RAMAN RESEARCH INSTITUTE
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RAMAN RESEARCH INSTITUTE

Bangalore

Annual Report 1991-92

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 3^0 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 being used for the study of these radiations.

In addition, the Institute has theoretical research programmes in many areas of Astrophysics like Pulsars, Supernova Remnants, the interstellar medium and Galaxies.

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 two decades.

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.

3. Theoretical Physics

The two main areas of theoretical physics pursued at the Institute are gravitation and optics. Einstein's general relativity is of great importance in the astrophysics of compact objects like neutron stars and black holes and also in the study of the universe as a whole. While the theory has a beautiful geometrical structure, it is a challenge to analyse the behaviour of the gravitational field and its coupling to matter and other fields because of the nonlinear equations involved. Many conceptual questions and aspects of formal structure continue to be fruitfully investigated more than seventy years after the theory came into being. Over the years, the work at the Institute has ranged

over topics such as perturbations, the exploitation of symmetries, rotation and the parallel with magnetic fields, a new Lagrangian formulation, gravitational radiation, etc. One of the challenges in the field is to make contact with quantum theory and some work has emerged in this area.

Coming to optics, two of the main interests have been in propagation in periodic media (like some liquid crystals) and polarisation phenomena, including the now well known geometric phase. There is a pleasing continuity with work in the fifties at the Institute on the optics of crystals and minerals. At the same time, introduction of a more modern viewpoint and techniques, brings about connections with other areas such as quantum theory, differential geometry, etc. In addition, astrophysics throws up a whole range of interesting optical problems in areas like gravitational lenses, scintillation and quantum effects in radiation and detection, making the study of optics in a broad sense particularly appropriate to this Institute.

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

THEORETICAL PHYSICS

Fermat's principle for the propagation of light in general space times has recently been formulated by Kovner and Perlick. A simple proof of this formulation was obtained. One application of this principle shows that in a recently proposed nongeodesic equation for light propagation, differences in arrival time for opposite circular polarisations vanish to lowest order in the coupling.

Scalar field quantisation in stationary (non-static) spacetimes was investigated. The Hamiltonian structure of Bianchi (homogenous anisotropic) cosmological models was clarified leading to some new results.

The multipole analysis for electromagnetism and linearised gravity was reformulated in terms of irreducible Cartesian tensors. The earlier work on post Newtonian gravitational wave emission was extended to include the spin moments.

Investigation of higher dimensional spacetimes and the separability of the Dirac equation in spacetimes with local rotational symmetry were continued.

In the area of polarisation optics, phase jumps occurring as the parameters of an apparatus are varied were investigated. A useful generalisation of Martinelli's set up for achieving "polarisation reversal" analogous to phase conjugation was proposed.

Optical diffraction in cholesteric solition lattices was investigated with particular emphasis on the nature of standing waves in Bragg Bands. In adition, the optical diffraction in the phase grating mode of ferrocholesteric solition lattices was worked out taking into account grain seggregation. An extensive review of the geometric theory of diffraction was undertaken and some new results are obtained in specific geometries.

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.

Recent experiments conducted in our laboratory and elsewhere show that in binary mixtures of smectogenic and non-mesomorphic compounds the smectic A liquid crystal separates from the isotropic phase in the form of highly elongated cylindrical structures. We have made detailed studies on such a system to show that these structures which have a large surface to volume ratio are stabilised by a negative radial concentration gradient of the non-mesmomorphic component. If the concentration of the latter is allowed to increase in the isotropic phase the cylindrical structure develops an undulation instability. It is argued that the concentration gradient leads to a spontaneous curvature of the smectic layers, making it necessary to include a term linear in curvature in the elastic energy of such systems. Using this idea, a simple theoretical model has been developed to qualitatively account for all the observations.

Continuing our investigastions on electrohydrodynamic instabilities in nematic liquid crystals, during the past year we have theoretically analysed the instability of a homogeneously aligned nematic subjected to transverse AC electric field applied parallel to the boundary plates. The threshold field and wavevector are calculated using the Galerkin approximation. The resulting phase diagram has many similarities with that of the standard geometry. However, unlike in the latter, in the present geometry two distinct solutions are possible in both the conduction and dielectric regimes. We have also conducted experimental investigations in this geometry. There is a broad agreement between the observed and theoretical phase diagrams.

A cholesteric liquid crystal gets transformed into a soliton lattice of twist walls in a magnetic field acting normal to its twist axis. At a threshold field this lattice degenerates into the nematic state. Optical Bragg reflections from such periodic structures were investigated. In many ways these Bragg reflections are different from their counterparts in classical cholesterics. Firstly we get many higher orders of reflections. In contrast cholesterics exhibit only one primary Bragg reflection. Secondly each Bragg band exhibits three distinct sub-bands separated by regions of no reflection. At fields close to the threshold, generally, higher orders will be more intense than the primary reflection. The electromagnetic nature of the standing waves in the Bragg bands were also worked out. We found some interesting features. In undistorted cholesterics these standing waves are linearly polarised with the electric vector parallel to

the magnetic vector with a relative phase difference of 90°. In the soliton lattice the nature of the standing waves in the three regions of each Bragg band are entirely different, as regards their polarisation, angle between electric and magnetic fields and their relative phases.

The optical diffraction pattern for linearly polarised light incident normal to the twist axis (phase grating mode) of a ferrocholesteric (with magnetisation M parallel to the local director) was studied. The intrinsic rotation of the magnetic grains considerably alters the diffraction pattern as compared to that of a normal cholesteric. Extra orders in addition to those that occur in a normal cholesteric were found. These extra orders, in comparison to usual orders, have very different polarisation properties. In ferrocholesterics, diffraction occurs for all azimuth angles of the incident light unlike a normal cholesteric in which diffraction is absent for linearly polarised incident light polarized along the twist axis. Calculations indicate that the effects of Faraday rotation are significant and are experimentally realisable.

The effect of electric fields and boundary conditions on the occurrence of bistability in nematics and cholesterics with positive diamagnetic anisotropy has been investigated when a single angle description of the director field is valid. When a weak magnetic field is applied to an aligned nematic sample, the resulting distortion changes continuously with the field direction. When the field is strong, however, there can occur discontinuous changes in the deformation at two values of the field tilt which form the edges of a bistable region. An additional electric field can profoundly influence the existence or otherwise of bistability. The nature of the distortion also depends on the magnitude of anchoring strengths at the sample boundaries. Scaling analysis (which holds in the rigid anchoring limit) shows that for a given reduced field the bistability width should be independent of the sample thickness. In the case of cholesterics the equilibrium pitch determines different aspects of the bistability.

Four different methods have been employed to determine the rotational viscosity γ_ϕ associated with the molecular motion around the cone about the layer normal in the smectic C* phase. The values are in good agreement with each other. In addition, the effect of chain length on γ_ϕ and also on the soft mode viscosity γ_s has been studied. The results suggest that the activation energy associated with these motions is basically controlled by the rigid core and not by the chain length of the molecule.

