RAMAN RESEARCH INSTITUTE

Bangalore

Annual Report 1994-95

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 Theoretical Physics, Liquid Crystals, and Astronomy & Astrophysics.

1. 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.

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. A new dimension to our LC research has now been added – the study of soft condensed matter.

3. 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 3^0 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 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. Another interactive project nearing completion is the low frequency (150 MHz) Mauritius Radio Telescope (MRT) built at Mauritius in collaboration with the University of Mauritius and the Indian Institute of Astrophysics for a radio map of the southern sky at full resolution of $4' \times 4'$.

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.

4. Experimental Optics

In view of the rapid and important recent advances made worldwide in modern optics, its enormous potential and taking full advantage of our traditional strength in this field, a modern optics laboratory is being set up at this Institute to address several basic problems, e.g., polarization optics and geometrical phases, interferometry, squeezing and noise, imaging, etc. This will have substantial overlap with our research activities in the field of liquid crystals and astronomy.

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

Gravitational Waves from Collapsing Compact Binaries: Using a recently developed second-post-Newtonian (2PN) accurate wave generation formalism, following quantities of observational interest have been calculated: (1) *source* quadrupole moment of a point-mass binary with finite mass ratio in circular orbits, (ii) the gravitational waveform and energy loss rate for a quasi-circular orbit, and (iii) the radiation reaction effects on the orbital frequency and phase. These are shown to contribute significantly to the accumulated phase of the theoretical template to be used in matched filtering of data from the LIGO/VIRGO gravitational wave detectors, expected to be operational by 1998.

Positive Energy Theorem of General Relativity (GR): Using the Ashtekar variables, a simplified proof for the positive energy theorem of GR was given that has the advantage of treating the Bondi mass and the ADM mass from a unified view-point.

Large-Scale Gravitational Clustering in an Expanding Universe: Statistical Approach: Lowest-order non-linear correction to the evolution of two-point correlation function of fluctuations for a critical matter dominated expanding background universe, filled with a system of collisionless particles interacting through Newtonian gravitation, was calculated using the BBGKY hierarchy for the distribution function. This allowed the initially assumed single-stream Gaussian perturbation to evolve to multistreaming, and yet the calculated two-point correlation agreed with the Zeldovich single-stream approximate results. This was found to hold to all orders of perturbation suggesting that the multi-stream effect, e.g. pressure, vorticity, are essentially non-perturbative in nature. Higher-order (3-point) correlation functions were also investigated.

Collisionless Stellar Dynamics and Gravitational Clustering: In the area of collisionless systems, one approach is to replace the formally infinite degrees of freedom contained in a phase space distribution function by a smaller and more tractable number, such as moments. Analysis of one such scheme, due to Channel at Los Alamos (and developed for particle beams in accelerators), showed the unexpected result that no matter how many moments were retained, the system would show only periodic behaviour! An improved scheme, based on the cumulant expansion has been set up. It differs in an essential way because it does not give rise to a Hamiltonian system, a feature which should be regarded as essential to reproduce the relaxation to a steady state by phase mixing. Work is in progress.

In the area of gravitational clustering, earlier work on scaling laws for clustering was extended to cases of current interest, namely nonflat models. Also, a variant of the adhesion model has been developed which has the advantage of being a limiting case of the exact dynamics. It passes qualitative tests but quantitative comparison to full scale N-body simulation is for the future.

Geometric Phase: Merons: The precise relationship between the Thomas Precession of a Dirac electron, the Meron and the Berry phase in NQR was clarified. It was shown that the non-abelian gauge field describing the Thomas Precession is globally trivial, thus correcting a subtle confusion in published literature.

Geometric Phase: Polarization Optics: Several interesting spinorial geometric phase-shifts induced by polarization-changes were exposed, analysed, experimentally verified, and prescribed for possible applications. Specifically (i) it was demonstrated that there is a discontinuous change in the sign of the pi-phase shift as function of control parameters that arises from a nodal-singularity of the wave-amplitude in the parameter space. Such phase jumps (of topological origin) are normally missed when the interference effects are probed through changes of the fringe pattern, (ii) a non-dispersive *geometric phase lens* using a QHQ combination was proposed, (iii) use of a QHQ combination as a variable linear retarder was proposed and its device potential as a phase-only modulator was demonstrated using a ferro-electric liquid crystal.

Interfacial Growth and Roughening in Imbibition: When a liquid (water) visualized by a solute dye (ink) is imbibed by a porous medium (filter paper), a roughened interfacial front grows. The associated critical exponent was evaluated experimentally and by computer simulation of an automaton growth model and was found to be non-universal (possibly evaporation rate dependent) in marked disagreement with the universality claimed in the recent literature. Also, the simulation suggests the roughened interface to be self-organized critically.

Non-Equilibrium Growth Model: A non-equilibrium model for conservative growth with non-conservative Gaussian white noise was studied by using Dynamic Renormalization Group (DRG). This leads to correct description of the pre-asymptotic regime, and identifies universality classes. Application to Molecular Beam Epitaxy (MBE) is envisaged.

Ferrofluid Phases in Magnetic Field: Phase diagram for a planar ferrofluid involving ordering of the magnetic holes in an applied magnetic field was studied for different field orientations. For the field normal to the plane, the phase diagram was in agreement with the one calculated using the density functional theory. For the parallel configuration, however, there was marked disagreement owing presumably to the formation of chains of holes.

Universal Diamagnetism of Charged Bose Field: A charged spinless relativistic Bose field was shown to be diamagnetic for all temperatures, with or without interaction. Finite results were obtained through a momentum cut-off regularization based on mode-counting. This generalized the earlier work for finite number of degrees of freedom. Perfect Meissner effect (flux expulsion) below a critical external magnetic field is obtained, suggesting 'superconductivity'.

Universal Minimum Metallic Diffusivity: Disordered Conductors: It was shown that the consistency of the Schrödinger equation, for the probability amplitude of a particle moving in a static random potential with the Diffusion equation for the associated probability density subsuming electrical transport, requires a minimum value for the metallic diffusion constant = $\hbar/2m$ which is universal. Implications for Mott's minimum metallic conductivity and the two-spectral fluid model are pointed out.

Decoherence at Absolute Zero: The question whether there is loss of quantum coherence at absolute zero of temperature was posed and answered in the affirmative. For a free particle coupled to an Ohmic bath of harmonic oscillators, the off-diagonal elements of the density matrix in the position representation are shown to decay algebraically, and not exponentially as is usually the case in the high temperature limit.

LIQUID CRYSTALS

Investigations on growth patterns of smectic liquid crystals were continued. Recently, in some binary mixtures, some unusual smectic-A structures have been found which interact with each other to form chains. Some quantitative studies have been made on the locomotion of smectic C cylindrical structures which arises due to their vectorial symmetry. In some cases the velocity appears to be too fast compared to an estimate based on the anisotropic diffusion mechanism.

Measurements of the electrooptic response of antiferroelectric liquid crystals synthesized in our laboratory have been extended to a new geometry with homeotropic boundary condition. While in the case of homogeneous boundary condition previously employed the surfaces had a very strong influence on the phase transitions, in the new geometry this influence is not so strong. Further, a peak has been observed in the electrooptic response as a function of frequency in the antiferroelectric phase. At present attempts are made to work out a theoretical model to account for the experimental results.

The electrooptic response of nematic liquid crystals with strong positive dielectric anisotropy has been investigated under the action of very large electric fields ($\sim$ 10 v/μm). An unexpected peak has been observed in this response as a function of voltage. Detailed investigations are being conducted to elucidate the origin of this response.

Synthesising and purifying carbon nanotubes have been started recently. Colloidal suspensions of the nanotubes have been obtained leading to the possibility of several experimental studies.

Several theoretical investigations have been carried out on field induced unwinding of the cholesteric phase which has a spontaneously twisted structure. An unusual transition has been found which is driven by a single soliton when the field is applied parallel to the twist axis. In cholesterics with negative diamagnetic anisotropy, it is predicted that an intertwisted pair of solitons, one with arbitrary winding ($\neq \pi$) and the other with a winding of π will be induced by the field.

The problem of chiral to achiral transition mediated by disclinations as well as multi solitons is being studied. Many new results like the occurrence of tricritical points, Lifshitz points etc., have been found in this type of transition. The dynamics of solitary waves in ferronematics as well as smectic C are being theoretically investigated. In particular, highly distorted slowly moving solitary wave solutions have been found.

Theoretical investigations on static periodic instabilities in nematic samples is extended to materials with both negative as well as positive dielectric and diamagnetic anisotropies. The dynamics of the system after a sudden application of the field is also being worked out. A collaborative effort in interpreting the experiments on electric field induced periodic instabilities taken up at Wooster College (USA) is also being pursued.

A perturbation analysis has been used to show that the periodic modulation of the intensity of diffraction in the phase grating mode of smectic C^* liquid crystals arises from a coupling between different orders of scattering.

Experimental investigation have been undertaken on the spreading of a smectogenic compound at the air-water interface. A transition from a monolayer to multilayer structure is found at lower temperatures while at higher temperatures, several micron thick layers appear to form.

Various physical properties of ferroelectric liquid crystals like the pitch, polarisation and dielectric constants have been measured as functions of pressure.

A new addressing technique has been proposed for displaying restricted patterns, as for example in oscilloscopes, on liquid crystal matrix displays. The new technique has a selection ratio which is independent of matrix size and a supply voltage requirement which is much lower than that for the line by line addressing technique which was also proposed earlier from our laboratory.

Developmental work on amorphous twisted nematic and polymer dispersed liquid crystal displays is progressing.

In the chemistry laboratory, two new areas of synthesis work were taken up: (a) Many homologous series of compounds exhibiting antiferroelectric and twist grain boundary phase have been synthesised and characterised. (b) Polysiloxanes exhibiting the ferroelectric liquid crystalline phase have been synthesised. In addition, synthesis of metallodiscogens is also being pursued.

In the electrochemistry laboratory, the fabrication of a scanning tunneling microscope is progressing well: The micro positioner and feed back mechanisms have been developed. A new electroanalytical technique for the study of corrosion inhibition of silver has been developed using chemically modified electrodes in collaboration with the National Aerospace Laboratory. In addition, metal finishing work is being carried out on various components needed for the GMRT project.

ASTRONOMY AND ASTROPHYSICS

Mauritius Radio Telescope

Optimal tuning of the telescope has been completed by observing a set of calibration sources. Roughly 20% of the data required for a full resolution ($4' \times 4'$) synthesis imaging has been acquired. This data collection was arranged in such a way that one has already been able to produce a complete map of the southern sky with a coarse resolution of $1/2° \times 1/2°$. These maps have the right resolution and sensitivity required to compare with earlier observations done at 408 MHz, and also at 34.5 MHz with the Gauribidanur Radio Telescope. Flux calibration, as well as astronomical interpretation of these low-resolution images is in progress.

Pulsars

Distances to some southern pulsars: Absorption measurements were made using the 21 cm line of neutral hydrogen in the direction of about eight southern pulsars with high Dispersion Measures. These observations were done with the Parkes Telescope in Australia. This data has been analysed and distance limits to five pulsars were obtained by examining the absorption profiles. This should provide useful constraints on the electron density distribution in the inner Galaxy. A new algorithm was developed and used for fitting baselines to the absorption profiles (in collaboration with W. Wilson, E. Davis, D. McConnell, P.M. McCulloch).

Pulsars in globular clusters: The search for pulsars in globular clusters with the Ooty Radio Telescope was continued using the new hardware specially built for this purpose. Nine candidate globular clusters were chosen in which there is at least one known pulsar, and out of these two were looked at carefully. For each of these two clusters observations were made with about five different pointings in declination (to cover the size of the cluster), and five different dispersion measures were tried for each of these pointings. A new mode for acquiring a time sequence with a reduced sampling rate was achieved by using an already existing mode for synchronous averaging with appropriate choice for the folding period, the number of samples, the period bins etc.. Analysis of the data is in progress (in collaboration with J.G. Ables, D. McConnell, M. Vivekanand).

Measurements of Faraday rotation using the Ooty Radio Telescope: A novel method was employed in which one made use of the fact that the amount of Faraday rotation depends on the frequency; this causes the apparent position angle

of any linearly polarized radiation to rotate as a function of frequency. Such a source when observed using fixed linear polarization antenna will show intensity modulation across the band. In these observations intensities of pulsars measured over a wide band using the Ooty Radio Telescope were used to estimate their linear polarization characteristics and the amount of Faraday rotation caused by the intervening medium. Measurements over large hour-angle ranges were made to study the contribution from the ionosphere to the amount of rotation observed.

Pulsar timing with the Ooty Radio Telescope: A programme has recently been undertaken to study the timing noise in the pulse arrival times from relatively long period pulsars. For this purpose a suitable hardware system was designed and built. This system will use an observatory clock that will keep time using a Rubidium oscillator as a local frequency standard. Any possible drift in the local time standard will be monitored using pulses from a GPS receiver. This hardware has been successfully tested in the laboratory, and observations using the Ooty Radio Telescope will commence shortly.

Pulsar search with the Ooty Radio Telescope: The survey that was started a couple of years ago has continued and nearly 150 square degrees of the sky has been covered (1500 fields). The analysis of this data is in progress. So far there are 15 suspected pulsar candidates and these will be re-observed in the near future for confirmation.

Average pulse profiles: The rate of stabilization of the average pulse profiles was studied for over two dozen radio pulsars. The pulse-to-pulse profile variations were separated into three components: evolution arising from changes in the intensity, phase, and the width of the pulse maximum. The rate of stabilization was found to vary from pulsar to pulsar, and a correlation analysis of this rate of stabilization with other pulsar properties gave some insights into the processes governing irregular variations from pulse to pulse. The stabilization rate for the polarized emission was also studied. This was generally found to be slower than the rate for the total intensity (in collaboration with J.M. Rankin).

Orthogonal polarization modes: A detailed investigation of single-pulse behaviour with respect to orthogonal polarization modes revealed that a correlation exists in most pulsars between the intensity at a given longitude and the polarization mode. In many instances higher intensities could be associated with either the infrequent mode or the dominant mode. However, in some instances no specific correlation was detected between the intensity and the occurrence of the orthogonal mode (in collaboration with J.M. Rankin).

Magnetic field decay in neutron stars: Investigation of the spin-down induced magnetic flux expulsion from neutron star cores in isolated pulsars, as well as massive X-ray binaries was continued. It was shown that this model provides a consistent picture of neutron star magnetic field evolution provided that the ohmic diffusion timescale after the expulsion lies in the range 10−100 Myr.

In a related study, a detailed modelling of the ohmic evolution of the magnetic flux after its expulsion from the superconducting interior suggests that diffusion timescales $\sim$ 100 Myr is what one would expect if the crustal lattice has moderate concentration of impurities and if the evolution of the magnetic field is purely diffusive (in collaboration with B. Datta).

Glitches: In the standard model, sudden spinning up of neutron stars and their subsequent relaxation are attributed to collective un-pinning and re-pinning of vortices in the crustal superfluid, and their thermally activated creep. The recent giant glitches in the Vela pulsar have clearly brought out the inadequacy of this model. An investigation was begun to construct an alternative theory of glitches based upon the pinning between the quantized fluxoids in the superconducting interior and the quantized vortices in the core superfluid. Preliminary indications are that if this pinning is important then it may have a variety of implications for the glitch phenomena itself, as well as the post-glitch relaxation.

Recycled pulsars: A Monte-Carlo simulation was undertaken to estimate (1) the fraction of pulsars recycled in massive binary systems, and (2) the coalescence rate of double neutron star systems in the Galaxy. The motivation for asking the first question was to find additional support for the conclusion arrived at earlier that as much as 10−15% of the solitary pulsars may have evolved in binary systems which were disrupted at the time of the second supernova explosion. The estimation of the total number of double neutron star systems in the Galaxy is of interest in the context of their spiralling in due to gravitational radiation and their eventual coalescence. The coalescence rate in the Galaxy is an essential input for estimating the total rate in the nearby clusters of galaxies. This question is of paramount importance in the context of designing gravitational wave detectors. This study is nearly complete and detailed conclusions can be drawn shortly.

Cometary Globules: Optical observations of cometary globules were undertaken with a view to studying the electron density, temperature distribution, and magnetic fields in cometary globules. Images were obtained of CG 22, ORI-12, and one of the globules in Cepheus OB2 in the Hα line using the Vainu Bappu Telescope

in Kavalur. These images clearly show Hα emission from bright rims, but more observations are needed to establish emission from the tail region.

Polarization studies were undertaken in order to understand the structure of the magnetic fields in cometary globules. Detailed observations were done with the 40" Telescope in Kavalur towards several background stars in the direction of CG 22. The observed pattern of polarization in the light from these stars suggests fairly strong magnetic fields $\sim 70\mu G$ in these globules aligned parallel to the tail. The strength of the deduced field is large enough to be dynamically important. Indeed, some of the structures seen in the tails may be caused by the frozen-in magnetic fields.

Recombination lines from external galaxies: Further observations of the southern galaxies NGC 4945 and Circinus were made with the Australia Telescope using additional configurations (up to 6 km baselines for NGC 4945, and down to 375 m for Circinus). NGC 4945 turned out to be the strongest recombination line source at 8.6 GHz and the velocity field in the central region of this galaxy was studied with a resolution of 1 arcmin. Recombination line was searched for in three more starburst galaxies (NGC 3256, NGC 7552, and NGC 6221), and two Seyfert 2 galaxies (IC 5063 and 18325−5926). There is a possible detection in NGC 3256. Data taken earlier on the Seyfert 2 galaxy NGC 1068 was re-analysed and a possible line at 8.6 GHz was found. Further observations are planned to confirm this.

Recombination line survey: The recently built multi-line spectrometer was used with the Ooty Radio Telescope to undertake a survey of hydrogen and carbon recombination line emission near the galactic plane. This study was done in two parts. In the first part a complete survey was made of the inner galactic plane accessible to the Ooty Radio Telescope with a coarse resolution of $2^\circ \times 2^\circ$ by using just one module of the telescope. Recombination lines were detected in more than 80% of the positions observed, and there have been many new detections. In the second part, several sections of the galactic plane were surveyed using the full resolution available at the telescope ($2^\circ \times 6'$). In all about 300 spectra have been obtained. Interpretation of this data is in progress.

Low-frequency recombination lines: Observations of carbon recombination lines at 34.5 MHz using the newly commissioned 8-line digital spectrometer at the Gauribidanur Radio Telescope has begun. Using the 1.4×0.5 km T-array data was collected towards 15 directions in the galactic plane with effective integration times of few tens of hours in each direction. The line was successfully detected towards Cas A with the expected strength. Possible new detections have been obtained in two other directions. The observations are continuing.

Ultra-compact HII regions: An improved criterion was obtained for reliably identifying ultra-compact regions from existing databases. This was necessary because the existing procedure for selecting these regions from the Infrared Point Source Catalogue (using the 2-colour criterion of Wood and Churchwell) suffers from significant contamination of the sample by cloud cores with low mass stars embedded in them. The improved criterion that has been suggested relies upon the differences in the radio properties of cores with embedded high mass stars compared to those that have low mass stars in them. It was shown that when this is taken into account the total number of potential ultra-compact HII regions in the Galaxy is likely to be approximately a factor of four less compared to what was previously estimated. This reduction in the total number eases the birth rate problem for massive stars.

Methanol Masers: A survey was undertaken of approximately 10 square degree region of the galactic plane for maser emission from the 6.7 GHz transition in CH_3OH. This was carried out using the 26 m dish at Mt.Pleasant (University of Tasmania, Hobart). The survey was sensitive to masers with peak flux density greater than $\sim 2.6 Jy$. Fifty distinct masers were detected, and out of these 26 were new detections. It was concluded that many CH_3OH masers are not associated with infrared sources (from the IRAS Catalogue), and that some are associated with sources that have colours differing from those of typical ultra-compact HII regions. This finding led to the suggestion that the number of ultra-compact HII regions in the Galaxy may be significantly more than the estimates based upon their association with infrared sources (in collaboration with S.P. Ellingsen, M.L. von Bibra, P.M. McCulloch, R.P. Norris, C.J. Phillips).

Carbon monoxide observations: The data obtained with the 10.4 m Millimeter-wave Telescope at RRI in the direction of about 200 extended radio emission regions in the galactic plane was analysed. ^{12}CO emission was found in more than 60% of the sources. One of the extended sources PKS 0607+17 with very strong ^{12}CO emission was completely mapped with a resolution of 10′ using a coarse graining technique. Analysis of this data is in progress.

Radio counterpart of hard X-ray sources: It was shown in an earlier study that the well known hard X-ray source in the Galactic Centre region 1E1740.7−2942 (which flared in X-rays and also in the 0.5 MeV electron-positron annihilation line) was associated with a radio source with morphology similar to that of radio galaxies. Recently the hard X-ray source EXS 1737.9−2952 was observed using the Very Large Array. Continuum images were made at 20 and 6 cm with an rms $\sim$ 80 and $\sim$ 30 μJy, respectively. Four radio sources were detected

within the error box of the X-ray source. So far it has not been possible to identify any one of these four sources as the radio counterpart of the X-ray source. Further observations are planned which might elucidate this question (in collaboration with Ph. Durouchoux and P. Wallyn).

Gaseous Nebulae: Radio continuum observations at 330 MHz of the W51 complex were made using the Very Large Array to estimate the electron temperature in the brightest HII region in the nebula. The derived value ($> 7500K$) was consistent with electron temperature estimates based on radio recombination line observations, and showed no evidence for a radial temperature decrement within the HII region as previously claimed. On the contrary, there is likely a radial increase in electron temperature within the Stromgren sphere (in collaboration with W.M. Goss).

Angular broadening in the Solar wind: Analysis and interpretation of the data on angular broadening of radio sources whose lines of sight pass within 0.5–4 degrees of the Sun was completed. The main results were as follows. The angular broadening is *anisotropic* with axial ratios in the range 2–16. Larger axial ratios were observed preferentially at smaller solar distances. If the anisotropy is interpreted as due to scattering by blobs elongated along the direction of the magnetic field, then the data indicates that the field lines are *non-radial* even at the largest heliocentric distances observed. Comparison with earlier results suggests that the level of turbulence may be higher during solar maximum. Assuming a power-law spectrum for the electron density fluctuations, the fitted exponents are in the range 2.8–3.4 for scale sizes between 2–35 km. The data also suggests temporal fluctuations in the spectral exponent on a timescale of a few tens of minutes.

Neutral hydrogen absorption in Hydra A: Observations were done with the Very Large Array in the 21 cm line of neutral hydrogen towards the core of the radio galaxy Hydra A. This is the central galaxy in the well known cluster Abell 780. These observations with improved spatial and velocity resolutions ($\sim 2'$ and ~ 1.4 km/s, respectively) indicate that the absorption arises very close to the nucleus, probably in a gaseous disc located in the central regions of the Galaxy. There was no evidence for absorption that might arise from a cooling flow of gas towards the centre of the cluster. The absorption feature could be decomposed into six Gaussian components with widths ~ 10–20 km/s and optical depths ~ 0.1–0.5. No narrow line features (~ 1 km/s) were, however, detected in Hydra A (down to a 3σ optical depth limit of 0.06) (in collaboration with F.N. Owen, J.H. van Gorkom).

Butcher-Oemler Effect: This effect is the occurrence of higher proportion of blue galaxies in clusters as the redshift increases to 0.5. An earlier observation of the cluster A2125 at a redshift of 0.25 revealed $\sim$ 140 radio sources within the primary beam of the telescope. Of these 36 had optical counterparts. This is very much larger than the number of associations that one expects. In the continuing effort to understand this, and also to interpret the Butcher-Oemler effect, radio observations of four other clusters are under way using the Very Large Array (in collaboration with F.N. Owen).

Radio Galaxies: The Australia Telescope was used to observe a sample of (southern) giant-sized radio galaxies to probe their environment viz. the intergalactic medium. Galaxy counts in the fields of the radio galaxies were used as an estimator of the invisible gaseous environment. It was concluded that sources located in environments with higher galaxy densities and presumably higher densities of the ambient intergalactic gas tend to have more uniform bridge structures (in collaboration with Lakshmi Saripalli, R.W. Hunstead).

Microwave background: The Australia Telescope Compact Array was used in a continuing experiment to measure the arcmin-scale anisotropy in the cosmic microwave background. Observations were made with an ultra-compact array to improve the brightness sensitivity over the results obtained earlier. Further observations were made at a factor of two lower frequency, and a factor of two more extended array, to measure the contamination due to foreground discrete sources. The reduction of these observations is in progress (in collaboration with M.J. Kesteven, R.D. Ekers, M. Sinclair, J. Silk).

INSTRUMENTATION FOR RADIO ASTRONOMY

GMRT-Pulsar Receiver

(a) A 30-dish array combiner for use at GMRT was designed and is presently being fabricated. The design caters to 32 MHz operation and incorporates a facility to compensate the gain variations across the band and also from dish to dish. High speed tests conducted on the subsystems have given encouraging results.

(b) The design specifications and hardware details of the polarimeter and a DSP-based processor for pulsar observations were worked out and finalised. The system design consists of a polarimeter followed by a bank of 16 DSP-based processors. Each of these processors will cater for signals over 2 MHz bands. The data from each of the 2 MHz band will be corrected for the Faraday rotation as far as possible,

processed separately and recorded. Final corrections for the ionospheric Faraday rotation will be made during later processing.

Several pulsar signal processing modes required for different applications are provided using the programmability of the DSP chip. A prototype DSP-based processor was built and successfully tested. The complete system is now being fabricated.

GMRT 21 cm project: Four 21 cm Front-end Receivers complete with all the subsystems have been installed on GMRT dishes. Field tests on individual dishes were carried out to determine the aperture efficiency, system temperature, power level etc.. Initial tests have been extremely encouraging. The production of the remaining units is in full swing.

Millimeter-wave astronomy: Work on the 3-stage low-noise amplifier using high electron mobility transistors (HEMTs) was continued. After getting satisfactory results at room temperature the design of the circuit was optimised for cryogenic operation. But stabilisation turned out to be difficult under cryogenic conditions. It was therefore decided to build a single-stage amplifier for cryogenic operation. This has yielded satisfactory results: a gain of 13.4 db around 4 GHz, gain bandwidth of about 10.1 db, and an average noise temperature of 5 K.

The collaborative project with the Chalmers University of Technology, Sweden for designing and making low-noise HEMT amplifiers in the frequency range 20–26 GHz and 43–50 GHz is continuing.

The other collaborative project undertaken with the Onsala Space Observatory for the design and construction of a digital correlator was successfully completed. After building the necessary interface this correlator has been integrated into the 10.4 m Millimeter-wave Telescope. Initial tests have been successful, and it is planned to use this correlator in the coming observing season.

Preliminary work on a whisker-contacted cooled Schottky barrier diode mixer for single sideband performance with 4 GHz IF has been carried out. Initial measurements have given encouraging results with a minimum sideband rejection of about 14 db at 4 GHz IF. Further work is continuing.

A tunable Gunn oscillator working in the fundamental mode in the frequency range 37–46 GHz giving a minimum output power of 30 milliwatts was designed and fabricated. This Gunn oscillator was also successfully phase-locked to a 400 MHz stable reference in the whole frequency range.

COMPUTERS

Major changes took place in the computing facilities at the institute. The VAX 11/780 system which was the work horse since 1986 was decommissioned and donated to an Engineering College. Twelve new workstations (8 DEC Alpha and 4 SUN Sparc systems) were added to the Computer Section. Astronomical image processing facility has been set up on six of these machines with a total disk capacity of about 12 Gigabytes. All the workstations are also available for general computing on a Local Area Network (LAN) with NIS facility. Electronic mail operations has been moved to a Sun workstation and is working efficiently round the clock through an automatic dial up line to the Indian Institute of Science. A 19 kbaud lease-line between the institute and the ERNET node at Indian Institute of Science has provided internet connectivity to all the users. To improve the efficiency of the LAN and to readily access large amounts of data residing in any workstation, purchase order has been placed for a 16-port ethernet switch and a few inter-connecting bridges. To provide connectivity to the workstations through X-terminal facility from various locations in the institute, 15 PCs (486 DX2 based) with X-window software were also ordered. The central computing facility now runs on a reliable uninterrupted power supply.

Ph.D.

Awarded

Name	Topic of Study
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

An SERC School on Liquid Crystals funded by DST was organized by the Institute during 2-20 May 1994. About sixty participants were selected for the school from all over the country. The participants were either fresh Ph.Ds or those with at least two years of research experience in their Ph.D. programme. The topics covered various aspects of the subject including chemical structures of the compounds, theories and applications of thermotropic, lyotropic, polymeric and biological liquid crystals. Several speakers from different R & D institutions and universities in the country delivered the lectures. In addition, three evening lectures of general interest were also arranged. The participants also had ample opportunity to visit the laboratory as well as the library during the period.

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, 144 lectures were given by them at other places.

Gandhi Memorial Lecture

The Gandhi Memorial Lecture for 1994 was given by Prof. M.S. Swaminathan on "Job-led Economic Growth in Rural India", on 2 October 1994.

Colloquia

The scientists of the Institute and visiting scientists both from within and outside the country gave 34 colloquia at the Institute on different topics during the year.

Journal Club Meetings

Eleven 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 informal meetings in Theoretical Physics, Liquid Crystals and Radio Astronomy meetings were held.

Visiting Scientists

A Five-Member Chinese Delegation led by Dr. Lou Zhaomei from the National Council for Science Foundation visited the Institute on 13 September 1994. Also, a number of scientists from institutions within the country and outside visited the Institute during the year. Their names are listed following those of the scientific and technical staff of the Institute given towards the end of the report.

Library

During the year, 285 new books were added to the library, bringing the total number of books to 18748. Of these, 38 were received gratis. One journal was discontinued as it ceased publication and one more journal was added to the list of subscribed journals. Hence the total number of subscribed journals remained the same at 143. Of these, 20 are received by airmail. In addition to this, the library has ordered several books for the Mauritius project and also subscribed to 5 journals for them. IAU circulars, some newsletters and preprint bulletin boards are being received by e-mail on an electronic bulletin board accessible to all RRI staff on the internal network. The internet facility is being used increasingly to get various kinds of information like bibliographic details of books and to search for journal articles. The work of creating the library database is being continued. The library keeps in contact with the other Bangalore libraries through inter-library transactions and by participating in the Bangalore Special Libraries Group activities. The library facilities are also being used by the staff/students from the Indian Institute of Astrophysics, Indian Institute of Science, National Aerospace Laboratories, Indian Space Research Organization and Tata Institute of Fundamental Research Centre, Bangalore.

Others

General

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

PLAN – RECURRING AND NON-RECURRING	Rs.350.00 Lakhs
NON PLAN – RECURRING	Rs.235.00 Lakhs
Total	Rs.585.00 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) up to 3 August 1994
N. Kumar (assumed charge as Director from 3 August 1994)

Abhijit K.Kshirsagar
K.R. Anantharamaiah
P.G. Ananthasubramanian
Antony Joseph
R. Bhandari
D. Bhattacharya
K. Chandrasekhara
S. Chanthrasekharan
Chitra M. Gokhale
Deepak Kumar Menon
B.S.Deepika*
A.A. Deshpande
V. Devadas
K.S. Dwarakanath††
M.S. Ezhilarasi
R. Ganesan&
M.R. Gopalakrishna
K. Gurukiran
B.R. Iyer
S. Kathyayini
P.A. Kamini
U.D. Kini
S.Krishna Murthy*
S. Krishnan
S. Krishna Prasad
V. Lakshminarayanan
Lakshmy P. Usha
S.Madhavi*
N.V. Madhusudana
M.O. Modgekar
Mohd. Imtiyaz
H.N. Nagaraja
R. Nandakumar
H. Narayanan
R. Nityananda
T. Prabu
R.Pratibha
E. Palanichamy
V.Radhakrishnan
K.B. Raghavendra Rao
A. Raghunathan
V.A.Raghunathan*
P. Rajasekar
P.S. Ram Kumar
P.N. Ramachandra
C. Ramachandra Rao
P. Ramadurai
S.Ramaseshan
K. Ramesh Kumar
B. Ramesh
G.S. Ranganath
N. Ravi Sankar
Ravi Subrahmanyam*
B.N.Ravishankar*
D.K.Ravindra
G. Rengarajan%
T.N.Ruckmongathan

B.K. Sadashiva
P.B. Sadik
P.Sandhya*
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
B. Sridhar
T.K. Sridharan
G. Srinivasan
K. Subramanya
M.R. Subramanyam
H. Subramonyam
K.A. Suresh
V. Suresh Rao
S. Swarna
B.K.Udaya Shankar*
N. Udaya Shankar
S.Venkatesh Prasanna*
C. Vinutha

Research Fellows

Amitabha Bhattacharyya
N. Andal
Arun Roy
Debnarayan Jana
Dipanjan Mitra*
Geetha Basappa
A. Gopakumar
C.R. Gopalakrishna
C. Indrani
Jayadev Rajagopal
Kamala Kanta Swain*
N. Kasturaiah
Mehdi Jahanmiri[1]
Nimisha G. Kantharia[1]
P.A.Pramod
Raka Dona Ray*
R. Ramachandran
T.P.Saravanan
D.S. Shankar Rao
Sobha R. Warrier
Somnath Bharadwaj[1]
Subramanian Raman*
P.B. Sunil Kumar
Sushan Konar[1]
Sreejith Sukumaran
P.K. Thiruvikraman
Veena Prasad
Yuvaraj Sah

Post-Doctoral Fellows

Alan R. Daughton
N.Rathnashree
T.R.Ravindran*
Supurna Sinha*

Visiting Professors/Scientists

T.G.Ramesh
A. K. Sood
A.K.Saxena

Consultant Physicians

M.R. Baliga
A.R. Pai

Resignations

V. Anand
R.Anantha
R.Archana Ghode
Geetha Nair
S.P.Gnana Raj
P.A.Johnson
Madhu Girimaji
K.S.Nagesh
Pravin Kumar Pereira
N.G.Raghavendra Rao
Y.Sindhu
M.J.Tulja Ram
Varghese George
V.Vijay
R.Vijayaraghavan

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†† On leave with the National Radio Astronomy Observatory, Socorro, USA, until 5.1.1995 New Mexico, USA

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

% On leave with the Universitat fur Bodenkultur Wien, Vienna

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[1] Under the Joint Astronomy Programme at the Indian Institute of Science

LIST OF VISITORS

Richard G. Dodson Durham University Durham, U.K.	April 8-25, 1994
Yeshwant Singh Banaras Hindu University Varanasi	April 30 - May 14, 1994
V. V. Kumar Hindusthan Lever Ltd. Bombay	May 5-7, 1994
Usha Deniz Bhabha Atomic Research Centre Bombay	May 11-14, 1994
Subhas Chandra National Physical Laboratory New Delhi	May 17-20, 1994
Joanna M.Rankin University of Vermont Vermont, USA	May - June 1994
M.S.Swaminathan M.S.Swaminathan Research Foundation Madras	October 2-4, 1994
Roy Booth Onsala Space Observatory Chalmers University of Technology Onsala, Sweden	October 18-24, 1994
A. Omant Institute of Astrophysics Paris, France	November 20-22, 1994
Onno Pols Institute of Astronomy Cambridge, U.K.	November 22 - December 1, 1994
Satyendra Kumar Kent State University Kent, U S A	December 4-12, 1994

Bikram Phookan National Centre for Radio Astrophysics Tata Institute of Fundamental Research, Pune	December 6-9, 1984
Abhay Ashtekar The Penn State University, USA	December 20-23, 1994
Anu Venugopalan Jawaharlal Nehru University New Delhi	January 3-9, 1995
J.P.Marcerou Centre de Recherche Paul Pascal Pessac, France	December 5-12, 1994
Dr. A.R. Prasanna Physical Research Laboratory Ahmedabad	December 12, 1994
M.V.Sadovskii Institute for Electrophysics Russian Academy of Sciences Ekaterinburg, Russia	January 20-24, 1995
A.M. Jayannavar Institute of Physics Bhubaneswar	January 11, 1995
Nandor Eber & Tiber Toth Katona Research Inst. for Solid State Physics Hungarian Academy of Sciences Budapest, Hungary	January 12-19, 1995
P. Hariharan CSIRO Division of Applied Physics Sydney, Australia	January 12-21, 1994
Devendra Lal University of California, USA	January 16-18, 1995
Stephen Lau Inter-University Centre for Astronomy & Astrophysics, Pune	January 26, 1995

Alfredo Strigazzi Politecnico di Torino Torino, Italy	February 6-24, 1995
S.Torgova Organic and Intermediate Dyes Institute Moscow, Russia	February 6-24, 1995
A.Peerally University of Mauritius Mauritius	February 7-9, 1995
R.P.Riesz Pleasant Hill, T.N., USA	February 8-12, 1995
Bissoondoyal University of Mauritius Mauritius	February 11-12, 1995
J.G.Ables CSIRO Division of Radiophysics Sydney, Australia	February 19 - March 18, 1995
Dave McConnel ATNE (CSIRO) Sydney, Australia	Feb.27 - March 6, 1995
I.D.Novikov & J.Artemova Nordisk Institut fur Astrofysik Copenhagen, Denmark	February 22-27, 1995
R.Rondelez Institut Curie Paris, France	Feb. 24 - March 3, 1995
M.Serio IUCAA, Pune	March 13-17, 1995
G.D.Love University of Durham Durham, U.K.	March 17-26, 1995

Annexure - I

PAPERS PUBLISHED

In Journals

1. "Generation of gravitational waves: the post-Newtonian spin octupole moment" (T.Damour and B.R.Iyer) *Classical & Quantum Grav.*, **11**, 1353 (1994)

2. "Length-scale-dependent ensemble averaged conductance of a 1D disordered conductor: Conductance minimum" (Nacir Tit, Prabhakar Pradhan and N.Kumar), Phys. Rev. B49, 14715 (1994).

3. "Paramagnetic Meissner effect in $YBa_2Cu_3O_{7-\delta}$: A non-resonant microwave absorption study" (S.V.Bhat, A.Rastogi, N.Kumar, R.Nagarajan and C.N.R.Rao), Physica C: Superconductivity, **C219**, 87 (1994).

4. "Novel polarization dependence in diffusing-wave spectroscopy of crystallizing colloidal suspensions" (S Sanyal, A K Sood, S Ramkumar, S Ramaswamy and N Kumar), Phys. Rev. Lett. **72**, 2963 (1994).

5. "Localization of light in coherently amplifying random media" (Prabhakar Pradhan and N Kumar), Phys. Rev. (Rapid Communications) **B50**, 9644 (1994).

6. "Discovery of top-quark at Fermilab" (A.Kshirsagar) Curr.Sci., **68**, 599 (1995)

7. "Pancharatnam's route to the geometric phase" (Rajaram Nityananda) *Curr. Sci.*, **67**, 238 (1994)

8. "Scaling properties of non-linear gravitational clustering" (Rajaram Nityananda and T.Padmanabhan) *Mon. Not. R. Astron. Soc.*, **271**, 976 (1994)

9. "Brownian motion and magnetism" (Supurna Sinha and J. Samuel) *Phys. Rev. B* **50**, 13871 (1994)

10. "Torches, clocks, mirrors and the Lorentz transformation" (J. Samuel) *Physics Education* **11**, 402 (1995)

11. "The Aharonov-Bohm effect" (J. Samuel) *Curr. Sci.*, **66**, 781 (1994)

12. "Perturbative growth of cosmological clustering: I. Formalism" (S.Bharadwaj) *Astrophys. J.*, **428**, 419 (1994)

13. "Magnetic field induced bistability in distorted nematic ground states" (U.D.Kini) *Liquid Crystals*, **17**, 65 (1994)

14. "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.Heppke and M.E.Neubert) *Mol. Cryst. Liq. Cryst.*, **238** 241 (1994)

15. "Phase diagram involving the twist grain boundary phase in the vicinity of a virtual cholesteric - smectic A - smectic C* point" (S.Krishna Prasad, V.N.Raja, Geetha Nair and J.W.Goodby) *Mol. Cryst. Liq. Cryst.*, **250**, 239 (1994)

16. "Observation of the smectic C - smectic I critical point" (S.Krishna Prasad, D.S.Shankar Rao, S.Chandrasekhar, M.E.Neubert and J.W.Goodby) *Phys. Rev. Lett.*, **74**, 270 (1995)

17. "Optical diffraction in chiral smectic-C liquid crystals" (K.A.Suresh, Yuvaraj Sah, P.B.Sunil Kumar and G.S.Ranganath) *Phys. Rev. Lett.*, **72**, 2863 (1994)

18. "Optics of absorbing anisotropic media" (G.S.Ranganath) *Curr. Sci.*, **67**, 231 (1994)

19. "Optical diffraction in some Fibonacci structures" (Yuvaraj Sah and G.S. Ranganath) *Opt. Comm.*, **114**, 18 (1995)

20. "Mesogenic β-diketones and metallonematogens" (Archana Ghode, Uma Shivkumar and B.K.Sadashiva) *Bull. Mater. Sci.*, **17**, 283 (1994)

21. "Liquid crystalline behaviour in some homologous series of β-diketones and a few of their copper(II) and palladium(II) complexes" (Veena Prasad and B.K. Sadashiva) *Mol. Cryst. Liq. Cryst.* **241**, 167 (1994)

22. "Mesogenic properties of Nickel(II) complexes of N-(2-hydroxy-4-n-alkyloxybenzylidene)-4'-n-dodecylphenylanilines" (Veena Prasad and B.K.Sadashiva), *Mol. Cryst. Liq. Cryst.*, **241**, 167 (1994).

23. "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, B.K.Sadashiva and Kalyani Vijayan), *Mol. Cryst. Liq. Cryst.*, **241**, 91 (1994).

24. "The ubiquitous phase grating" (K.A.Suresh) . *Curr. Sci.*, **67**, 978 (1994)

25. "Raman phase conjugator" (K.A.Suresh) . *Curr. Sci.*, **67**, 3 (1994)

26. "Electroconvective instabilities in nematic liquid crystals" (N.V.Madhusudana) *Phase Transitions*, **50**, 177 (1994)

27. "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.*, **33**, 2641 (1994)

28. "Electroclinic measurement of the coefficients of Landau expansion of some ferroelectric liquid crystals" (H.P.Padmini, N.V.Madhusudana and B.Shivkumar) *Bull. Materials Sci.*, **17**, 1119 (1994).

29. "Liquid crystals - Old and new" (N.V.Madhusudana) *Curr. Sci.*, **67**, 832 (1994).

30. "Pancharatnam in Mysore" (N.V.Madhusudana) *Curr. Sc.*, **67**, 259 (1994)

31. "Optical properties of a QHQ ferroelectric liquid crystal phase-modulator", (Gordon D. Love and R.Bhandari) *Opt. Comm.*, **110**, 475 (1994)

32. "Polarization eigenmodes of a QHQ retarder - Some new features" (R.Bhandari and Gordon D. Love) *Opt. Comm.*, **110** 479 (1994)

33. "Geometric phase in interference experiments" (R.Bhandari) *Curr. Sci.*, **67**, 224 (1994)

34. "Magnetic evolution of neutron stars in wide low-mass binary systems" (M. Jahan Miri and D.Bhattacharya) *Monthly Notices of the Royal Astronomical Society* **269**, 455 (1994)

35. "High Rydberg state carbon recombination line towards Cassiopeia A: 332 MHz VLA observations and comparison with HI and molecular lines" (K.R.Anantharamaiah, W.C.Erickson, H.E.Payne and Nimisha G. Kantharia) *Astrophysical J.*, **430**, 682 (1994)

36. "High Rydberg state carbon recombination line towards Cassiopeia A: Physical conditions and a new class of models (H.E.Payne, K.R.Anantharamaiah and W.C. Erickson) *Astrophysical J.*, **430**, 690 (1994)

37. "Radio synthesis imaging of anisotropic angular broadening in the solar wind (K.R.Anantharamaiah, Pradeep Gothoskar and T.J.Carnwell) *J. Astrophys. Astron.*, **15**, 387 (1994)

38. "A VLA search for neutral hydrogen in cooling flow clusters" (K.S.Dwarakanath, J.H. van Gorkom and F.N.Owen) *Astrophysical J.*, **432**, 469 (1994)

39. "Detection of an HI disk in Hydra A?" (K.S.Dwarakanath, F.N.Owen and J.H. van Gorkom), *Astrophys. J. Letters*, **442**, 1 (1995)

40. "A digital signal pre-processor for pulsar search" (P.S.Ramkumar, T.Prabu, Madhu Girimaji and G.Markandeyulu) *J. Astrophy. Astron.*, **15**, 343 (1994)

41. "Can massive X-ray binaries be the progenitors of millisecond pulsars?" (N.Rathnasree) *Comments on Astrophysics*, **17**, 263 (1994)

42. "Observations of the bright-rimmed molecular clouds near the Cepheus OB2 Association" (C.Indrani and T.K.Sridharan) *J. