

# RAMAN RESEARCH INSTITUTE

Bangalore

Annual Report 1993-94

## 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, Liquid Crystals and Theoretical Physics.

## 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 range of wavelengths (30 metres to 1 millimetre) 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<sup>0</sup> k cosmic background radiation, quasars, pulsars, etc.

The Raman Research Institute has observational programmes in Radio Astronomy extending over most of the available radio spectrum. It has set-up a Decametrewave Radio Telescope at Gauribidanur jointly with the Indian Institute of Astrophysics. It is one of the few largest among the telescopes in the world operating at a wavelength of 10 metre wavelength 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 (TIFR), Bombay. This instrument operates at a wavelength of approximately 1 metre and is used for carrying out observations of pulsars, and nebulae of various kinds in the Galaxy. There is an active programme under way to build instrumentation for and use the Giant Metre wavelength Radio Telescope (GMRT) being built by TIFR near Pune.

During the past two decades, millimetrewave astronomy has assumed great importance because of the discovery of numerous molecules (combinations of Hydrogen, Carbon, Nitrogen, Oxygen, Silicon, etc.) by their emitted line radiations in the shortest wavelength region of the radio spectrum. These molecules are generally found in dense molecular clouds in our own and other Galaxies where star formation is thought to be taking place. The Raman Research Institute has set-up a millimetrewave telescope of diameter 10.4 metre, which is being used for such studies.

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 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 covers areas like their unique mechanical and electrical properties, defects, X-ray and light scattering and synthesis of new materials. Work on applications such as displays is also carried out.

### 3. Theoretical Physics

The two main areas of theoretical physics pursued at the Institute are gravitation and optics. Einstein's general theory of 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 analogy 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, specific and detailed account of the work carried out in the past year is given in the following pages.

## THEORETICAL PHYSICS

A novel optical interferometric technique was devised in which two orthogonally polarised beams traverse the same optical path, and beam splitters and mirrors are eliminated. The resulting reduction of systematic errors leads to better quantitative agreement between the observed phase changes and predicted ones, in the regime in which they both vary rapidly and non-linearly with the orientation of the optical elements. Using this technique, the Pancharatnam phase for a two state system was demonstrated along with its associated discontinuities and singularities. The discontinuities for the QHQ (Quarter wave, Half wave, Quarter wave) arrangement were calculated.

Employing the gravitational wave generation formalism, the post Newtonian accurate spin octupole moment has been computed. Using this one can compute the post post Newtonian accurate waveform and linear momentum flux. Starting from the effects of spin-orbit coupling on the far zone energy and angular momentum flux, the corresponding radiation reaction in the (near zone) equation of motion was derived. One finds that a post Newtonian radiation reaction leads to a formula applicable to general orbits.

A previously proposed scaling law for the correlation function in non-linear gravitational clustering was pursued with the help of an artificial, but exact, 'spherical top hat model', first on a regular and then on a random lattice. Although the scaling is not perfect the approximate scaling function emerging from this model is quite close to available N-body simulation results. The formalism for perturbative analysis of the BBGKY hierarchy for the lowest order non-linear correction to the pair correlation function was also considered. The results were compared with those obtained by others in the fluid formalism.

The optics of twist grain boundary smectics (TGB) was analysed. For normal incidence, one can have many optical reflection bands the strongly reflected state being either right or left circular. In some other bands all incident states can be reflected. Analysis of diffraction of a beam propagating perpendicular to the twist axis leads to an elucidation of structural parameters of TGB phases.

A spin-statistics relationship was established for topological geons in 2+1 dimensions. The problem of distribution of solid angles in a diffusion process on a sphere was also considered. This was solved by mapping it on to a problem in magnetism. A connection between Brownian Motion and Magnetism was established. Another problem investigated pertained to the use of Berry Phase arguments in the Hubbard Model. One finds the partition function to be the expectation value of a Wilson loop with a gaussian measure.

## LIQUID CRYSTALS

Studies on the growth patterns of smectic liquid crystals to the smectic C phase in which the director makes an angle with the layer normal were extended. In appropriate binary mixtures, it was found that very unusual cylindrical structures are formed. The symmetry of the cylinders which is vectorial in nature brings about additional dynamical features compared to those of the smectic A phase in which the director is along the layer normal. For example, the cylinder as a whole can have locomotion. Further, disturbances in the structure are seen to propagate from one end of the cylinder to the other.

A new technique was devised to measure the azimuthal anchoring energy of nematic liquid crystals which are oriented between two glass plates such that the pretilt angles at the two surfaces are slightly different. A lateral AC electric field produces a twist distortion due to flexoelectric coupling. The distortion is detected optically and a theoretical analysis is used to estimate the azimuthal anchoring energy.

A computer controlled set up was used for electroclinic measurements to detect a soft mode in the antiferroelectric liquid crystalline phase of a couple of compounds. This response was missed by earlier workers in the field.

Detailed experiments on the optical diffraction of chiral smectic C liquid crystals in the phase grating mode showed that depending on the thickness of the sample, the diffracted beam was polarised either parallel or perpendicular to the helical axis irrespective of the azimuthal angle of the incident beam polarisation. A rigorous analysis has been made including the effect of internal diffractions, to account for all the observations.

A theoretical investigation has been undertaken of the anomalous transmission at oblique incidence in absorbing cholesterics. The eigen state which is circular at small angles of incidence changes over to elliptical and finally to linear as the angle is increased. This accounts for some experimental data available in the literature. Further, in the non-Bragg reflection band, some interesting polarization features have been found.

Photon correlation spectroscopy of the Goldstone and soft modes of chiral smectic C liquid crystals has been taken up.

Theoretical studies on the optical properties of the twist grain boundary (TGB) phases have been taken up. Both Bragg and non-Bragg reflection bands have been found. The studies have been extended to the case of absorbing TGB liquid crystals, and to the phase grating mode.

The influence of flexoelectricity on electrooptic properties of a nematic sample with different anchoring conditions on the two bounding surfaces has been investigated theoretically. The effect of an additional magnetic field applied at an oblique angle with respect to the electric field has also been calculated.