Precise layer spacing, polarisation and dielectric measurements have been carried out on two compounds exhibiting tilted fluid and hexatic phases. In one of the materials, there is a first order transition between these phases, while in

the other there is a continuous evolution from one phase to the other without a phase transition. The thermal variation of the tilt order is found to be reflected in the temperature dependence of polarisation and dielectric constants.

Although the physical properties of ferroelectric liquid crystals have been well studied at room pressure, there have been hardly any detailed studies on the effect of high pressure on these properties. Detailed investigations of the pressure dependence of different properties of these materials were undertaken. For this purpose, suitable modifications were made to the existing optical high pressure set up in order to perform electrical measurements. The spontaneous polarisation, coercive field, dielectric constant, rotational viscosity, etc., have been measured. The pressure-temperature phase diagrams have also been mapped involving different kinds of hexatic phases, the most significant outcome of which is the observation of a new kind of multicritical point.

The crystal structure analysis of a palladium complex, viz., bis[1,3-di(p-n-octylphenyl)propane-1,3-dionato]palladium(II) has been completed. As there is only one molecule in the unit cell and the space group is $P1$, the palladium atom has to lie on an inversion centre. Placing the palladium atom at $0,0,0$, a difference electron density map was computed and the rest of the non-hydrogen atoms were located. The structure was refined to $R = 0.057$ by the full matrix least squares procedure. The structure was found to be isomorphous with the prismatic form of the copper complex bis[1,3-di(p-n-octylphenyl)propane-1,3-dionato]copper(II). The crystal structure of bis[1,3-di(p-n-octylphenyl)propane-1,3-dionato]nickel(II) was solved by the isomorphous replacement method using coordinates from the palladium complex structure. Refinement of the structure is in progress.

In continuation of our effort on the synthesis of metallomesogenic compounds, we have recently made oxovanadium(IV) and Platinum(II) complexes. The ligands as well as the metal complexes exhibit nematic, smectic A and C phases, the exact phase behaviour depending on the chain length. Some of the oxovanadium complexes exhibit a very wide range of enantiotropic nematic phase. Many new Schiff bases formed from substituted resorcilaldehydes, 4[4'-alkylbenzoyloxy]aniline and the corresponding copper complexes have been found to exhibit the smectic A phase.

Development of supertwist nematic liquid crystal displays which have electrooptic characteristics with a very sharp threshold were undertaken and some preliminary work on the development of polymer dispersed liquid crystal displays was also started. In the electrochemistry laboratory, a large number of

connectors were coated with copper for the Mauritius Radio Telescope Project. Many parts of the receiver systems of the Millimeter Wave project were also electroplated with various metals. Efforts are going on for developing highly stable electroless copper and nickel baths for plating on nonconducting surfaces. To develop chemically modified carbon electrodes for trace analytical determinations of > .1 *ppm* of copper and mercury the Institute is collaborating with the Chemistry Group of the National Aeronautical Laboratory. A study of corrosion of reinforcing steel in concrete using electrochemical techniques is also being carried out. A novel electrical sensitivity measurement technique has been developed for concrete specimens.

ASTRONOMY AND ASTROPHYSICS

Pulsars

(a) *Vela Pulsar Timing*: The variations in the measured flux from the Vela pulsar were studied and were found to be correlated with the *differences* in the (apparent) pulse arrival time at two frequencies (635 and 950 MHz). The flux variations at the two frequencies are also correlated (60% correlation) with each other. These variations are most likely *intrinsic* to the pulsar, and their correlation with differences in the arrival times at the two frequencies can be explained by slow variations in the contribution from the leading-edge component of the pulse.

(b) *Fluctuation spectra of Pulsars*: The Pulsar PSR 1055-52 in which a significant correlation had been noticed between the fluctuations in the main and the interpulse energy was studied in detail. This information along with the polarization data suggests that the regions contributing to the correlated fluctuations are at roughly the same distance (within the measurement uncertainties) from the magnetic axis of the pulsar.

(c) A search was conducted using the Parkes radio-telescope in Australia to look for a second pulsar in the Vela-X region. These observations lasting about 8 hours were made at 950 MHz with a bandwidth of 20 MHz. The processing of the data is in progress.

(d) Analysis of the timing data (on about 40 pulsars) obtained over 4 years using the 26 m dish at Mount Pleasant, Hobart has been undertaken. This has already yielded improved parameters for about a dozen pulsars.

(e) *Field decay in isolated radio pulsars*: The statistical evidence for the decay of the magnetic fields of isolated radio pulsars was reinvestigated by generating synthetic populations using a Monte Carlo method, subjecting them to survey

selection effects and comparing the properties of the resulting population with those of the observed population of pulsars. The conclusion was that there is no evidence for any significant field decay during the active lifetime of isolated radio pulsars.

(f) *Pulsar search with the Ooty Radio Telescope*: Detailed Monte-Carlo simulations to evaluate the probability of discovering pulsars in different regions of the sky in the proposed observations with the Ooty Radio Telescope were carried out. Based on these results two specific areas of the sky have been selected for a deep survey using the Pulsar Receiver being built for the Giant Meter Wave Telescope (GMRT). These observations are expected to start in late 1992.

(g) *The birthplace of Pulsars*: Recent proper motion measurements of pulsars show that some of them with relatively short characteristic ages are moving towards the plane of the galaxy. This confirms the earlier predictions that a sizeable fraction of pulsars must, in fact, be born at relatively large distances from the galactic plane. A plausible explanation for the origin of these pulsars is that they were born in binaries which had moved away from the plane of the galaxy in the time between the first and second supernova explosions. When such a binary disrupts two pulsars will be released. A detailed investigation has been undertaken to ascertain whether massive binary systems can acquire sufficient velocities during the first supernova explosion to move several hundred parsecs away from their original birth place. Preliminary results indicate that this may, indeed, be possible.

ROSAT Sources: An investigation of the nature of the supersoft x-ray sources discovered by ROSAT was undertaken. It was concluded that these objects are likely to be heavily accreting white dwarfs rather than neutron stars.

Spin Evolution of Neutron Stars: The problem of the spin evolution of neutron stars accreting from stellar winds was investigated for the case when the incoming flow of matter has an oscillating nature, such as found in some recent hydrodynamic simulations. The results show that spin-down of neutron stars may be more efficient in an oscillating flow than in a steady flow.

Radio Astronomy

(a) *Carbon Recombination Lines towards Cas A*: The interpretation of the entire body of low-frequency recombination line data towards Cas A was examined in the light of a new model introduced by Gulyovev and Nefedo in 1989. In this model, the boundary condition for calculating the high quantum number level populations are modified to take into account two effects, namely, that the population must become zero above a critical quantum number n_q due to blending together of discrete levels, and, secondly, the statistical weights of the high quantum number levels must decrease because of the increased probability of ionization by free electrons. It was found that the model gives a good overall fit to the data, and provides the right pressure and thermal balance for the clouds.

