detected in the direction of the galactic centre. The strength of this line not only clarifies the nature of a nearby HII region, but also puts strong constraints on the properties (such as the temperature and the filling factor) of the diffuse warm ionized gas.

*Recombination lines from the Star Burst Galaxy NGC 253:* NGC253 was observed in  $H166\alpha$ ,  $H110\alpha$  and  $H92\alpha$  recombination lines using the VLA. Lines were detected in the nuclear region, which also dominates the continuum emission. The location of the  $H166\alpha$  line emitting region is different from that of the other two. It is suggested that the higher frequency lines arise in high density and high emission measure gas, and the lower frequency line in a region of low density and lower emission measure. The observed velocity distribution indicates unusual motions of the ionized gas near the nucleus.

*Orion B:* The spatial and velocity distribution of the narrow  $H166\alpha$  and  $C166\alpha$  lines in Orion B, observed with an angular resolution of  $\sim 45''$ , were found to be similar.

This strongly suggests that the CII and  $H^\circ$  regions, which are adjacent to the HII region, are spatially coincident. The heavy element line ( $X166\infty$ ) has a different distribution and its identification as due to sulfur, based on its velocity, is not certain. A new  $H166\infty$  feature was detected at a velocity of  $+48\text{kms}^{-1}$  in the south-western portion of Orion B.

## Millimeterwave Astronomy

### *10.4 meter telescope*

*Observations:* Very Long Baseline Interferometric (VLBI) observations of strong water vapour maser sources at 22 GHz have been carried out using our 10.4m telescope, the 22m telescope in Crimea, USSR and the 100m telescope in Bonn, West Germany – during September, 1989. These observations were only intended for testing the RRI system and the problem areas were identified and rectified. Main observations are planned for May, 1990.

Further observations on Mira variables by SiO maser emission in the  $V = 1, J = 2 \rightarrow 1$  transition at 86 GHz were continued during the first half of the observing session which had to be cut short by bad weather in the initial period. During this session 50 more sources were observed. Besides supporting the earlier conclusions about the dependence of maser emission on the spectral type of the star, it was found that the maser luminosity varies inversely with the amplitude of variation of the visual magnitude. Interpretation of these results is in progress.

$^{12}\text{CO}$  and  $^{13}\text{CO}$  observations were also undertaken during the last three weeks of the observing session on Herbig Haro objects and Lynds' clouds. Under a collaborative programme with the Infrared Astronomy Group of the Tata Institute of Fundamental Research, Bombay, two regions W31 and G351.6-1.3 were selected for mapping in  $^{12}\text{CO}$ . Limited observations indicated that the spectra are complex and show a wealth of information. It is hoped to undertake detailed mapping during the next observing session.

Another observational project, using the 10.4m telescope in conjunction with the newly developed 400 MHz bandwidth acousto-optic spectrometer, was the search at 104 GHz, for  $\text{SO}_2$  molecules in the atmosphere of Venus. New calibration techniques for observation of broad lines in the presence of strong continuum radiation were tested. The data is under reduction.

*Receiver and Component Development:* A dual polarisation cooled receiver operating in the band 86 to 115 GHz was fabricated and tested in the laboratory. Initial tests on the telescope revealed several minor problems which have been solved. Further tests will be carried out on the telescope. Four more GaAs FET amplifiers operating at the intermediate frequency of 1.45 GHz with an instantaneous bandwidth of 400 MHz have been fabricated, tested and optimised for cryogenic operation at an ambient temperature of 20K. Two more Schottky barrier diode mixer blocks for the frequency range 86 to 115 GHz have also been fabricated and optimised for cryogenically cooled operation. A tunable Gunn oscillator for the frequency range 80 to 114 GHz has also been fabricated and tested. It yields enough power for operation of cryogenically cooled mixers even at the higher frequency end which is the difficult region.

A cooled 22 GHz receiver for observations of galactic water vapour maser sources has been assembled using a circular polariser ahead of a HEMT amplifier obtained on loan from the National Radio Astronomy Observatory, USA. In order to use this receiver at the nasmyth focus of the 10.4 metre radio telescope, a 2.3 metre long conical horn with an aperture dia of 26 cm was designed and fabricated. The system was primarily intended for observations in the Very Long Baseline Interferometric (VLBI) mode between Crimea in the USSR, Bonn in West Germany and Bangalore. For these observations, two Hydrogen Maser frequency standards and a Mark II VLBI data recording system have been supplied by the Space Research Institute, Moscow, USSR.

A sensitive CCD camera system was designed based on a Philips camera module of 0.05 lux sensitivity and was used along with a Questar telescope for optical pointing of the 10.4 m telescope. A pointing correction model was obtained using this system by observing stars upto the sixth magnitude.

*Data acquisition:* The computer which controls the 10.4 metre telescope was enhanced by incorporating a faster CPU system and additional memory so that both the control operations and preprocessing of the on line data could be performed in real time. The software for controlling the telescope and acquiring data from the receiver was suitably modified.

A microcomputer based on Motorola 68000 processor was developed and was used in the current observing session to act as slave computer to acquire data from both the 64 MHz filter bank and 40 MHz Acousto-optic spectrometer (AOS). Stability tests of all the back-end spectrometers were carried out with an Allan variance test procedure.

### **Decameterwave Astronomy**

*All sky map at 34.5 MHz:* Further analysis was done on the recently completed sky survey at 34.5 MHz. The survey was found to be confusion limited at 5 Jy. The maps which have a resolution of  $26' \times 42'$  at zenith, were smoothed to a resolution of  $2^\circ$  to highlight the large angular scale features. Several well known Galactic loops and spurs were identified in the 34.5 MHz maps and their spectra were obtained by comparing with already existing 408 MHz observations. All the spectra indicated the non-thermal nature of the loops and spurs. The well known warp of the galactic plane was also clearly seen in the 34.5 MHz map.

Absorption of the galactic background emission due to the foreground thermal gas in the Galaxy was seen clearly in the inner Galaxy. There was no sign of such absorption in the direction of the outer Galaxy. Several discrete absorption regions were detected in the present survey. The nature of the gas causing these absorptions was studied. There is strong evidence to suggest that this gas is fairly nearby ( $\leq 3$  kpc), extended (20-100 pc) and of low density ( $10 \text{ electrons cm}^{-3}$ ). Most of the low velocity ( $\leq 50$  kms)  $\text{H}166\alpha$  and  $\text{H}272\alpha$  galactic ridge recombination lines can be easily accounted for as arising in this nearby gas. This interpretation has thrown considerable doubt on the core-envelope picture of HII regions.

*Solar Observations:* The study of type III solar bursts using the broad band array in Gauribidanur (operating at the range 35 MHz to 65 MHz) is being continued. The frequency drifts with time of Solar bursts are being studied using a 1760-channel acousto-optic spectrometer. Such studies will help in understanding the movement of charged particles in the Solar corona.

*Long baseline interferometry:* The construction of two receiver systems for acquiring data from two stations has been completed. Data will be recorded at each of the two stations, and the correlation will be performed off-line. Initial tests with a 5 kilometer baseline have yielded satisfactory results.

### **MAURITIUS TELESCOPE PROJECT**

An interferometer using 32 helices with a baseline of 700 meters, operating at a frequency of 150 MHz is operational at Gauribidanur. After finalising the sub-assemblies used at this prototype system, equipment necessary for a similar set-up at Mauritius has been fabricated. Installation of this system has just started there.

Part of the equipment from the Clark Lake Radio Observatory (CLRO), which includes the Front-end post amplifiers and Two-stage mixers has been fully tested and reconfigured to suit the requirement of the Mauritius synthesis array.

Design and development of an on-line 1024 channel data acquisition and monitoring system for the CLRO correlators has been taken up, using a PC-AT as a basis.

Fabrication of first stage low-noise amplifiers and the cabling network for combining the antennas into groups is also in full progress.

#### *Optical interferometry*

During the past year a small group has been investigating the possibility of building a long base line optical interferometer. Before doing a feasibility study, it was proposed to gain first hand experience by setting up a Michelson interferometer in the campus. A pilot version of this with two 10 cm mirrors with a separation of 1.5 m has been set up. A suitable tracking system has been designed and testing is in progress. The design of an optical delay line with a resolution of 1 micron has been undertaken. With a view to selecting a suitable site for the full-scale interferometer, some 'seeing' measurements were done at Gauribidanur, Nandi Hills, Kavalur, etc., using a 15 cm telescope, a CCD camera, and frame grabbing techniques.

Advanced training in research is being offered to the following teachers from other organisations under the UGC Faculty Improvement Programme:

<b>Name</b>	<b>Topic of Study</b>
P.R. Maheshwara Murthy Govt. Science College Bangalore	Electric and Magnetic Field effects in Liquid Crystals
H.P. Padmini The National College Bangalore	Some physical studies on Liquid crystals
Sharanabasava M. Khened Laxmi Venkatesh Desai College, Raichur	Experimental studies of Phase Transitions in Ferroelectric Liquid Crystals
<b>Ph. D</b>	
<i>Awarded</i>	
<b>Name</b>	<b>Topic of Study</b>
K.S. Dwarakanath	A synthesis study of the radio sky at decameter wavelengths
S.N. Karbelkar	Statistical methods of phase reconstruction of speckle interferometry
R. Pratibha	Investigations on Liquid Crystalline Mixtures.
V.A. Raghunathan	Investigations on Some Field Induced Instabilities in Nematic Liquid Crystals
S. Sridhar	Some exact analytic models of time dependent collisionless stellar systems
<i>Submitted</i>	
C. Nagabhushan	Experimental Studies of Phase Dielectric Properties of Liquid Crystals
V.N. Raja	High Pressure and X-ray Studies of Liquid Crystals
S. Somasekhara	Experimental Studies of Phase Diagrams of Liquid Crystals

**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 at Annexure-I (Page 19).

**Conferences/Seminars and Meetings**

The staff of the Institute visited various institutions in India and abroad and attended conferences and presented papers. In addition, 74 lectures were given by them elsewhere.

**Gandhi Memorial Lecture**

The Gandhi Memorial Lecture for 1989 was given by Swami Ranganathananda on "The uniqueness of man in the Upanishads and modern science", on 2nd October, 1989.

**Colloquia**

The scientists of the Institute and visiting scientists both from within and outside the country gave 22 colloquia at the Institute on different topics during the year.

**Journal Club Meetings**

Fourteen meetings were held during the year. Preprints, as well recently published papers, dealing with topics of great current interest were reviewed in the meetings. A new 'Weekly Science Meeting' has been started during the year. In the 'Radio Astronomy Meetings' series each meeting is devoted to an informal presentation and discussion of a preselected topic; the 'Weekly Science Meetings' are without a fixed agenda and topics covering the work being carried on at the Institute, topics of current interest, etc., are discussed very informally.

**In-house Discussion Meeting**

An in-house discussion meeting was held on 7th April 1990 on the current research activities of all groups in 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 twenty eight new books were added to the library during the year. The total book collection now is 17,100. The library presently subscribes to one hundred and forty six periodicals and has a collection of 20,762 bound volumes. Of the periodicals subscribed, 21 are received by airmail and IAU circulars are received via electronic mail.

**General**

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

	(Rs. in lakhs)
PLAN-RECURRING	125.07
PLAN-NON RECURRING	186.92
NON PLAN – RECURRING	52.00
Total	<u>363.99</u>

**STAFF**

The scientific and technical staff of the Institute is given below. Additions during the year are marked with an asterisk.

V. Radhakrishnan

K.R. Anantharamaiah  
 P.G. Ananthasubramanian  
 Antony Joseph  
 Arvind K. Shenai\*  
 T.K. Babu  
 R. Bhandari  
 D. Bhattacharya†  
 S. Chandrasekhar  
 K. Chandrasekhara  
 S. Chanthrasekharan  
 Chitra M. Gokhale  
 A.A. Deshpande  
 K.S. Dwarakanath  
 R. Ganesan  
 B.R. Iyer#  
 G. Jayakumar  
 N. Jayaprakash  
 P.A. Johnson  
 U.D. Kini  
 S. Krishna  
 S. Krishnan+  
 S. Krishnaprasad  
 V. Lakshminarayanan  
 Lashmy P. Usha  
 N.V. Madhusudana  
 M.O. Modgekar@@  
 Mohd. Ateequlla  
 R. Nandakumar  
 H. Narayanan\*  
 B.V. Nataraja  
 R. Nityananda  
 P. Rajasekhar\*  
 P.S. Ram Kumar  
 P.N. Ramachandra  
 C. Ramachandra Rao

**Joint Astronomy Programme**

Somnath Bhardwaj  
 Nimesh Patel  
 B. Ramesh  
 T.K. Sridharan  
 Umesh Salian

S. Ramaseshan  
 P. Ramachandran\*  
 K. Ramesh Kumar  
 G.S. Ranganath  
 B.R. Ratna%  
 N. Ravi Sankar\*  
 D.K. Ravindra  
 T.S. Ravishankar  
 G. Rengarajan  
 T.N. Ruckmongathan@  
 B.K. Sadashiva  
 J. Samuel%%  
 G. Sarabagopalan  
 N.V.G. Sarma  
 P.S. Sasi Kumar  
 M. Seethalakshmi\*  
 M. Selavamani  
 Shaji P.  
 K. Shanthi\*  
 S. Shivkumar Nair  
 C.S. Shukre  
 K. Smiles Mascarenhas  
 P.S. Somasundaram  
 G. Srinivasan  
 K. Subramanya  
 M.R. Subramanyam  
 H. Subramonyam  
 K. Sukumaran  
 K.A. Suresh  
 V. Suresh Rao  
 N. Udaya Shankar  
 Umesh S. Nayak\*  
 C.V. Vishveshwara++  
 Vivek Dhawan\*  
 M. Vivekanand##

**Resignations**

V.K. Anuradha  
 Jayanthi Ramachandran  
 T. Ramachandran  
 R. Vijayalakshmi

**Consultant Physicians**

M.R. Baliga  
A.R. Pai

**Post-Doctoral Fellows**

R. Pratibha  
V.A. Raghunathan  
V.N. Raja  
Rani P. Rao  
Ravi Kulkarni\*  
Sai K. Iyer  
Senthil Kumar\*  
Subash Karbelkar

**Research Fellows**

Archana Ghode  
Geetha G. Nair  
V. Rajeswari  
D.S. Shankar Rao  
G.B. Sivakumar  
P.B. Sunil Kumar  
L. Uma Devi  
K. Usha  
Veena Prasad

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† On leave with the Centre for High Energy Astrophysics, University of Amsterdam, The Netherlands.