The magnetic field induced bistabilities in a super twisted nematic cell have been investigated theoretically. These correspond to symmetric and antisymmetric splay-bend deformation. For certain angles of the applied field, a second order transition to an asymmetrically distorted state is predicted to occur.

In binary mixtures the topology of the phase boundaries near the cholesteric-TGB-smectic A meeting point has been found to be characteristic of a critical end point rather than that of a bicritical point predicted theoretically. We have found experimentally a pressure induced TGB phase in a binary mixture which exhibits only cholesteric and smectic A phases at atmospheric pressure. The first example of a binary system showing a critical end point in the smectic C\* to smectic I\* transition has also been found experimentally.

The helical pitch of a smectic C\* liquid crystal has been measured as a function of pressure using an appropriate optical set up. Monolayer studies at the air-water interface of a smectogenic compound have been taken up.

In the chemistry laboratory, 1,3-diketones and salicylideneamines have been synthesised to be used as ligands in metallomesogens. Many of these ligands themselves exhibited liquid crystalline properties. Two homologous series of 1-3 diketones with lateral long chain substituents were also synthesised and found to exhibit nematic and smectic A phases at relatively low temperatures. The first example of a diacylated 1-3 diketone mesogen was also prepared. Salicylaldiminato platinum (II) complexes exhibiting mesomorphism were also synthesised.

In the applications oriented work, the developmental activity on amorphous twisted nematic and polymer dispersed liquid crystal displays was continued. Some improvements in the operating characteristics have been made during the year.

The brightness uniformity of the display depends on many parameters, including the frequency spectrum of the addressing wave forms. An analysis of the spectra corresponding different addressing techniques has been taken up.

There has been considerable progress in the fabrication of a scanning tunneling microscope. An inertial sliding mechanism has been built and tested. The micropositioner has been calibrated using a laser interferometer.

A Potentiostat/Galvanostat has been fabricated for taking up electrochemical investigations on a number of systems. A computer controlled cyclic voltammetry and differential voltammetry system has also been developed.

As in the past, a number of metal finishing jobs required for the GMRT project were taken up. Plating of various metals was also undertaken for different users in the institute.

The laboratory continues to provide CHN analysis and DSC data for scientists of a number of academic institutions.



# ASTRONOMY AND ASTROPHYSICS

## Pulsars

*Pulsars and spiral arms:* It had been conjectured in the literature that the present spatial distribution of pulsars may correspond to the location of spiral arms in the Galaxy at the epoch of the formation of their progenitors. Through a detailed statistical analysis of the observed population of pulsars this conjecture has been confirmed: the distribution of pulsars seem to be consistent with the location of the spiral arms of the Galaxy  $\sim 60$  Myr ago. Allowing for a mean lifetime of the pulsars since their birth, this would suggest a mean lifetime of  $\sim 50$  Myr for their progenitors. This, in turn, would imply that the majority of the progenitors of pulsars must have masses in the range  $\sim 7 - 8 M_{\odot}$ .

*Progenitors of pulsars:* A re-analysis was undertaken of the observed population of pulsars to estimate the fraction of solitary pulsars that may have evolved in binary systems. The main conclusion of this study is that as much as 25% of pulsars may have come from binary systems. Of these, those that were first-born in binary systems would have been *recycled* like the famous Hulse-Taylor pulsar. These would have characteristic ages  $\sim 10^7$  years "at birth". There is reasonably strong evidence for this in the observed population of pulsars. The remaining i.e. the second-born will be indistinguishable from pulsars born from solitary stars since the binary will most likely disrupt during their birth.

*Decay of neutron star magnetic fields:* According to the recently proposed model for the magnetic field evolution of neutron stars, the flux expulsion from the superconducting interior is a consequence of the slowing down of neutron stars. This effect is expected to be significant only for neutron stars in interacting binary systems. Previous efforts had concentrated mainly on neutron stars with massive companions. In a recent study the rotational history of a neutron star with a *low mass companion* was investigated in detail. The study revealed that neutron stars in such systems are expected to be spun down to much longer periods than in massive binary systems. This would naturally explain why millisecond pulsars, which are recycled in low mass binaries, have much smaller magnetic fields than recycled pulsars from massive binaries. The observed asymptotic fields of millisecond pulsars also find a natural explanation in

terms of a maximum rotational period beyond which neutron stars are unlikely to be spun down in such low mass systems.

In a parallel investigation, the effect of accretion of matter on the magnetic fields of neutron stars in binaries was investigated. In these studies the initial magnetic field was confined to the outer layers of the crust of the neutron star. In such situations it was found that the compression of the current carrying layers due to accretion has a very significant effect on the field strength. In particular, this shortens the characteristic length scale of the magnetic field distribution, and consequently enhances ohmic dissipation.

*Distances to pulsars:* 21 cm absorption studies were made towards 8 pulsars using the Parkes telescope in Australia. The distances to these pulsars derived from their observations together with their dispersion measures will help to improve the existing model for electron density distribution in the inner Galaxy (in collaboration with W.Wilson, D.McConnell and P.M.McCulloch).

*Spectral analysis of pulsar timing residuals:* A new method based on the well known technique CLEAN (commonly used in the processing of radio maps) was developed to estimate high dynamic range power spectra from unevenly sampled time sequence of residuals from the timing of pulsars. This technique was applied to real data and a significant improvement was obtained in the dynamic range of the power spectra (in collaboration with F.D'Alessandro and P.M.McCulloch).

*Timing noise of 45 southern pulsars:* Pulse arrival time data obtained over a period of five years at the Mt.Pleasant observatory in Tasmania were analyzed with a view to provide a description of the nature of the *timing noise* of 45 southern pulsars. The results show that for 22 pulsars *timing activity* is very weak. In most other cases it was possible to attribute the timing activity to a variety of mechanisms such as random-walk processes comprising of a large number of unresolved events, resolved jumps in the rotation frequency, and its derivative etc.. In the case of 4 pulsars no simple description was possible (in collaboration with F.D'Allasandro, P.M.McCulloch and P.A.Hamilton).

*Search for pulsars in globular clusters:* A new programme was begun at Ooty to search for pulsars in globular clusters using a special

purpose receiver built at CSIRO, Australia. The data obtained from the first set of observations towards two globular clusters is presently being analyzed (in collaboration with J.G.Ables, D.McConnell, C.Jacka and P.M.McCulloch).

*Pulsar search with the Ooty Radio Telescope:* In the first phase of the search for pulsars at high galactic latitudes an area of about 200 sq. deg. was covered. The analysis of the data has not so far revealed the existence of any new pulsars in the region surveyed. The search is continuing in other regions of the sky.

**Recombination lines from external galaxies:** Three southern galaxies – NGC 4945, NGC 1808 and Circinus were observed with the Australia Telescope compact array. Lines were detected in NGC 4945 and Circinus; the line strengths from the former were extremely strong approaching that of NGC 253. The search for recombination lines towards the Seyfert II galaxy NGC 1608 was not successful. A possible explanation for this surprising negative result has been suggested (in collaboration with Alan Roy, W.M.Goss, F.Viallefond and Jun-hui Zhao).

**Carbon recombination lines in the galactic plane:** A new programme was begun to search for these lines at 75 MHz using the 64 m telescope in Parkes, Australia. In the first set of observations carried out in June 1993 absorption lines were detected in 8 positions in the longitude range 335 deg. to 20 deg. The radial velocities of these lines were consistent with galactic rotation effects. The new data doubles the number of known sources of carbon recombination lines. Most likely, these lines arise in a cold distributed component of the Interstellar Medium such as the diffuse neutral hydrogen clouds (in collaboration with W.C.Erickson and D.McConnell).

**A recombination line survey with the Ooty Radio Telescope:** The construction of a 1-bit digital spectrometer which can simultaneously observe four lines at two adjacent positions was completed. The first set of observations towards the galactic centre was successful and confirms the expected performance of the new spectrometer. A major survey of the galactic plane is now under way.

**Small scale structure in the interstellar clouds:** To clarify the possible existence of very small scale structures in diffuse

interstellar clouds, extensive 21 cm observations are carried out using the Parkes telescope in Australia. The absorption profiles towards two pulsars when compared with similar data obtained about 15 years ago indicate that changes in fractional absorption are very small ( $< 0.1$ ).

**The Vela supernova remnant:** To understand the asymmetric radio morphology of this important supernova remnant a map was made of the surrounding regions in the 21 cm line of neutral hydrogen using the 26 m telescope at Mt. Pleasant in Tasmania. The distribution of neutral hydrogen appears to be well correlated with the radio surface brightness of the remnant — there is considerably more gas in regions of enhanced radio emission such as Vela Y and Vela Z components of the remnant, and there is very little interstellar gas in other directions. Thus it appears that the asymmetric morphology of the Vela supernova remnant is related to large scale inhomogeneities in the interstellar medium into which it is expanding, and there is no compelling need to invoke exotic scenarios.

**The Butcher-Oemler Effect:** This effect refers to the occurrence of a larger proportion of blue galaxies in clusters as one goes to larger and larger redshifts. In an effort to clarify the reason for this the Abell cluster 2125 was observed with the VLA. Continuum images of this cluster show around 140 sources above the detection limit and within the primary beam. Of these, 36 have optical counterparts brighter than 19th magnitude. One would normally expect only about 5 radio sources with optical counterparts in the field observed. In order to understand the nature of the optical counterparts efforts are under way to obtain the magnitudes and colours of these sources.

**Cooling flows in clusters of galaxies:** X-ray observations of clusters of galaxies have implied that there may be large quantities of cold neutral hydrogen gas in the cores of clusters. We may therefore expect to see this gas in absorption against strong continuum sources. With this in view, deep absorption studies were undertaken towards three clusters Virgo, Abell 2199 and Abell 780. But no evidence was found for a spatially extended distribution of cold neutral hydrogen clouds.

**Neutral hydrogen absorption in Hydra A:** This is believed to be a cluster with an associated cooling flow. Earlier 21 cm absorption against the core of Hydra A was detected. Recently this has

been re-observed with higher spectral and spatial resolution using the VLA. The observed 21 cm absorption is more consistent with a gas disc close to the centre, rather than very small cold and optically thick clouds.

**Bright-rimmed molecular clouds:** As a continuation of the earlier study of bright-rimmed clouds in the Gum nebula, observations were undertaken to study similar clouds near the Cepheus and Orion OB associations. These observations were carried out using the 10.4 m telescope at RRI. The molecular clouds in the Cepheus OB2 region appear to be expanding at  $\sim 4$  km/s, whereas in the Orion OB1 region there is no simple systematic motion away from a possible common centre. At this stage the only statement that can be made with confidence is that motions of molecular clouds seem to be a common feature in the vicinity of massive stars.

**Monitoring of SiO maser sources:** During the course of monitoring these sources with the RRI 10.4 m telescope it was found that both the intensity and the nature of polarization of some of these maser sources change over timescales very short compared to the pulsation periods of the stars which harbour them. The source RX Boo showed an almost three-fold increase in the intensity in a span of eight hours, with accompanying changes in polarization.

Three new sources S Crt, RT Hya and BK Vir were detected as maser sources. These observations suggest that for the SRb stars only the spectral type seems to be correlated with maser emission and not the bolometric magnitude as in the case of Mira variables.

**Carbon monoxide observations of some galactic radio sources:** All the extended radio sources in the available 2.7 GHz continuum map in the longitude range 240 deg. to 55 deg., and latitude range  $-5$  deg. to  $+5$  deg. were observed in the  $J = 1 \rightarrow 0$  line of  $^{12}\text{CO}$  using the 10.4 m telescope at RRI. A total of about 600 spectra were taken covering in all about 200 sources. When the analysis is completed, these observations should provide some useful information concerning the molecular gas associated with supernova remnants, ionized hydrogen clouds etc..

## Instrumentation for Radio Astronomy

*Millimeter-wave Astronomy:* It is proposed to use 4.5 GHz as the first intermediate frequency instead of the present 1.4 GHz at the 10.4 m telescope. With this in mind a 3-stage broad-band low-noise amplifier was designed using HEMTs. Room temperature tests have given very encouraging results (a gain of about 29 db, a bandwidth of 1 GHz centred around 4 GHz, and an average noise temperature of 45 K across the band). Design of a similar amplifier for cryogenic operations is in progress.

As reported earlier, a member of RRI staff is presently at the Chalmers University of Technology in Sweden making low-noise HEMT amplifiers for use in the frequency range 20 - 26 GHz and 43 - 50 GHz. Cooled amplifiers have measured noise temperatures  $\sim 30 - 40$  K at 22 GHz. The corresponding figure for the 43 GHz amplifiers will be available soon.

The collaboration between RRI and the Onsala Space Observatory in Sweden for designing and constructing a digital spectrometer for use with the 10.4 m telescope at RRI is progressing well. The complete digital autocorrelator is expected here within the next few months.

A dual polarization receiver is now available at the 10.4 m telescope.

A microprocessor-based microswitching drive was also installed on the telescope to improve the accuracy of the chopper and beam switching operations.

A special purpose polarimeter for the millimeter-wave telescope was designed and built to enable measurements of all the 4 Stokes parameters in observations where only the total power is measured. After laboratory tests this is now being tested at the telescope.

*Holography of the 10.4 m telescope:* Attempts were made to estimate the surface error in the primary reflector by employing phase-reconstruction holographic technique. A set of measurements of the power pattern of the dish as sampled by a near-field radiator were made. The data was analyzed using standard techniques to reconstruct the phase distribution. The phase distribution thus obtained showed rapid/large fluctuations at locations that correspond to partial shadowing by

the support structure close to the secondary. In the central regions of the dish, phase variations implied an rms error in the surface of the reflector of  $\sim 120 - 150$  microns. Further measurements are planned to obtain improved spatial resolution.

**The Gauribidanur Radio Telescope:** The necessary hardware and software required for observing highly excited carbon recombination lines were developed and installed. This consists of an 8-line spectrometer and a PC-based data acquisition system. This allows simultaneous observations of 8 recombination lines corresponding to 8 transitions that are observable within the bandwidth of the telescope. After several tests, spectral line observations of the galactic plane using the telescope have begun.

**The Mauritius Radio Telescope:** During the past year the installation of the East-West and the North-South arm has been completed, and the entire system together with the field electronics and the 1024-channel correlator is functioning satisfactorily. After tuning the system, a 24-hour observation was carried out in the fan-beam mode of the East-West array. The antenna phases were calibrated using strong sources like Hydra and Centaurus A. A one-dimensional 24-hour scan with a 4 arcminute resolution was obtained using this data and phase calibration. The signal-to-noise ratio obtained from several sources were very close to what was expected. A more detailed analysis of the data is in progress.

### **GMRT-Pulsar Receiver Project**

*Search Pre-processor:* After the successful trials at Ooty using the prototype, and incorporating the necessary modifications, a new version of the search pre-processor with a 4-dish array combiner for a single side band was built and installed at the GMRT site. The debugging of the system is nearly complete. A similar system for the second side band is expected to be ready soon.

*A Polarimeter and Signal Processor for known pulsars:* The design specifications and hardware details of the polarimeter and a DSP-based processor for pulsar observations were worked out and finalized. A prototype DSP-based processor has been built and is being tested.

*Off-line Processor for analyzing pulsar search data:* A special

purpose hardware processor to meet the computational requirements is being developed. This will consist of dedicated pipeline stages like a dedisperser, FFT modules, an acceleration compensator, followed by a 30-50 MFLOPS general purpose computer. The processor will have a throughput rate of  $\sim 3$  MHz. As a first step a prototype of an acceleration compensator has been built. An algorithm was developed to re-sample the uniformly sampled data in order to compensate for acceleration effects in the signals from fast binary pulsars. A hardware module designed and built based on this algorithm is being tested.

**21 cm Receiver for GMRT:** A wide flare angle corrugated conical horn for the frequency band 1000-1500 MHz was designed and fabricated. The measured performance meets the desired specifications. The performance of the low-noise amplifier was further improved by re-designing it; at present its noise temperature is 25 K as against 32 K reported earlier. This is expected to be improved even further when the circuit is optimized. The switchable band pass filters built using microstrip design have shown very stable and repeatable performance. One front-end receiver complete with all units, together with a noise injecting system, circular polarizer and phase switching units was fabricated and tested, and has been sent to Pune for installation on one of the GMRT antennae.

## COMPUTERS

A 4-wire data communication line between RRI and the ERNET node at IISc. has been leased from the Department of Telecommunications to obtain INTERNET connection to our local area network. Remote logins and file transfer facilities are being tested. Eight Alpha workstations from Digital (Models: 600AXP - 1 No., 300LX - 6 Nos. and 2000/300 - 1 No.) and four Sparc workstations from SUN (Models: Sparc 10/41 - 2 Nos. and Sparc Classic - 2 Nos.) have been acquired and are ready for installation. These workstations are meant for image processing, reduction of 10m telescope data and general computing. The existing VAX 11/780 system will be decommissioned shortly.



**Ph.D.****Awarded**

<u>Name</u>	<u>Topic of Study</u>
S.M. Khened	Experimental studies of physical properties of ferroelectric liquid crystals
Geetha G.Nair	Experimental studies on liquid crystalline phases and phase transitions
P.R. Maheshwara Murthy	Some electric and magnetic field effects in liquid crystals
B. Ramesh	A study of the kinematics of the local dark clouds

**Submitted**

<u>Name</u>	<u>Title of the Thesis</u>
K. Usha	X-ray analysis of the crystal and the molecular structure of some discotic compounds
H.P. Padmini	On some physical studies on liquid crystals and their mixtures
D.S. Shankar Rao	Experimental studies on phase transitions in liquid crystals
P.B. Sunil Kumar	Some theoretical studies on the defect structures in liquid crystals
Archana Ghode	On synthesis and properties of some thermotropic mesogens
Veena Prasad	Liquid crystalline properties of compounds containing some transition metals

## **Conferences/Symposia held**

To commemorate the Diamond Jubilee of the Indian Academy of Sciences, the Institute organised an International Discussion Meeting on Pulsars during the period March 14-17, 1994. Almost all the leading experts in the field participated in this meeting. The Proceedings will be published by the Academy.