Recombination lines of carbon near 700 MHz were observed from this cloud and the measured integrated line strengths are consistent with the model mentioned above.

(b) *Radio Counterpart of the "Great Annihilator" near the Galactic Centre*: Recently the Einstein X-ray source 1E1740.7-2942 was identified by satellite observations as the source responsible for the time variable positron-annihilation line observed during the late 1970s. The Very Large Array (VLA) was used to search for radio continuum and positronium recombination lines from this source. No lines were detected (presumably because the source was in a low-state), but the presence of a variable continuum source coincident with the x-ray source was established.

(c) *Extragalactic Radio Recombination Lines*: Further searches for radio recombination lines from four extragalactic sources were conducted using the VLA. Lines were detected at 8 GHz from two galaxies ARP 220 and NGC 2146 at the level of 300 microjansky/beam. These, and the earlier search in which lines were detected in two other galaxies, indicate that radio recombination lines may be detectable in many more external galaxies.

(d) *Neutral Hydrogen Observation*: A two-element interferometer using the 26m and 14m dishes at Mount Pleasant in Hobart has been configured to study HI emission with a resolution of few arcminutes. Preliminary tests have been successfully completed.

(e) *Point sources in the 34.5 MHz survey*: The all-sky survey at 34.5 MHz done with the Gauribidanur telescope detected about 5000 sources. Given the resolution of the survey ($\sim 30'$) they appear as "point sources" in the survey. The sources within $\pm 10^{o}$ of the galactic plane were compared with their counterparts in the higher frequency catalogues such as the Molonglo

408 MHz survey, and the Texas 365 MHz survey. This comparison revealed that 10 sources in the Gauribidanur survey (in two regions of $30^{\circ} \times 20^{\circ}$ size) did not have counterparts in any of the higher frequency surveys.

Using the VLA, these 10 sources were observed simultaneously in both the L-band and the P-band. This enabled the estimation of both their sizes, as well as their spectral indices. Preliminary results show that 6 of these sources are 'doubles' with a separation of about 1 arcminute. What was unusual was that their spectral indices were ~ -1.8 between the L and P bands, suggesting that they may be high redshift galaxies. Further observations of these sources using the C-array configuration of the VLA are planned.

(f) *Abell Clusters*: The low frequency survey at 34.5 MHz detected radio emission from several of the Abell clusters. This information was used in conjunction with higher frequency observations of these clusters to look for steep spectrum emission which may be indicative of halos around galaxies, or emission from intra-cluster gas. Based on this study some candidate clusters were chosen for further high resolution observations using the VLA, and these observations are now in progress.

(g) *Low-frequency observations with the VLA*: Recently, the 75 MHz system has become operational at the VLA, and this raises the possibility of many exciting observations. The biggest problem is, of course, the ionosphere which renders the usual mapping techniques impossible at these frequencies for the long baselines which the VLA can provide. Therefore new mapping techniques are required. One possible approach is to observe a given source in both the P-band (333 MHz) and the 75 MHz band *simultaneously*, and "transfer" the ionospheric phase from the P-band to the 75 MHz band. To try out this idea, some strong sources were observed at 75 MHz using the B-array of the VLA. The analysis of the data shows that the idea of "phase transfer" basically works. However, there are clear indications of 'drifts' of phase in the 75 MHz band, and these need to be understood thoroughly before further observations can be planned.

(h)*Cometary Globules*: The analysis and interpretation of the ^{12}CO observations of the cometary globules in the Gum Nebula have been completed leading to the following conclusions:

1. The system of cometary globules is expanding at 15kms; the 'expansion age' is 5 Million years. The most likely cause for the expansion is the 'rocket effect'.

2. Velocity gradients are present along the tails of the globules. The 'tail stretching age' estimated from these gradients is 3 Million years.

The rough agreement between these ages suggests a common origin for the expansion and the formation of the tails. Presence of young stars of similar ages in some of the globules points to star formation triggered by the same cause.

The globule CG22 in the Gum Nebula was mapped partially in $^{13}CO(J = 2 \rightarrow 1)$ using the Swedish-ESO Submillimeter Telescope in Chile. This data, complemented by observations from Bangalore, is to be used for studying the structure of CG22.

(i)*High Latitude Molecular Clouds*: The detailed map of the dark cloud L1616 in the $J = 1 \rightarrow 0$ line of ^{12}CO and ^{13}CO has been completed, and the analysis of the data is in progress. A preliminary study of the map shows that the cloud is influenced by stellar winds from the Orion belt stars. It has the morphology of a "cometary cloud" similar to others found in the same region. The map also clearly shows outflow of molecular gas from the vicinity of one of the stars located near the edge of the cloud facing the Orion belt stars. Since such an outflow is generally associated with very young stars it may imply that the star mentioned above may have recently formed due to the compression of the cloud by the winds from the nearby stars.

While trying to understand the location of this cloud quite far from the galactic plane (~185 pc) it was noticed that many dark clouds, as well as some of the well known giant molecular cloud complexes, are also quite far from the plane. Moreover, at least so far as their distribution in the sky is concerned, they seem to lie in the plane of the well known Gould's belt – a system of bright young stars forming an expanding ring. This raises the question as to whether the molecular clouds mentioned above are, indeed, part of this expanding ring system. Towards clarifying this, single point spectra for about 400 small dark clouds have been obtained. Also, an estimate of the distances to a subset of these clouds from associated reflection nebulosities is also being made.

INSTRUMENTATION FOR RADIO ASTRONOMY

MILLIMETERWAVE LABORATORY

A cryogenically cooled L-band amplifier using Pseudomorphic HEMTs of AVANTEK make has been developed. It has a broadband performance and the measured input noise temperature in the band 1.0 to 1.6 GHz is $(5 \pm 3)K$ at an

ambient temperature of 20K. A cooled attenuator method of measuring very low noise temperatures (<10K) has been developed and the errors of measurement have been evaluated. A tunable (85-115 GHz) Gunn Oscillator in a 90-140 GHz waveguide mount has been fabricated and tested as a student project. The aim, not yet realised, is to improve the output power in the 110-115 GHz frequency range.

22 GHz HEMT Amplifier Development: This is being carried out at the Chalmers University of Technology in Goteborg, Sweden. Single stage amplifiers using the Chalmers Pseudomorphic HEMTs operating at 22 GHz and 43 GHz have been designed using the Hewlet Packard Microwave Design System, and built on alumina substrates. The main results are summarized below:

1. The maximum stable gain was 18 dB at 20 GHz (using HEMTs with $f_{max} = 200GHz$).
2. Gain of 15 dB at 22 GHz and 6 dB at 43 GHz (using HEMTs with $f_{max} = 100GHz$).
3. Although not optimized for low noise, the noise figure was 3.2 dB at 20 GHz.