# On deputation with the Institut des Hautes Etudes Scientifiques, France.

+ On deputation with the National Aeronautical Laboratory, Bangalore.

@@ On deputation with the Australia Telescope National Facility, Sydney, Australia.

% On leave with Georgetown University, Washintgon DC, USA.

@ On leave with N.V. Philips, The Netherlands.

%% On leave with Syracuse University, New York, USA.

++ On deputation as Director, Bangalore Planetarium, Bangalore.

## On leave with the U.S. Naval Observatory, Mt. Wilson, California, USA.

## LIST OF VISITORS

P.A.G. Scheuer Cavendish Laboratory Cambridge, U.K.	March 3-April 7, 1989
L. Kogan V. Vassili S. Gordeev Space Research Institute The USSR Academy of Science Moscow USSR	May 23-June 17, 1990
Paul J. Wiita Georgia State University Atlanta, USA.	June 23, 1989
A. Ashtekar Syracuse University Syracuse, N.Y., USA	August 8-13, 1989
T.P. Singh Tata Institute of Fundamental Research Bombay	August 8-16, 1989
T. Prabhu American College Madurai	September 7-9, 1989 January 8-11, 1990
G. Barbero Politecnico Torino Torino, Italy	Sept. 12-Oct. 15, 1989
L. Taneja National Physical Laboratory New Delhi	September 14-15, 1989
J. Hogbom Stockholm Observatory Stockholm, Sweden	Nov. 11 '89-Feb. 4, 1990
L. Mestel University of Sussex Brighton, U.K.	December 3-10, 1989
V.V. Zheleznyakov Inst. of Applied Physics Gorky, USSR.	December 6-11, 1989

- R.S. Arora & G.S. Uppal  
National Physical Laboratory  
New Delhi. December 7-9, 1989
- P. Dierich  
Observatoire de Meudon  
Paris, France December 7-12, 1989
- D.L. Bata & A. Buka  
Central Research Inst. for Physics  
Budapest, Hungary December 10-17, 1989
- W.T. Ford  
Oklahoma State University  
USA. December 13-15, 1989
- R.I. Kozhuharov  
Institute of Electronics  
Bulgaria December 15-20, 1989
- D. Malin  
Anglo-Australian Observatory  
Sydney, Australia December 15-31, 1989
- S. Chandrasekhar  
University of Chicago  
Chicago, Illinois, USA. December 13, 1989
- D.L. Lambert  
University of Texas  
Austin, Texas, USA. December 22, 1989
- J. Anandan  
Uni. of South Carolina  
Columbia, USA. January 12-15, 1990
- D. Gross  
Princeton University  
Princeton, USA January 16-19, 1990
- L. Matveyenko  
M. Aleksei  
M. Alexander  
Space Research Institute  
The USSR Academy of Science  
Moscow, USSR Jan. 19-Feb. 2, 1990

A.I. Mashoshin  
Inst. of Macromolecular Compounds  
Leningrad, USSR

Jan. 27-Feb. 9, 1990

R.W. Wilson  
AT & T Bell Laboratories  
Holmdel, N.J., USA

Jan. 29-Feb. 4, 1990

T. Padmanabhan  
Tata Institute of Fundamental Research  
Bombay

March 9-23, 1990

M. Bose  
Bose Institute  
Calcutta

March 12-18, 1990

E.G. Ponyatovsky  
Inst. of Solid State Physics  
Chernogolovka, USSR.