The Institute was also involved in organising the Fourth Group Monitoring Workshop on DST Funded Projects in Condensed Matter Physics during 17th to 19th June 1993.

## **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, lectures were given by them at other places. In all, 137 lectures were given by them at other places.

## **Gandhi Memorial Lecture**

The Gandhi Memorial Lecture for 1993 was given by Dr. M.S. Valiathan on "Science as Service", on 30th January 1994.

## **Colloquia**

The scientists of the Institute and visiting scientists both from within and outside the country gave 26 colloquia at the Institute on different topics during the year.

## Journal Club Meetings

Fifteen 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, three 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 18,463 books and 21,718 bound volumes of periodicals. 208 new books were added to the library this year. 30 of them were received gratis. It subscribes to 143 periodicals of which 20 are received by air mail. Based on a readership survey, subscription to 7 journals were discontinued and 7 journals added. International Astronomical Union circulars, some newsletters, and preprint bulletin boards are being received via electronic mail. All the library routines are now being carried out with the help of the existing LIBSYS software and the library database is also being created. It also took part in the Bangalore Special Libraries Group activities. Besides catering to the Institutes requirements the library also helped some users from the Indian Institute of Science, The National Aerospace Laboratories, the Indian Institute of Astrophysics and the Indian Space Research Organisation.

## Others

### General

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

PLAN - RECURRING AND NON-RECURRING	Rs.340.00 Lakhs
NON PLAN - RECURRING	<u>Rs.205.00</u> Lakhs
Total	<u>Rs.545.00</u> Lakhs.

## STAFF

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

V. Radhakrishnan (Director)

Abhijit K.Kshirsagar*	Lakshmy P. Usha
V. Anand	Madhu Girimaji
R. Anantha*	N.V. Madhusudana
K.R. Anantharamaiah	M.O. Modgekar
P.G. Ananthasubramanian	Mohd. Imtiyaz
Antony Joseph	H.N. Nagaraja
R. Bhandari	K.S. Nagesh
D. Bhattacharya	R. Nandakumar
K. Chandrasekhara	H. Narayanan
S. Chanthrasekharan	R. Nityananda
Chitra M. Gokhale	T. Prabu
Deepak Kumar Menon*	Pravin Kumar Pereira*
A.A. Deshpande	E. Palanichamy
V. Devadas	K.B. Raghavendra Rao
K.S. Dwarakanath <sup>††</sup>	N.G. Raghavendra Rao
M.S. Ezhilarasi	A. Raghunathan
R. Ganesan <sup>&amp;</sup>	P. Rajasekar
S.P. Gnana Raj	P.S. Ram Kumar
M.R. Gopalakrishna	P.N. Ramachandra
K. Gurukiran	C. Ramachandra Rao
B.R. Iyer	P. Ramadurai
P.A. Johnson	K. Ramesh Kumar
S. Kathyayini	B. Ramesh
P.A. Kamini*	S. Ramaseshan
U.D. Kini	G.S. Ranganath
S. Krishnan	N. Ravi Sankar
S. Krishna Prasad	D.K. Ravindra
V. Lakshminarayanan	G. Rengarajan <sup>%</sup>

T.N. Ruckmongathan  
 B.K. Sadashiva  
 P.B. Sadik  
 J. Samuel  
 A. Santosh Kumar  
 G. Sarabagopalan  
 N.V.G. Sarma  
 S. Sarala  
 P.S. Sasi Kumar  
 K.V. Satyaprakash\*  
 M. Seethalakshmi  
 M. Selvamani  
 S. Seshachala  
 P. Shaji  
 C.S. Shukre  
 Y. Sindhu

B. Sridhar  
 T.K. Sridharan  
 G. Srinivasan  
 K. Subramanya  
 M.R. Subramanyam  
 H. Subramonyam  
 K.A. Suresh  
 V. Suresh Rao  
 S. Swarna  
 M.J. Tuljaram  
 N. Udaya Shankar  
 Varghese George\*  
 V. Vijay  
 R. Vijayaraghavan\*  
 C. Vinutha\*

### Research Fellows

Archana Ghode  
 Arun Rao  
 Amitabha Bhattacharyya\*  
 N. Andal  
 Debnarayan Jana  
 Geetha Basappa  
 Geetha G. Nair  
 A. Gopakumar\*  
 C.R. Gopalakrishna\*  
 C. Indrani  
 Jayadev Rajagopal  
 N. Kasturaiah\*  
 Mehdi Jahanmiri<sup>1</sup>

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 Yuvaraj Sah  
 Ninisha G. Kantharia<sup>1</sup>

**Post-Doctoral Fellows**

Alan R. Daughton  
R. Pratibha

N. Rathnashree\*

**Visiting Professors/Scientists**

N. Kumar  
T.G. Ramesh

A.K.Saxena

**Consultant Physicians**

M.R. Baliga

A.R. Pai

**Resignations**

R. Prameela

K. Smiles Mascarenhas

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†† On leave with the National Radio Astronomy Observatory, Socorro,  
New Mexico, USA

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

% On leave with Universitat fur Bodenkultur Wien, Vienna

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<sup>1</sup> Under the Joint Astronomy Programme at the Indian Institute of Science