The design of two-stage amplifiers using different types of HEMTs, including commercially available one, have been completed and the construction is in progress. The preliminary results are as follows:

1. The Fujitsu HEMTs gave a gain of 16 dB and a noise figure (NF) of 2 dB at 22 GHz.
2. InP HEMTs gave a gain of 20 dB and NF of 2.3 dB at 22 GHz. The NF was 3 dB over 4 GHz bandwidth.
3. PHEMTs gave a gain of less than 20 dB and NF of about 2.5 dB.

With cryogenic cooling the noise performance will improve. This is being attempted presently.

Holographic mapping: Holography measurements to determine the surface irregularities of the 10.4 m dish were undertaken during the summer of 1991. A transmitter at a frequency of 93 GHz was located on the TV tower which is about a kilometer away from the telescope and the data was taken in 16×16 grid with 1 arc minute spacing. A phase reference was provided from the horizontal channel of the dual polarisation receiver. A preliminary analysis of the data has shown an r.m.s. panel-to-panel deviation of 200 microns. To confirm

this result, further data acquisition and analysis is planned for the summer of 1992.

21cm RECEIVER FOR GMRT:

Test Receiver: A test receiver and a broad-band horn which were developed have undergone several tests and debugging. The data acquisition software and various other low-level routines have been written and are being tried out. The mechanical packaging of the receiver is in progress and it will be taken to the GMRT site during June 1992 for testing the first of the GMRT antennas which should be up and operational by then.

Front-end Receivers for the full array: A scaled version (10X) of the proposed broad-band corrugated horn was made and is being tested in the 10-14 GHz band. Discussions are in progress with the Communications Division of ISRO Satellite Centre (ISAC) for alternate designs to develop wide-band dual-mode feeds and septum polarizers for the 1-1.5 GHz band.

A variety of wide-band low-loss quadrature hybrids were prototyped. The most promising of these had under 0.2 dB loss and good circular polarization over a 350 MHz band. The VSWR was also good over 1-1.5 GHz.

A prototype low-noise amplifier using GaAs FETS & HEMTS has been developed. It has enough bandwidth and an average noise temperature of 55K within the band of interest (1-1.5 GHz). Efforts are continuing to reduce this noise temperature further.

GMRT PULSAR PROJECT

The construction of the first phase of the pulsar receiver for GMRT is nearing completion. Prototype modules have been developed and successfully tested for:

1. The Array Combiner designed to combine signals from four dishes (1 polarization and 1 sideband, to begin with)
2. The Input Selector (to select between phased or incoherent method of combining the array outputs and to preintegrate the data)
3. The Search Preprocessor (to calculate and subtract the running mean from the data, to put in gain calibration, and perform bit-packing before interfacing with the data acquisition system)
4. The Data Acquisition System (to acquire data through a PC-AT and record it on to an exabyte recorder at a rate of 64Kbytes/sec).

All the prototype modules have built-in menu-driven diagnostics and fault isolation software, as well as suitable hardware test jigs. After subjecting these prototypes to various tests the final modules are now being developed and tested. The integrated system is expected to be ready within the next few months. Soon after that, it is proposed to use this receiver with the Ooty Radio Telescope for a period of, say, four months to conduct a deep search for pulsars at high galactic latitudes.

MAURITIUS RADIO TELESCOPE PROJECT

This is a joint project between the University of Mauritius, the Raman Research Institute and the Indian Institute of Astrophysics. The telescope designed to operate at 150 MHz and located at Bras d'eau, Mauritius (latitude 20° S) is a T-array with a 2 km long East-West arm and a 1 km long North-South arm. The East-West array has 1000 helices with an inter-element spacing of 2 metres, and the North-South array has 128 helices mounted on 32 moveable trolleys on a 1 km long railway track. The helices have been mounted with a 20° tilt towards the South to enable detailed mapping of the southern galactic plane.

The installation of the helices is in the final stages with all the helices in the East-West array installed, and the reflector meshes laid for more than half of them. VSWR measurements on the helices are in progress, the early measurements yielding encouraging results.

The front-end of the Digital Correlator Receiver has been fully tested at Bangalore and already shipped to Mauritius. This includes the front-end amplifiers, the 48-channel second IF-stage, and the quantizer. The 1024-Channel Correlator is presently being tested, and will be shipped to Mauritius during the next few weeks.

The design of a Recirculator System to increase the sky coverage has been completed. When this is installed the primary beam of the helix ($\sim 60^{o}$) can be covered in a single observational schedule. The development of software to analyse the data is well under control. This includes programmes to handle data files, to calibrate the instrumental phase, and to analyse the visibilities obtained from a set of non-coplanar baselines. Algorithms to deconvolve the raw maps using concepts such as multi-resolution CLEAN, and Wavelet Transforms are being developed.

The formal inauguration of the Telescope is planned for early November 1992.

OPTICAL ASTRONOMY : HIGH RESOLUTION TECHNIQUES

1.Rotational Shear Interferometry: Near diffraction-limited imaging of stellar objects using the 90″ Vainu Bappu Telescope at Kavalur is being attempted. The technique being used is pupil-plane interferometry using a 180° Rotational Shear Interferometer. The Rotational Shear Interferometer was fabricated at the Indian Institute of Astrophysics by the Optics Group there. The necessary optics and mounting were designed, and observations using the instrument were carried out at the 90″ telescope on several sessions jointly by the Raman Research Institute and the Indian Institute of Astrophysics. The first results (interferograms) have been obtained and initial data analysis is being done. Further improvement in data quality is required before serious analysis can be attempted. The instrument is being currently modified towards this end. Observations with the 40″ telescope at the Kavalur Observatory have also been scheduled. Other high resolution techniques (especially speckle interferometry) and methods of data analysis are being studied. A simple speckle camera has been made and initial testing is in progress.

2. Siderostat Control System: A Siderostat Control System is under development. A 2-axes drive using precision DC motors has been built and integrated to a computer. Tests show that the motor response is repeatable and linear to within an arcsecond accuracy; the residual non-linearity has been modelled. The software necessary to track a star is under development. When completed, such Sideorstat Control Systems can control the primary mirrors of a Michelson interferometer.

3. Auto Guider: An Auto Guider which can compensate for image motion caused by atmospheric turbulence is being built. It consists of a 14x14 CCD sensor, a fast-readout logic, and a centroid estimator based on digital signal processing system. The testing of the prototype is presently in progress. When completed it can provide auto-tracking for, say, the 90″ telescope at Kavalur tracking stars as faint as 7th magnitude.

GAURIBIDANUR TELESCOPE

A spectrometer capable of observing eight recombination lines simultaneously from the low frequency T-array at Gauribidanur has now been installed. Development of necessary software to carry out observations using this instrument is in progress.

COMPUTERS

Two SUN workstations, a HP laserjet printer and a UNIX based 386 machine for electronic mail have been added to the computing facilities.

A plan has been made to build a Local Area Network which will interconnect the existing VA 11/780, PDP 11/84, the SUN workstations and several PCs located in different parts of the Institute. Some of the required hardware and software components have been acquired.