March 22-29, 1990

## (ANNEXURE 1)

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1. "Geometric Phases in Optics" (R. Bhandari), Proc. of *DAE Solid State Physics Symposium*, Bhopal, **31A**, (1988)
2. "Quantum to classical Transition - A Perspective" (R. Bhandari), Proc. of Meeting on the Philosophical Foundations of Quantum Mechanics, New Delhi, (1988) in *Quantum Queries*, ed. Ranjit Nair, World Scientific, (1989).
3. "Why the Barker Sequence Bit Length Does Not Exceed Thirteen?" (B.V. Rao and A.A. Deshpande), *IETE (Lett)*, **34**, 461 (1989).
4. "The Decameter-wave Radio Telescope at Gauribidanur: Antenna Arrays and Control System" (A.A. Deshpande, R.K. Shevagaonkar and Ch. V. Sastry), *IETE*, **35(6)**, 342 (1989).
5. "Undamped Oscillations of Collisionless Stellar Systems, spheres, Spheroids and Discs, (S. Sridhar and R. Nityananda), *J. Astrophys. Astron.*, **10**, 279 (1989).
6. "The Vaidya Solution in Higher Dimensions" (B.R. Iyer and C.V. Vishveshwara), *Pramana*, **32**, 749 (1989).
7. "Black hole thermodynamics and Hawking radiation" (B.R. Iyer), in *Gravitation, Gauge Theories and the Early Universe*, Kluwer Academic Publishers, Netherlands (1989).
8. "Quantum field theory in curved spacetime-canonical quantisation" (B.R. Iyer), in *Gravitation, Gauge Theories and the Early Universe*, Kluwer Academic Publishers, Netherlands (1989).
9. "Scalar Waves in the Boulware-Deser Black Hole Geometries" (B.R. Iyer, Sai Iyer and C.V. Vishveshwara), *Class. Quant., Grav.*, **6**, 1627 (1989).
10. "Compact Objects, Killing Vectors, Symmetries and Gravitational Collapse" (B.R. Iyer), in Proc. of *Silver Jubilee Institute on General Relativity and Cosmology*, Mysore, ed. A. Maheshwari, 6.1-6.53 (1989).
11. "Introduction to Black Holes" (C.V. Vishveshwara), in *Gravitation, Gauge Theories and the Early Universe*, eds. B.R. Iyer, N. Mukunda and C.V. Vishveshwara, Kluwer Academic Publishers (1989).
12. "Introduction to Relativistic Cosmology" (C.V. Vishveshwara), in *Gravitation, Gauge Theories and the Early Universe*, eds. B.R. Iyer, N. Mukunda and C.V. Vishveshwara, Kluwer Academic Publishers (1989).
13. "Geometry and the Universe" (C.V. Vishveshwara), in *Cosmic Perspectives*, eds. S.K. Biswas, D.C.V. Mallik and C.V. Vishveshwara, Cambridge University Press (1989).

14. "Black Holes" (C.V. Vishveshwara), in *Proc. of the Silver Jubilee Institute on General Relativity and Cosmology*, Mysore, ed. A. Maheshwari (1989).
15. "Comment on Evolving Geometric Phase and its Dynamical manifestation as a Frequency Shift - An Optical Experiment" (R. Bhandari), *Phys. Rev. Lett.*, **63**, 1020 (1989).
16. "Synthesis of General Polarization Transformers - A Geometric Phase Approach" (R. Bhandari), *Phys. Lett.*, **A138**, 469 (1989).
17. "Are You Really Seeing Right-Circular-Light in your Experiment?" (R. Bhandari), *Applied Optics*, **28**, 3272 (1989).
18. "Berry's Phase and the Pancharatnam Angle - Some Recent Observations" (R. Bhandari), *Bull. Cal. Math. Soc.*, **81**, 496 (1989).
19. "Stimulated Emission of Carbon Recombination Lines from Cold Clouds in the Direction of Cassiopeia A" (H.E. Payne, K.R. Anantharamaiah and W.C. Erickson), *Astrophys. J.*, **341**, 890 (1989).
20. "Radio Studies of the Galactic Centre I. The Saggitarius A Complex" (A. Pedlar, K.R. Anantharamaiah, R.D. Ekers, W.M. Goss, J.H. Van Gorkom, U.J. Schwarz and Jun-Hui Zhao), *Astrophys. J.*, **342**, 769 (1989).
21. "Search for Localized Sources of Non Cosmological Deuterium near the Galactic Centre" (D.A. Lubowich, K.R. Anantharamaiah and J.M. Pasachoff), *Astrophys. J.*, **345**, 770 (1989).
22. "Refractive Radio Scintillations in the Solar Wind" (Ramesh Narayan, K.R. Anantharamaiah, and T.J. Cornwell), *Mon. Not. R. astr. Soc.*, **241**, 403 (1989).
23. "Propagation of Coherence in Scattering - an Experiment Using Interplanetary Scintillations" (T.J. Cornwell, K.R. Anantharamaiah and Ramesh Narayan), *J. Opt. Soc. of America A*, **6**, 977 (1989).
24. "Noise in images of very bright sources" (K.R. Anantharamaiah, R.D. Ekers, V. Radhakrishnan, T.J. Cornwell and W.M. Goss), in *Synthesis Imaging in Radio Astronomy*, eds. R.A. Perley, F.R. Schwab and A.H. Bridle, Astr. Soc., of Pacific, San Francisco, USA (1989).
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26. "Black Hole Normal Modes: A WKB Approach IV, Kerr Black Hole" (Edward Seidel and Sai Iyer), *Phys. Rev. D*, **41**, 374 (1990)
27. "A Spin 1/2 Interferometer Using Light Beams" (R. Bhandari), *Phys. Lett. A*, **143**, 170 (1990).