## LIST OF VISITORS

V. Urpin Ioffe Institute St.Petersburg, Russia	March 26, 1993 - April 4, 1993
I. Fagoonce University of Mauritius Mauritius	April 4, 1993 - May 2, 1993
Dhananjai Pandey Banaras Hindu University Varanasi	June 21 - 24, 1993
Nick Whyborn Chalmers University of Technology Gothenburg, Sweden	July 13 - August 12, 1993
T. Padmanabhan IUCAA, Pune	July 21 - 27, 1993
John Ponsonby Nuffield Radio Astronomy Labs University of Manchester England	July 29 - August 8, 1993 December 30, 1993 - January 3, 1994
C. Destrade Centre de Recherche Paul Pascal Pessac, France	August 4 - 24, 1993
Raja Guhathakurta Princeton University Observatory Princeton, USA	August 20 - 25, 1993 -
Judith Perry Institute of Astronomy Cambridge, UK	September 3 - 20, 1993 -
R.S. Arora National Physical Laboratory New Delhi	October 12 - 19, 1993



- P.K. Mandal  
University of North Bengal  
Darjeeling  
October 24 - 28, 1993
- S.V. Chervon  
Moscow State University  
Moscow, Russia  
November 21 - 28, 1993
- Fodor Csorba &  
Tamas Kosa  
Hungarian Academy of Sciences  
Hungary  
November 23-  
December 2, 1993
- H.T. Nguyen  
Centre de Recherche Paul Pascal  
Pessac, France  
December 4 - 19, 1993
- Frank Verbunt  
University of Utrecht  
Utrecht, The Netherlands  
December 28, 1993 -  
January 25, 1994
- Joanna M. Rankin  
University of Vermont  
Vermont, USA  
December 31, 1993 -  
January 21, 1994
- Michael Disney  
University of Cardiff  
Cardiff, UK  
December 2, 1993  
January 22, 1994
- Jerry Ostriker  
Princeton University  
Princeton, USA  
January 1 - 10, 1994
- R. Hanbury Brown  
Hampshire, UK  
January 6 - 12, 1994
- J. Prost & D. Bensimon  
Ecole Normale Superieure  
Paris, France  
January 11, 1994

John Ables  
CSIRO Division of Radiophysics  
Epping, NSW, Australia.

August 23 - 24, 1993  
February 28 -  
April 5, 1994

D. McConnell  
CSIRO Division of Radiophysics  
Epping, NSW, Australia.

February 28 -  
April 5, 1994

PAPERS PUBLISHED

In Journals

1. "Fractional spin from gravity" (Joseph Samuel) *Phys. Rev. Lett.*, **71**, 215 (1993)
2. "The Frenet-Serret description of gyroscopic precession" (B.R. Iyer and C.V. Vishveshwara) *Phys. Rev. D.*, **48**, 5706, (1993)
3. "Interferometry without beam splitters - A sensitive technique for spinor phases" (Rajendra Bhandari) *Phys. Lett.*, **A180**, 21 (1993)
4. " $4\pi$  spinor symmetry - some new observations" (Rajendra Bhandari) *Phys. Lett.*, **A180**, 15 (1993)
5. "Oorts review of stellar dynamics" (Rajaram Nityananda) *Curr. Sci.*, **65**, 144 (1993)
6. "Aharonov-Bohm effect" (Joseph Samuel). *Curr. Sci.*, **66**, 781 (1994)
7. "Optical properties of magnetically doped cholesterics" (Yuvaraj Sah, K.A. Suresh and G.S. Ranganath) *Liquid Crystals*, **15**, 25 (1993)
8. "Structure and optical behaviour of cholesteric soliton lattices" (P.B. Sunil Kumar and G.S. Ranganath) *J. Phys. II France*, **3**, 1497 (1993)
9. "Beyond Mendeleev" (G.S.Ranganath) *Curr. Sci.*, **64**. 449 (1993)
10. "High pressure studies on ferroelectric liquid crystals" (S. Krishna Prasad, S.M. Khened and S. Chandrasekhar) *Ferroelectrics*, **147**, 351 (1993)
11. "Dielectric study of a ferroelectric liquid crystal at high pressure" (S. Krishna Prasad, S.M. Khened and S. Chandrasekhar) *Modern Topics in Liquid Crystals*, Ed. A. Buka (World Scientific, 1993)

12. "Influence of boundary conditions on electrooptical and magneto-optical effects in nematics" (U.D. Kini) *Liquid Crystals*, **13**, 735 (1993)
13. "A simple molecular theory of a nematic-nematic phase transition in highly polar nematic liquid crystals" (A.S. Govind and N.V. Madhusudana) *Liquid Crystals*, **14**, 1539 (1993)
14. "An AC electrooptic technique of comparing the two anchoring energies of a hybrid aligned nematic cell" (P.R. Maheshwara Murthy, V.A. Raghunathan and N.V. Madhusudana) *Liquid Crystals*, **14**, 1107 (1993)
15. "Electroclinic response of some ferroelectric liquid crystals" (H.P. Padmini, R. Pratibha, N.V. Madhusudana and B. Shivkumar) *Liquid Crystals*, **14**, No.2, 435-443 (1993)
16. "Liquid crystal phase modulator for unpolarized light" (Gordon D. Love), *Appl. Opt.*, **32**, 222 (1993).
17. "Experimental determination of the flexoelectric coefficients of some nematic liquid crystals" (P.R. Maheshwara Murthy, V.A. Raghunathan and N.V. Madhusudana) *Liquid Crystals*, **14**, 483 (1993)
18. "Electromechanical effects in cholesteric mixtures with a compensation temperature" (H.P. Padmini and N.V. Madhusudana) *Liquid Crystals*, **14**, 497 (1993)
19. "Electromechanical coupling in cholesteric liquid crystals" (N.V. Madhusudana) *Modern Topics in Liquid Crystals*, Ed. A. Buka (World Scientific, Singapore), p.195 (1993)
20. "Liquid crystalline properties of O-Hydroxy substituted Schiff's bases and their copper(II) and palladium(II) complexes" (Veena Prasad and B.K. Sadashiva) *Mol. Cryst. Liq. Cryst.*, **225**, 303 (1993)
21. "Should entropy always drive a system to disorder?" (K.A. Suresh and G.S. Ranganath) *Curr. Sci.*, **66**, 101 (1994)
22. "An experimental study of the smectic A-smectic C transitions in monolayer, partially bilayer and bilayer systems" (S. Krishna Prasad, D.S. Shankar Rao, V.N. Raja, S. Chandrasekhar, G. Heppe and M.E. Neubert) *Mol. Cryst. Liq. Cryst.*, **238**, 241 (1994)