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

Name	*Topic of Study*
H.P. Padmini The National College Bangalore	Some Physical Studies on liquid crystals
P.R.Maheshwara Murthy Govt. Science College Bangalore	Electric and magnetic field effects in liquid crystals
Sharanabasava M.Khened Laxmi Venkatesh Desai College, Raichur	Experimental studies of phase transitions in ferroelectric liquid crystals

Ph.D.

Awarded

Name	*Topic of Study*
A. Ratnakar	Trends in Scientific Communication in India - A study of Indian Scientific journals especially Physics and Astronomy journals
Nimesh A. Patel	A study of circumstellar silicon monoxide Masers

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 27).

Conferences/Seminars and Meetings

The staff of the Institute visited various institutions in India and abroad and attended conferences and presented papers. In addition, 63 lectures were given by them elsewhere.

Gandhi Memorial Lecture

The Gandhi Memorial Lecture for 1991 was given by Mr. R.K. Laxman on "Verbal caricature of our leaders, our people and our times ", on 2nd October, 1991.

Colloquia

The scientists of the Institute and visiting scientists both from within and outside the country gave 37 colloquia at the Institute on different topics during the year.

Journal Club Meetings

Sixteen meetings were held during the year. Preprints, as well as recently published papers, dealing with topics of great current interest were reviewed in the meetings and, as in the past, several Radio Astronomy meetings were held.

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

The library has a total collection of 18,034 books and 21,342 bound volumes of periodicals. 300 new books were added to the library this year. Forty seven of them were received gratis. It subscribes to 140 periodicals of which 21 are received by air mail. Based on a readership survey, subscription to 12 journals were discontinued and four journals added. International Astronomical Union

circulars are now being received via electronic mail.
The library is a member of the Astrolib Network (a network of Astronomy and Astrophysics Librarians from all over the world operated from the National Radio Astronomy Observatory Library at Charlottesville, U.S.A.) and exchanges information pertaining to astronomy and astrophysics literature with the group via e-mail. It also takes part in the Bangalore Special Libraries Group activities.

Others

A paper entitled "Mesogenic-diketones and metallonematogens" by Archana Ghode and B.K.Sadashiva presented during the Third Annual General Meeting of the Materials Research Society of India, Bangalore, February 9-11, 1992, was awarded a prize for the best poster.

General

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

	Rs. in lakhs
PLAN - RECURRING AND NON-RECURRING	236.00
NON PLAN - RECURRING	180.00
Total	416.00

STAFF

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

V. Radhakrishnan *(Director)*

K. Ananth*
K.R. Anantharamaiah
P.G. Ananthasubramanian
Antony Joseph
P.R. Amuda
S. Arun Prasad*
T.K. Babu
R. Bhandari
D. Bhattacharya
K. Chandrasekhara
S. Chanthrasekharan
Chitra M. Gokhale
A.A. Deshpande†
V. Devadas*
K.S. Dwarakanath††
M.S. Ezhilarasi*
R. Ganesan&
K. Gurukiran
B.R. Iyer
P.A. Johnson
S. Kathyayini*
U.D. Kini
S. Krishnan+
S. Krishnaprasad
V. Lakshminarayanan
Lakshmy P. Usha
Madhu Girimaji*
R. Madhu Krishnan*
N.V. Madhusudana
M. O. Modgekar
Mohd. Ateequlla
I. Mohd. Imtiyaz*
H.N. Nagaraja
R. Nandakumar
H. Narayanan
R. Nityananda
T. Prabhu
E. Palanichamy*
E. Prameela
K.B. Raghavendra Rao
N.G. Raghavendra Rao*
A. Raghunathan
P. Rajasekhar
P.S. Ram Kumar
P.N. Ramachandra
C. Ramachandra Rao
P. Ramadurai*
P. Ramachandran
K. Ramesh Kumar
S. Ramaseshan
G.S.Ranganath
Ravi Kulkarni*
N. Ravi Sankar
D.K. Ravindra%%
T.S. Ravishankar
G. Rengarajan
T.N. Ruckmongathan@
B.K. Sadashiva
P.B. Sadik*
J. Samuel
G. Sarabagopalan
N.V.G. Sarma
S. Sarala*
P.S. Sasi Kumar

Staff contd.

M. Seethalakshmi
M. Selvamani
P. Shaji
C.S. Shukre
Y. Sindhu*
K. Smiles Mascarenhas
G. Srinivasan
K. Subramanya
M.R. Subramanyam
H. Subramonyam
K. Sukumaran
K.A. Suresh
V. Suresh Rao
S. Swarna*
M.J. Tulajaram*
N. Udaya Shankar
V. Vijay
C.V. Vishveshwara
Vivek Dhawan
M. Vivekanand

Research Fellows

N. Andal*
Archana Ghode
Geetha Basappa
Geetha Nair
C. Indrani*
Jayadev Rajagopal
P.R. Maheshwara Murthy[1]
Nimisha G. Kantharia[2]
H.R. Padmini[1]
R. Ramachandran
B. Ramesh[2]
D.S. Shankar Rao
Sharanabasava M. Khened[1]
T.P. Sharavanan
G.B. Sivakumar
Somnath Bhardwaj[2]
T.K. Sridharan[2]
Sudha Srivastava*
P.B. Sunil Kumar
K. Usha
Veena Prasad
Vijay S. Chickaramane*
Yuvaraj Sah

Post-Doctoral Fellows

R. Pratibha
L. Uma Devi
V.N. Raja

Visiting Professors/Scientists

Indira Rajagopalan
N. Kumar
A. Krishnan
S.R. Rajagopalan

Consultant Physicians

M.R. Baliga
A.R. Pai

Staff contd.

Resignations

K. Ananth
K. Aravind Shenai
G. Jayakumar
S. Kalyanakrishnan
S. Krishna Das
B.V. Nataraja
V.A. Raghunathan
R. Sarada
P. Sivakumar
S. Shivakumaran Nair
Umesh S. Nayak
V.K. Valsan

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† On leave with the University of Tasmania, Hobart, Australia.

†† On leave with the National Radio Astronomy Observatory, Socorro, New Mexico, U.S.A.

& On leave with Chalmers University of Technology, Gothenburg, Sweden.

+ On deputation with the National Aeronautical Laboratory, Bangalore.

%% On leave with National Radio Astronomy Observatory, Charlottesville, VA, U.S.A.

@ On leave with Asahi Glass Electronic Products R&D Centre, Japan.

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1 Under the UGC Faculty Improvement Programme.