28. "Detection of Parity of a Binary Star in Triple Correlation Speckle Interferometry" (S.N. Karbelkar), *Astrophys. J.*, **351**, 334 (1990).
29. "On the Lifetime of Low Mass X-ray Binaries" (G. Srinivasan and D. Bhattacharya), *Current Science*, **58**, 953 (1989).
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31. "Pulsars: Their Origin and Evolution" (G. Srinivasan), *The Astronomy and Astrophysics Review*, **1**, 209 (1989).
32. "Towards an empirical theory of pulsar emission. V. On the circular polarization in pulsar radiation" (V. Radhakrishnan and Joanna M. Rankin), *Astrophys. J.*, **352**, 258 (1990).
33. "X-Ray Binaries" (D. Bhattacharya), in *Proc. of 23rd ESLAB Symposium on X-ray Binaries*, Bologna, Italy (1989).
34. "The Decay of Neutron Star Magnetic Fields" (D. Bhattacharya), in *Proc. of the 23rd ESLAB Symp., Part I: X-ray Binaries*, eds. J. Hunt and B. Battrick, ESA SP-296, 179-184 (1989).
35. "The Association Between Pulsars and Supernova Remnants" (G. Srinivasan), in *Proc. of NATO ASI Series on Neutron Stars and Their Birth Events*, ed. W. Kundt, Kluwer Academic Publishers (1990).
36. "Millisecond Pulsars: A New Population of Gamma Rays Sources?" (G. Srinivasan), *Adv. Space Res.*, **10**, 167 (1990).
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38. "Thermal, Field Growth in Neutron Stars: An Alternative to 'Injection'?" (D. Bhattacharya), in *Proc. of NATO ASI Series on Neutron Stars and Their Birth Events*, ed. W. Kundt, Kluwer Academic Publishers, 133-137 (1990).
39. "A Novel Mechanism for the Decay of Neutron Star Magnetic Fields" (G. Srinivasan, D. Bhattacharya, A.G. Muslimov and A.I. Tsygan), *Current Science*, **59**, 31-38 (1990).
40. "High Angular Resolution Optical Interferometry, (N. Udaya Shankar), *Science Focus* **1**, 8 (1989).
41. "Discotic liquid crystals" (S. Chandrasekhar and G.S. Ranganath), *Reports on Progress in Physics*, **53**, 57 (1990).

42. "X-ray study of a thermotropic biaxial nematic liquid crystal" (S. Chandrasekhar, V.N. Raja and B.K. Sadashiva), *Mol. Cryst. Liq. Cryst. Lett.*, **7**, 65 (1990).
43. "Elastic constants of a biaxial nematic liquid crystal" (U.D. Kini and S. Chandrasekhar), *Physica* **A156**, 364, (1989) - Special issue in honour of Prof. J. Trappaeniers, Van der Waal's Laboratory, Amsterdam.
44. "Viscosity coefficients of a biaxial nematic liquid crystal, (U.D. Kini and S. Chandrasekhar), *Mol. Cryst. Liq. Cryst.*, **179**, 27 (1990).
45. "Possibility of a deformed ground state in free standing nematic films (G. Barbero, N.V. Madhusudana and C. Oldano) – *J. Physique* **50**, 2263 (1989).
46. "On a theoretical analysis of the influence of non-uniformity of the order parameter on the surface energy in nematics" (G. Barbero and N.V. Madhusudana), *Liquid Crystals* **7**, 299 (1990).
47. "A simple molecular theory of double reentrance exhibited by highly polar compounds" (N.V. Madhusudana and Jyotsna Rajan), *Liquid Crystals* **7**, 31 (1990).
48. "On the occurrence of point and ring defects in the nematic-nematic coexistence range of binary mixtures of rod like and disc like mesogens" (R. Pratibha and N.V. Madhusudana), *Mol. Cryst. Liq. Cryst.*, **178**, 167 (1990).
49. "Influence of flexoelectricity on electrohydrodynamic instabilities in nematics" (N.V. Madhusudana and V.A. Raghunathan) *Liquid Crystals* **5**, 1789 (1989).
50. "An experimental investigation of electromechanical coupling in Cholesteric Liquid Crystals" (N.V. Madhusudana and R. Pratibha), *Liquid Crystals* **6**, 1827 (1989).
51. "Experimental determination of the elastic constant  $k^{13}$  of a nematic liquid crystal" (N.V. Madhusudana and R. Pratibha), *Mol. Cryst. Liq. Cryst.*, **179**, 207 (1989).
52. "A New threshold flexoelectric instability in nematic liquid crystals," (V.A. Raghunathan and N.V. Madhusudana), *Mol. Cryst. Liq. Cryst. Lett.*, **6**, 103 (1989).
53. "Ferronematics in magnetic and electric fields" (P.B. Sunil Kumar and G.S. Ranganath), *Mol. Cryst. Liq. Cryst.*, **177**, 123 (1989).
54. "On certain liquid crystal defects in a magnetic field" (P.B. Sunil Kumar and G.S. Ranganath), *Mol. Cryst. Liq. Cryst.*, **177**, 131 (1989).
55. "Pressure studies on phase transitions in 4-alkoxyphenyl-4'-nitrobenzoyloxybenzoates" (V.N. Raja, R. Shashidhar, B.R. Ratna, G. Heppke and Ch. Bahr), *Phys. Rev. A (Rapid Commun.)* **39**, 4341 (1989).