23. "Cyclic voltammetric behaviour of certain copper - azole systems using carbon paste electrodes" (V. Lakshminarayanan, R. Kannan and S.R. Rajagopalan) *J. Electroanal. Chem.*, **364**, 79 (1994)
24. "Anomalous transmission at oblique incidence in absorbing cholesterics" (Yuvaraj Sah and K.A. Suresh) *J. Opt. Soc. Am. A*, **11**, 740 (1994)
25. "Synthesis and mesomorphic properties of some platinum(II) and oxovanadium (IV) complexes" (B.K. Sadashiva and Archana Ghode) *Liquid Crystals*, **16**, 33 (1994)
26. "VLA observations of 1E 1740.7-2942 - a search for radio recombination lines of positronium" (K.R. Anantharamaiah, K.S. Dwarakanath, D. Morris, W.M. Goss, V. Radhakrishnan) *Astrophys. J.*, **410**, 110 (1993)
27. "Subarcminute resolution imaging of radio sources at 74 MHz with the very large array" (N.E. Kassim, R.A. Perley, W.C. Erickson, K.S. Dwarakanath) *AJ*, **106**, 2218 (1993)
28. "Detection of H $92\alpha$  recombination line from the Galaxies NGC 3628, IC 694 and NGC 1365" (K.R. Anantharamaiah, Jun-Hui Zhao, W.M. Goss, J.H. Van Gorkom and F. Viallefond) *Astrophys. J.*, **419** 585 (1993)
29. "The RRI 10.4m millimeter-wave telescope" (T.K. Sridharan), *Bulletin of the Astronomical Society of India*, **21**, 339 (1993)
30. "A study of the cometary globules in the Gum Nebula" (T.K. Sridharan) *Bulletin of the Astronomical Society of India*, **21**, 379 (1993)
31. "The spatial distribution of pulsars and the spiral structure of the galaxy" (R. Ramachandran and A.A. Deshpande) *J. Astrophys. Astr.*, **15**, 69-83 (1994)

In Conference Proceedings

1. "Comparing optical and radio - quantum issues in very high resolution imaging" (Rajaram Nityananda), Proceedings of the IAU Symposium #158 "Very High Angular Resolution Imaging", Sydney, January 11-15, 1993. eds. J.G. Robertson and W.J. Tango *Reidel*, 1994) p.11-18

"Source noise in radio synthesis images of polarised sources" (A.A. Deshpande), Proceedings of the IAU Symposium # 158 on "Very High Angular Resolution Imaging", Sydney, January 11-15, 1993. eds. J.G. Robertson and W.J. Tango *Reidel*, 1994) p.95-99

Papers in Press/Submitted

In Journals

1. "Brownian Motion and Magnetism" (Supurna Sinha and Joseph Samuel), *Phys. Rev. B.* (in press)
2. "Special Relativity" (Joseph Samuel), *Physics Education* (in press)
3. "Generation of Gravitational Waves: The post-newtonian spin octupole moment" (T. Damour and B.R. Iyer), *Classical and Quantum Gravity* (in press)
4. "Optical properties of a ferroelectric liquid crystal phase-only modulator" (Gordon D. Love and Rajendra Bhandari), *Optics Communications*, (in press)
5. "Polarization eigenmodes of a QHQ retarder - some new features" (Rajendra Bhandari and Gordon D. Love), *Optics Communications*, (in press)
6. "Scaling properties of non-linear gravitational clustering" (Rajaram Nityananda and T. Padmanabhan), *MNRAS* (in press)
7. "Perturbative growth of cosmological correlations-I : Formalism" (Somnath Bharadwaj), *Astrophysical Journal* (in press)
8. "Phase diagram involving the twist grain boundary phase in the vicinity of a virtual cholesteric-smectic A-smectic C\* point" (Krishna Prasad, V.N. Raja, Geetha G. Nair and J.W. Goodby), *Mol. Cryst. Liq. Cryst.* (in press)
9. "Kinetics of droplet formation in UV-cured polymer-dispersed liquid crystal films" (V.G Nazarenko, S. Sarala and N.V. Madhusudana), *Jap. J. Appl. Phys.* (in press)
10. "Mesogenic properties of Nickel(II) complexes of N-(2-hydroxy-4-n-alkyloxybenzylidene)-4'-n-dodecylanilines" (Veena Prasad and B.K. Sadashiva), *Mol. Cryst. Liq. Cryst.* (in press)
11. "Crystal and molecular structures of the isomorphous bis[1,3-di-(p-n-octylphenyl) propane-1,3-dionato] palladium(II) and bis[1,3-di-(p-n-octylphenyl)propane-1,3-dionato] nickel(II) (K. Usha, Kalyani Vijayan and B.K. Sadashiva), *Mol. Cryst. Liq. Cryst.* (in press)

12. "Optical diffraction in chiral smectic-C liquid crystals" (K.A. Suresh, Yuvaraj Sah, P.B. Sunil Kumar and G.S. Ranganath), *Phys. Rev. Lett.* (in press)
13. "Symmetry properties of anisotropic dielectric gratings" (P. Galatola, C. Oldano and P.B. Sunil Kumar), *Jou. Opt. Soc. Am.A* (in press)
14. "Observations of Bright-rimmed molecular clouds near the Cepheus OB2 association" (C. Indrani and T.K. Sridharan), *Journal of Astrophysics and Astronomy* (in press)
15. "A VLA search for neutral hydrogen in cooling flow clusters" (K.S. Dwarakanath, J.H. van Gorkom, F.N. Owen), *Astrophysical Journal* (in press)
16. "High Rydberg state carbon recombination line towards Cas A: 332 MHz VLA observations and comparison with III and Molecular lines" (K.R. Anantharamaiah, W.C. Erickson, H.E. Payne and Nimisha G.Kantharia), *Astrophys. J.* (in press)
17. "High Rydberg state carbon recombination line towards Cas A: Physical conditions and a new class of models" (H.E. Payne, K.R. Anantharamaiah and W.C. Erickson), *Astrophys. J.* (in press)
18. "Radio synthesis imaging of anisotropic angular broadening in the solar wind" (K.R. Anantharamaiah, Pradeep Gotoskar, T.J. Cornwell), *J. Astrophys. Astron.* (in press)
19. "Magnetic evolution of neutron stars in wide low-mass binary systems" (M. Jahan Miri and D. Bhattacharya) *MNRAS* (submitted)