2 Under the Joint Astronomy Programme at the Indian Institute of Science.

LIST OF VISITORS

Joanna M. Rankin Department of Physics University of Vermont Burlington, Vermont, U.S.A.	28 December 1990 - 27 June 1991
Claes-Ingvar Björnsson Stockholm Observatory Stockholm, Sweden	20 March - 20 April 1991
C.R. Subrahmanya National Centre for Radio Astrophysics Tata Institute of Fundamental Research Ganeshkhind, Pune	18-19 April 1991 28 October - 1 Nov. 1991
V.K. Kapahi National Centre for Radio Astrophysics Tata Institute of Fundamental Research Ganeshkhind, Pune	22-29 April 1991
D.N. Bhowmick Bombay University Bombay	26 May - 16 June 1992
Richard Dodson York, England	11 June 1991 - 30 June 1992
J.N. Desai Physical Research Laboratory Ahmedabad	14-15 June 1991
A. Paulraj Central Research Laboratory Bharat Electronics Limited Bangalore	12 July 1991
S. Venugopal Department of Physics University of Binghamton Binghamton, U.S.A.	14-19 July 1991

Raja Guhathakurtha Institute for Advanced Studies Princeton, U.S.A.	17-23 August 1991
I. Kazes Meudon Observatory Paris, France	26-30 August 1991
A. Peerally School of Sciences University of Mauritius Mauritius	26 September - 1 October 1991
K. Ratnathunga Institute for Fundamental Studies Kandy, Sri Lanka	29 September - 5 October 1991
R.K. Laxman Bombay	30 September - 3 October 1991
P. Dierich Meudon Observatory Paris, France	3-15 October 1991
A.W. Wolfendale University of Durham Durham, U.K.	11-13 October 1991
T.P. Singh Tata Institute of Fundamental Research Bombay	14-26 October 1991
P. Saha Canadian Institute of Theoretical Astrophysics Toronto, Canada	21-26 October 1991
Soumya Chakravarti University of California California, U.S.A.	17-19 November 1991

Srinivas Kulkarni California Institute of Technology Pasadena, California U.S.A.	25 November - 2 December 1991
K. Neelakantan ANURAG Hyderababd	27-30 November 1991 28 February - 1 March 1992
Prof. A. Vodja Prof. L Bata Central Research Institute for Physics Budapest, Hungary	5-13 December 1991
J. Madore Laboratoiré de Physique Theorique et Hautes Energies Universite Paris - XI Orsay, France	6-9 December 1991
N. Behera Department of Physics Indian Institute of Science Bangalore	13-31 December 1991
E.A. Abramenkov V.V. Krymkin M.A. Sidorchuk Institute of Radio Astronomy Kharkov, USSR	12-26 December 1991
G.D. Love Department of Physics University of Durham Durham, U.K.	4 January 1991 - (for one year)
Prof. R.P. Reisz American College Madurai	5-22 January 1992

C.H. Townes Department of Physics University of California California, U.S.A.	12 February 1992
G. Venkataraman ANURAG Hyderabad	28 February 1 March 1992
F. Rondelez Laboratoire de Physico Chimie des Surfaces et Interfaces Paris, France	1-6 March 1992
K. Kiseleva J.P. Anosova Leningrad University St. Petersburg, USSR	11-14 March 1992
T.R. Ramadas Tata Institute of Fundamental Research Bombay	31 March - 10 April 1992

PAPERS PUBLISHED – Annexure - I

In Journals

1. "Formation and Evolution of Binary and Millisecond Radio Pulsars" (D. Bhattacharya, E.P.J.van den Heuvel), *Phys. Rpts.*, **203**, 1 (1991).
2. "On the Decay of the Magnetic Fields of Single Radio Pulsars" (D.Bhattacharya, R.A.M.J.Wijers, J.W.Hartman and F.Verbunt), *Astron. Astrophys*, **254**, 198 (1992).
3. "Genesis of a Pulsar's Planets" (R.A.M.J.Wijers, E.P.J. van den Heuvel, M.H. van Kerkwijk and D.Bhattacharya), *Nature (Scientific Correspondence)*, **355**, 593 (1992).
4. "Pulsars and Binary Stars" (C.S.Shukre), *Bull. Astron. Soc. India*, **18**, 191 (1990).
5. "Low-frequency Observations of the Vela Supernova Remnant and their Implications" (K.S.Dwarakanath), *J.Astrophys. Aston.*, **12**, 199 (1991).
6. "Evolution of the magnetic fields of neutron stars" (G. Srinivasan), in *Annals of the New York Academy of Sciences*, **647**, 538 (1991).
7. "Radio studies of the Galactic Centre-II. The arc, threads and related features at 90cm (330 MHz)" (K.R.Anantharamaiah, A.Pedlar, R.D.Ekers, and W.M.Goss), *Mon. Not. R. astr. Soc.*, **249**, 262 (1991).
8. "Accuracy of Binary Star Separations Estimated from Interferometric Data" (M. Vivekanand), *Astron. J.*, **100**, 2047 (1990).
9. "Bianchi Cosmologies: the role of Spatial Topology" (A. Ashtekar and J. Samuel), *Classical and Quantum Gravity*, **8**, 2191 (1991).
10. "Multiple Analysis for Electromagnetism and Linearized Gravity with Irreducible Cartesian Tensors" (T. Damour and B.R. Iyer), *Phys. Rev. 'D'*, **43**, 3259 (1991).
11. "Post-Newtonian Generation of Gravitational Waves – II: The Spin Moments" (T. Damour and B.R. Iyer), *Ann. Inst. Henri Poincare*, **54**, 115 (1991).
12. "Separation of Variables for the Dirac Equation in an extended class of Lorentzian Metrics with Local Rotational Symmetry" (B.R. Iyer and N. Kamran), *J. Math. Phys.*, **32**, 2497 (1991).
13. "Modified Photon Equation of Motion as a test for the Principle of Equivalence" (B. Bhawal, H.S. Mani and C.V. Vishveshwara), *Phys. Rev. 'D'*, **44**, 1323 (1991).

14. "SU(2) Phase jumps and Geometric Phases" (R. Bhandari), *Phy. Let.'A'*, **157**, 221 (1991).

15. "Evolution of light beams in Polarization and Direction" (R. Bhandari), *Physica 'B'*, **175**, 111 (1991).

16. "A useful Generalization of the Martinelli Effect" (R. Bhandari), *Opt. Comm.*, **88**, 1 (1992).

17. "The Phase problem and its relation to the Spin-Glass problem" (Rajeswari Venkatesan), *Acta Crystallographica 'A'*, **47**, 400 (1991).

18. "Comment on the Derivation of Reciprocity Relations for a Beam Splitter from Energy Balance" (K. Smiles Mascarenhas), *American J. Phys.*, **59**, 1150 (1991).

19. "Component Orientational Order Parameter in Binary Mixtures" (R. Pratibha and N.V.Madhusudana), *Mol. Cryst. Liquid Cryst.*, **198**, 215 (1991).

20. "Propagating Electrohydrodynamic Instabilities in Nematics" (V.A. Raghunathan, P.R. Maheswara Murthy and N.V. Madhusudana), *Mol. Cryst. Liquid Cryst.*, **199**, 239 (1991).