56. "Experimental studies on a terminally non-polar reentrant nematogenic mixture" (B.R. Ratna, R. Shashidhar, V.N. Raja, C. Nagabhushan, S. Chandrasekhar, G. Pelzl, S. Diele, I. Latif and D. Demus), *Mol. Cryst. Liq. Cryst.*, **167**, 233 (1989).
57. "Crystal and molecular structure of the discogen bis[1,3-di-(p-n-octyloxy-phenyl) propane-1,3-dionato]copper (II)" (K. Usha and Kalyani Vijayan), *Mol. Cryst. Liq. Cryst.*, **174**, 39, (1989).
58. "Electric field induced static modulated structures in nematics" (U.D. Kini), *J. Physique* **51**, 529 (1990).
59. "Static periodic distortion above the bend Freedericksz transition in nematics" (U.D. Kini), *Liquid Crystals* **7**, 185 (1990).
60. "Mesomorphic properties of a homologous series of aryl  $\beta$ -diketones and a few related derivatives" (B.K. Sadashiva, P. Rani Rao and B.S. Srikanta), *Mol. Cryst. Liq. Cryst.*, **168**, 103 (1989).
61. "Pattern growth during the liquid expanded -liquid condensed phase transition in langmuir monolayers of myristic acid" (K.A. Suresh, J. Nittmann and F. Rondelez), *Progress in Colloid and Polymer Science*, **79**, 184 (1989).
62. "Piezooptics of crystals" (G.S. Ranganath and S. Ramaseshan), *Defence Science J.*, **40**, 1 (1990).

**BOOKS PUBLISHED**

1. "Gravitation, Gauge Theories and the Early Universe", eds. B.R. Iyer, N. Mukunda and C.V. Vishveshwara, Kluwer Academic Press (1989).
2. "Cosmic Perspectives" eds S.K. Biswas, D.C.V. Mallik and C.V. Vishveshwara, Cambridge University Press (1989).

**PAPERS IN PRESS**

1. "Geodesics in Boulware-Deser Black Hole Spacetime" (Biplab Bhawal), Physical Review D (1990).
2. "Scalar Waves in the Witten Bubble Spacetime" (Biplab Bhawal and C.V. Vishveshwara), Physical Review D (1990).
3. "A Synthesis Map of the Sky at 34.5 MHz" (K.S. Dwarkanath and N. Udaya Shankar), J. Astrophys. Astron. (1990).
4. "A Modified Algorithm for CLEANing Wide Field Maps with Extended Structures" (K.S. Dwarkanath, A.A. Deshpande and N. Udaya Shankar), J. Astrophys. Astron. (1990).
5. "An Algorithm for Calculating Poisson Noise on Image Intensity Correlations" (S.N. Karbelkar), J. Opt. Soc. Am. (1990)
6. "Focal Plane Analysis of the Knox Thompson Algorithm in Speckle Interferometry" (S.N. Karbelkar), J. Astrophys. Astron. (1990).
7. "Optimum Weighting function in Bispectral Analysis in Speckle Interferometry. Binary Star Parity Detection" (S.N. Karbelkar), J. Astrophys. Astron. (1990).
8. "A Wide Field  $\lambda$  90 cm Image Around the Galactic Centre - Evidence for a Poloidal Magnetic Field" (K.R. Anantharamaiah and A. Pedlar), Proc. of IAU Symp. No. 140, Galactic and Intergalactic Magnetic Fields, ed. R. Beck, Kluwer Academic Publishers, Dordrecht (1990).
9. "Limits on the Temperature and Filling Factor of the Warm Ionized Medium towards the Galactic Centre" (K.R. Anantharamaiah, H.E. Payne, D. Bhattacharya), Proc. of IAU Colloquium 125, Radio Recombination Lines - 25 Years of Investigations, ed. M.A. Gordon and R.L. Sorochenko, Kluwer Academic Press, Dordrecht (1990).
10. "VLA Observations of Recombination Lines from the Starburst Galaxy NGC 253" (K.R. Anantharamaiah, W.M. Goss, and P.E. Deudney), Proc. of IAU Colloquium 125, Radio Recombination Lines - 25 years of Investigations, eds. M.A. Gordon and R.L. Sorochenko, Kluwer Academic Press, Dordrecht (1990).

11. "Interferometric Observations of HII, CII and  $H^{\circ}$  Regions in Orion B" (K.R. Anantharamaiah, W.M. Goss and P.E. Deudney), Proc. of IAU Colloquium 125, Radio Recombination Lines – 25 years of Investigations, eds. M.A. Gordon and R.L. Sorochenko, Kluwer Academic Press, Dordrecht (1990).
12. "Interferometric Observations of Carbon Recombination Lines towards Cassiopeia A at 332 MHz" (H.E. Payne, K.R. Anantharamaiah and W.C. Erickson), Proc. of IAU colloquium 125, Radio Recombination Lines – 25 years of Investigations, eds. M.A. Gordon and R.L. Sorochenko, Kluwer Academic Press, Dordrecht (1990).
13. "Search for Protoclusters at  $z = 3.3$ " (Ravi Subramanyan and K.R. Anantharamaiah), J. Astrophys. Astron. (1990).
14. "Geometric Phase Experiments - A unified description" (R. Bhandari), Proc. Raman Centenary Symp. 'Waves and Symmetry', Bangalore, Dec. 1988. eds. G. Srinivasan and S. Ramaseshan.
15. "Geometric Phase Light Propagation and Polarization Optics" (R. Bhandari), Proc. of Workshop on Quantum Optics, Panaji (1989).
16. "Spinors and Classical Light Waves (R. Bhandari), Analogies in Optics and Micro-Electronics, eds. D. Lenstra and W. van Haeringen, Kluwer Academic Press (1990).
17. "Geometric Phases in Physics" (R. Bhandari), Horizons of Physics, II ed. N. Nath, Wiley Eastern Publishers (1990).
18. "Experimental Study of Spin 1/2 Phases by Laser Interferometry - In Search of Quantum Reality" (R. Bhandari), Proc. of Conference on Conceptual Foundations of Quantum Theory, ed. Ranjit Nair, (1990).
19. "True Dependent Dynamics of a Planar Galaxy Model" (S. Sridhar and R. Nityananda), Mon. Not. Royal astron. Soc. (1990).
20. "Pulsars and Binary Stars" (C.S. Shukre), Proc. of the Workshop on Binary Stars and Stellar Atmospheres, Hyderabad (1990).
21. "Gamma-Rays from Millisecond Pulsars" (D. Bhattacharya and G. Srinivasan), J. Astrophys. Astron. 11 (1990).
22. "On the Morphology of Supernova Remnants with Pulsars" (D. Bhattacharya), J. Astrophys. Astron. 11 (1990).
23. "Statistics of Refractive Pulsar Scintillations: Effect of Limited Data Length" (A.A. Deshpande and R. Nityananda), J. Astrophys. Astron. (1990).
24. "Estimating Slow Intensity Fluctuations from Short Data Stretches - the Case of Pulsar Scintillations" (A.A. Deshpande and R. Nityananda), Proc. of URSI/IAU Symp. on 'Radio Astronomical Seeing', Beijing (1989).

25. "Optical observations of close binaries with the Mark III Stellar Interferometer" (X.P. Pan, M. Shao, M.M. Colavita, J. Armstrong, D. Mozukewich, R.S. Simon, C. Denisson, M. Vivekanand and K.J. Johnston), to appear in Proc. SPIE Meeting, Tucson, 1990.
26. "Gravitational Lenses" (R. Nityananda), Proc. Raman Centenary Symp. 'Waves and Symmetry', Bangalore, Dec., 1988, eds. G. Srinivasan and S. Ramaseshan.
27. "Accuracy of Binary Separations from Interferometric Data" (M. Vivekanand), Astr. J., (1990).
28. "The Biaxial nematic liquid crystal" (S. Chandrasekhar), Festschrift in honour of Sir Charles Frank (Adam Hilger, Bristol).
29. "Liquid crystals: Physics and applications" (S. Chandrasekhar), Shriram Institute Publication, Delhi.
30. "Charged twist walls in nematic Liquid Crystals" (N.V. Madhusudana, J.F. Paliarne, Ph.Martinot-Lagarde and G. Durand), Solitons in liquid crystals, Ed. Lin Lei and J. Prost (Springer Verlag).
31. "Defects in liquid crystals" (G.S. Ranganath), Proc. Raman Centenary Symp. 'Waves and Symmetry', Bangalore, Dec., 1988, eds. G. Srinivasan and S. Ramaseshan.
32. "Ferroelectric liquid crystals derived from trans-p-n-alkoxycinnamic acids" (B. Shivkumar, B.K. Sadashiva, S. Krishna Prasad and S.M. Khened), Ferroelectrics.
33. "Spontaneous Polarization and Rotational Viscosity Measurements on Ferroelectric Liquid Crystals Derived from trans-p-n-alkoxycinnamic Acids" (S.K. Prasad, S.M.Khened, S. Chandrasekhar, B. Shivkumar and B.K. Sadashiva). Mol. Cryst. Liq. Cryst.
34. "Thermotropic mesomorphism in a series of copper  $\beta$ -diketones and their ligands, (Veena Prasad and B.K. Sadashiva), Mol. Cryst, Liq. Cryst.
35. "Crystal and molecular structure of the discogen bis[1,3-di(p-n-decyl phenyl)propane 1,3-dionato]palladium(II)" (K. Usha, Kalyani Vijayan, B.K. Sadashiva and P. Rani Rao), Mol. Cryst. Liq. Cryst.