In Conference Proceedings

1. "Spin and Statics of Topological Geons in 2+1 Gravity" (J. Samuel). Proceedings of the International Colloquium on Modern Quantum Field Theory, held at Bombay 5th January to 11 January 1994
2. "The Hubbard model as a paradigm for strongly correlated electron systems" (M. DiStasio, E. Ercolesi, G. Morandi, J. Samuel, A. Tagliacozzo and G.P. Zucchelli). Proceedings of a Conference, Amalfi, 1994
3. "Approxiation and Perturbation Methods" (B.R. Iyer) *General Relativity and Gravitation, 1992*, Eds. R.J. Gleiser, C.N. Kozameh and O.M. Moreschi. (IOP Publishing, Bristol, 1993)
4. "The Generation problem in gravitational radiation theory" (B.R. Iyer) *Advances in Gravitation and Cosmology*, Eds. B.R. Iyer, A.R. Prasanna, R.K. Varma and C.V. Vishveshwara. (Wiley Eastern, New Delhi, 1993)
5. "Multipole expansion techniques for gravitational radiation problems" (B.R. Iyer) *Quantum Gravity, Gravitational Radiation and Large Scale Structure in the Universe*, Eds. B.R. Iyer, S.V. Dhurandhar and K. Babu Joseph. (IUCAA, Pune, 1993)
6. "Perturbative growth of cosmological correlations-I: Formalism" (Somnath Bharadwaj), Proceedings of the 6th Asia Pacific Regional Meeting of the International Astronomical Union.
7. "Pattern formation in the growth of smectic A liquid crystals in some binary mixtures" (R. Pratibha and N.V. Madhusudana), Proceedings of the workshop on 'Spatio-Temporal Patterns in Non Equilibrium Complex Systems'. Vol.XXI in the Saute Fe Institute Studies in the Sciences of Complexity series (Ed. P.E. Gladis and P. Palffy Muhoray), Addison-Wesley Publishing Company
8. "Corrosion inhibition study of different azoles on copper using Carbon-paste electrodes" (V. Lakshminarayanan, R. Kannan and S.R. Rajagopalan), Proceedings of the International Corrosion Congress, Houston, Texas

9. "Measurement of corrosion rate reinforcing steel and electrical resistivity of concrete using Galvanostatic steady state polarisation technique" (V. Lakshminarayanan, P.S. Ramesh, S.R. Rajagopalan), Proceedings of the International Corrosion Congress, Houston, Texas
10. "Electrochemical relaxation techniques for the measurement of instantaneous corrosion rates" (V. Lakshminarayanan and S.R. Rajagopalan), Proceedings of the International Corrosion Congress, Houston, Texas
11. "Observations of Bright-rimmed molecular clouds near massive stars" (C.Indrani and T.K. Sridharan), Proceedings of 6th Asia Pacific Regional Meeting of the International Astronomical Union.
12. "The interstellar medium surrounding the vela supernova remnant" (T.P. Saravanan, A.A. Deshpande and G. Srinivasan), Proceedings of the 6th Asia Pacific Regional Meeting of the International Astronomical Union.
13. "Evolution of magnetic fields of neutron stars in low-mass binaries" (M. Jahan Miri and D. Bhattacharya), Proceedings of the Asia Pacific Regional Meeting of the IAU, held in Pune, August 1993
14. "Ionized gas in the inner galaxy" (K.R. Anantharamaiah, F.J. Lockman, Nimisha G. Kantharia and Anish D. Roshi), Proceedings of Asia Pacific Meeting held in August 1993 (to be published as supplement to J. Astrophys. Astron., by the Indian Academy of Sciences)
15. "Radio recombination lines from external galaxies" (K.R. Anantharamaiah, Jun-Hui Zhao, W.M. Goss and F. Viallefond), Proceedings of Asia Pacific Meeting held in August 1993 (to be published as supplement to J. Astrophys. Astron., by the Indian Academy of Sciences)
16. "Molecular, Atomic and Ionized Gas towards CasA" (Nimisha G. Kantharia, K.R. Anantharamaiah, W.C. Erickson and H.E. Payne), Proceedings of Asia Pacific Meeting held in August 1993 (to be published as supplement to J. Astrophys. Astron., by the Indian Academy of Sciences)
17. "Radio synthesis imaging of Scatter-broadening at small solar elongations" (K.R. Anantharamaiah, Pradeep Gothoskar and T.J. Cornwell), Proceedings of Asia Pacific Meeting held in August 1993 (to

be published as supplement to J. Astrophys. Astron., by the Indian Academy of Sciences)

18. "Evolution of the magnetic field of an accreting neutron star" (Sushan Konar, Dipankar Bhattacharya, Vadim Urpin), Proceedings of the Asia Pacific Regional Meeting held at IUCAA, Pune in August 1993

Books Edited

1. "Advances in Gravitation and Cosmology" Eds. B.R. Iyer, A.R. Prasanna, R.K. Varma and C.V. Vishveshwara, (Wiley Eastern, New Delhi, 1993)
2. "Quantum Gravity, Gravitational Radiation and Large Scale Structure in the Universe" Eds. B.R. Iyer, S.V. Dhurandhur and K. Babu Joseph, (IUCAA, Pune, 1993)