21. "Electromechanical Effect in Cholesteric Liquid Crystals with fixed Boundary Conditions" (N.V. Madhusudana, R. Pratibha and H.P. Padmini), *Mol. Cryst. Liquid Cryst.*, **202**, 35 (1991).

22. "A Matter of Phenomenology" (N.V.Madhusudana), *Curr. Sci.*, **61**, 497 (1991).

23. "Unusual Growth of Smectic A Liquid Crystals" (R. Pratibha and N.V. Madhusudana), *Curr. Sci.*, **62**, 419 (1992).

24. "Cylindrical Growth of Smectic A Liquid Crystals from the Isotropic Phase in some Binary Mixtures" (R.Pratibha and N.V.Madhusudana), *J. de Physique II*, **2**, 383 (1992).

25. "On Some Topological Solitons in Ferronematics" (P.B. Sunil Kumar and G.S.Ranganath), *Mol. Cryst. Liquid Cryst.*, **196**, 27 (1991).

26. "Geometrical Theory of Diffraction" (P.B. Sunil Kumar and G.S. Ranganath), *Pramana, J. Phys.*, **37**, 457 (1991).

27. "Geometrical Theory of Diffraction - A Historical Perspective" (P.B. Sunil Kumar and G.S. Ranganath), *Curr. Sci.*, **61**, 22 (1991).

28. "Optical Diffraction in Twisted Liquid-crystalline Media-phase Grating Mode" (K.A. Suresh, P.B. Sunil Kumar and G.S. Ranganath), *Liquid Crystals* **11**, 73 (1992).

29. "Synthesis and Mesogenic Properties of some β-diketones and their Copper (II) and Palladium (II) Chelates" (B.K.Sadashiva, Archana

Ghode and P. Rani Rao), *Mol. Cryst. Liquid Cryst.*, **200**, 187 (1991).

30. "Crystal and Molecular Structure of the Discogen bis[1,3-di(p-n--octylphenyl)propane-1,3-dionato]copper(II)" (K.Usha, Kalyani Vijayan and B.K. Sadashiva), *Mol. Cryst. Liquid Cryst.*, **201**, 13 (1991).
31. "Terminally Chloro-substituted Mesogenic β-diketones" (Archana Ghode and B.K.Sadashiva), *Mol. Cryst. Liquid Cryst. Lett.*, **8(2)**, 39 (1991).
32. "NMR and EPR Studies of the Phase Transitions in the Discogen bis[1,3- (p-n-octyloxyphenyl)propane-1,3-dionato]CU(II), (Monisha Bose and B.K. Sadashiva), *Mol. Cryst. Liquid Cryst. Lett.*, **8(3)**, 59 (1991).
33. "Dielectric Studies of Goldstone mode and Soft mode in the Vicinity of the A-C* transition" (S.M. Khened, S.Krishna Prasad, B.Shivkumar and B.K.Sadashiva), *J. Phys. II*, **1**, 171 (1991).
34. "Magnetic and Electric Field Induced Bistability in Nematics and Cholesterics" (U.D.Kini), *Liquid Crystals* **10**, 597 (1991).
35. "Faceted Two Dimensional Crystals" (K.A.Suresh), *Curr. Sci.*, **61**, 439 (1991).
36. "On the Variation of Pitch and Polarisation-Tilt Coupling in Chiral Smectic C" (S.K.Prasad and G.G. Nair), *Mol. Cryst. Liquid Cryst.*, **202**, 91 (1991).
37. "Dielectric Behaviour near a Smectic A_d - Smectic A_2 Critical Point" (D.S. Shankar Rao, S.Krishna Prasad and V.N.Raja), *Mol. Cryst. Liquid Cryst.*, **198**, 291 (1991).
38. "Experimental Studies in the Vicinity of the C*-I* Transition" (V.N. Raja, S. Krishna Prasad, S.M. Khened and D.S.Shankar Rao), *Ferroelectrics* **121**, 343 (1991).
39. "Effect of the I* Phase Temperature Range on the Nature of the Tilted Fluid to Hexatic Transition" (V.N. Raja, S. Krishna Prasad, D.S. Shankar Rao, J.W. Goodby and M.E. Neubert), *Ferroelectrics* **121**, 235 (1991).
40. "High Pressure Studies on Ferroelectric Liquid Crystals" (S.M. Khened, S. Krishna Prasad, V.N.Raja, S. Chandrasekhar and B. Shivkumar), *Ferroelectrics* **121**, 307 (1991).
41. "Measurement of Rotational Viscosity in the Smectic C* Phase" (S. Krishna Prasad, S.M. Khened, V.N. Raja and B. Shivkumar), *Ferroelectrics* **121**, 319 (1991).

42. "A Potential Controlled Transient Technique for Corrosion Studies" (V.Lakshminarayanan and S.R.Rajagopalan), *J. Electroanal. Chem.*, **303**, 95 (1991).
43. "Corrosion Problems and Solutions in Packaging and Manufacture of Electronic Circuits" (V.Lakshminarayanan), *J. Electrochem.Soc. India*, **40**, ws13 (1991).
44. "A Simple Analog Interface Circuit for Recording Fast Repetitive Transients in an X-Y Recorder" (V.Lakshminarayanan, A. Poojary and S.R. Rajagopalan), *Indian J. Tech.*, **29**, 498 (1991).
45. "A New Technique for the Measurement of Electrical Resistivity of Concrete" (V. Lakshminarayanan and S.R.Rajagopalan), *Mag. Concr. Res.*, **44**, 47 (1992).
46. "Nanometre Electrodes - A New Tool for Electrochemical Studies" (V. Lakshminarayan and S.R. Rajagopalan), *Curr. Sci.*, **60**, 670 (1991).

In Conference Proceedings/Books

1. "Source-noise in Radio Synthesis Images" (K.R. Anantharamaiah, A.A. Deshpande, V. Radhakrishnan, R.D. Ekers, T.J.Cornwell, W.M.Goss), in Proc. IAU Colloq. No. 131 *Radio Interferometry: Theory, Technique and Applications*, eds. T.T. Cornwell & R.A. Perley, p6, Astronomical Society of Pacific Conference Series, **19**.
2. "Polarisation" (V. Radhakrishnan), (Tutorial TJ delivered at the URSI General Assembly, Prague, Czechoslovakia), in *Modern Radio Science*, ed. J. Bach Anderson, Oxford Uni. Press, Oxford, 1991.
3. "The Formation of Neutron Stars in the Galaxy" (D.Bhattacharya), in Proc. NATO Advanced Study Inst. on *Neutron Stars: Theory and Observation*, eds. J.Ventura & D.Pines, Kluwer Academic, Dordrecht, p. 103 (1991).
4. "The Evolution of Neutron Star Magnetic Fields" (D.Bhattacharya and G.Srinivasan), in Proc. NATO Advanced Study Inst. on *Neutron Stars: Theory and Observation*, eds. J.Ventura & D.Pines, Kluwer Academic, Dordrecht, p.219 (1991).
5. "Scalar Field Quantisation in Stationary Non-static Spacetimes" (T. Dray, Ravi Kulkarni and C. Manogue), in Proc. of the 3rd Canadian Conf. on *General Relativity and Relativistic Astrophysics,* eds. A. Coley et al., World Scientific, p.164 (1991).
6. "Charged Twist Walls in Nematic Liquid Crystals" (N.V. Madhusudana, Ph. Martinot-Lagarde and G. Durand), in *Solitons in Liquid Crystals,* eds. Lui Lam & J. Prost, Springer Verlag, p.253 (1992).

Pappers in Press

In Journals

1. "Pulsar Observations at 34.5 MHz using the Gauribidanur Telescope:I" (A.A. Deshpande, V. Radhakrishnan), (to appear in *J. Atrophy. Astron.*).
2. "A Sweeping Local Oscillator System for Pulsar Observations" (A.A. Deshpande), (to appear in *J. Astrophy. Astron.*).
3. "Evolution of the Sub-parsec Structure of 3C84 at 43 GHz" (T.P. Krichbaum, ...Vivek Dhawan.... et al), (to appear in *Astron. Astrophys.* – Main Journal).
4. "Towards an Empirical Theory of Pulsar Emission: VI. The Geometry of the Conal Emission Regions" Joanna M. Rankin, (submitted to *Astrophy. J.*).
5. "Comments on 'Modified Photon Equation of Motion as a test for the Principle of Equivalence' " (R. Nityananda), (to appear in *Phys. Rev. D.*).
6. "Fermat's Principle in General Relativity" (R. Nityananda and J. Samuel" (to appear in *Phys. Rev. 'D'.*).
7. "Must a Fermion Wavefunction change sign under 2ϕ roations?" (R. Bhandari), (submitted to *Phys. Rev. Lett.*).
8. "Dielectric studies in the vicinity of the A - C* transition (S. Krishna Prasad, S.K. Khened, V.N. Raja, S. Chandrasekhar and B. Shivkumar), (submitted to *Ferroelectrics*).

In Conference Proceedings

1. "Pulsar Observations at Decametric Wavelengths using the Gauribidanur Telescope" (A.A.Deshpande, V. Radhakrishnan), (to appear in Proc. of IAU Colloq. No.128 on *The Magnetospheric Structure and Emission Mechanisms of Radio Pulsars*), eds. J.A. Gil, T.H. Hankins & J.M. Rankin, Kluwer Academic, Dordrecht.
2. "The Evolution of the Magnetic Fields of Neutron Stars" (D.Bhattacharya), (to appear in Proc. of IAU Colloq. No.128 on *The Magnetospheric Structure and Emission Mechanisms of Radio Pulsars*), eds. J.A. Gil, T.H. Hankins & J.M. Rankin, Kluwer Academic, Dordrecht.
3. "The Polarisation of Pulsar Radiation" (V. Radhakrishnan), (to appear in Proc. of IAU Colloq. No.128 on *The Magnetospheric Structure and Emission Mechanisms of Radio Pulsars*), eds. J.A. Gil, T.H. Hankins & J.M. Rankin, Kluwer Academic, Dordrecht.

4. "A Report on the Panel Discussion" (C.S.Shukre), (to appear in Proc. of IAU Colloq. No.128 on *The Magnetospheric Structure and Emission Mechanisms of Radio Pulsars*), eds. J.A. Gil, T.H. Hankins & J.M. Rankin, Kluwer Academic, Dordrecht.
5. "From Low-Mass X-ray Binaries to Binary and Millisecond Pulsars" (D. Bhattacharya), (to appear in Proceedings of the NATO Advanced Research Workshop on *X-ray Binaries and the Formation of Binary and Millisecond Radio Pulsars*), eds. S.A.Rappaport & E.P.J.van den Heuvel, Kluwer Academic, Dordrecht.
6. "Pulsar Velocities and their Origins" (V. Radhakrishnan), (to appear in Proceedings of the NATO Advanced Research Workshop on *X-ray Binaries and the Formation of Binary and Millisecond Radio Pulsars*), eds. S.A.Rappaport & E.P.J.van den Heuvel, Kluwer Academic, Dordrecht.
7. "SiO Masers and Emission and the Intrinsic Properties of Mira Variables" (N.A. Patel, A.Joseph, R.Ganesan and C.S.Shukre), (to appear in Proc. of *Astrophysics Masers*), Washington, 1992.
8. "Self duality in Classical Gravity" (J. Samuel), (to appear in *Recent Advances in General Relativity*), eds. A.I. Janis & J.R. Porter, Birkhauser, Boston (1992).
9. "Black Holes, Bubbles and Radiation: An Excursion into Higher Dimension" (C.V. Vishveshwara), (to appear in *Frontier Papaers - Essays in honour of Jayme Tiomno,*) eds. S. McDowell et al., World Scientific (1991).
10. "Effect of pressure on the Spontaneous Polarisation, the Critical Unwinding Field and the Transverse Dielectric Constant in Ferroelectric Liquid Crystals" (S. Krishna Prasad, S.K.Khened, V.N.Raja, S.Chandrasekhar and B.Shivkumar), (to appear in Proc. of *XIII AIRAPT International Conference*, Bangalore, 1991).
11. "Rotational Viscosity in the Ferroelectric C* phase - A high pressure study" (S.M. Khened, S. Krishna Prasad, V.N. Raja, S. Chandrasekhar and B. Shivkumar), (to appear in Proc. of *XIII AIRAPT International Conference*, Bangalore, 1991).
12. "Observations of Triply Reentrant Behavior and a Multicritical Point in Single Component Liquid Crystal system at high pressure" (V.N.Raja), (to appear in Proc. of *XIII AIRAPT International Conference*, Bangalore, 1991).
13. "High pressure studies of Materials Exhibiting Fluid to Hexatic phase Transitions in Liquid Crystals" (D.S. Shankar Rao, V.N.Raja, S.Krishna Prasad and S.Chandrasekhar), (to appear in Proc. of *XIII AIRAPT International Conference*, Bangalore, 1991).

14. "Smectic A - smectic C - hexatic B Meeting Point at high pressure – A new Multicritical Point" (Geetha G. Nair, V.N.Raja, S.Krishna Prasad, S.Chandrasekhar and B.K.Sadashiva), (to appear in Proc. of *XIII AIRAPT International Conference*, Bangalore, 1991).
15. "High pecision density studies near the mectic A - nematic Tricritical Point" (V.N.Raja, S.Krishna Prasad, D.S.Shankar Rao and S.Chandrasekhar), (to appear in *Liquid Crystals*).
16. "EHD Instability of a Nematic under a Transverse Electric Field" (V.A. Raghunathan, P.R. Maheswara Murthy and N.V. Madhusudana), (to appear in *Pattern Formation in Complex Dissipative Systems*, ed. S.Kai, World Scientific).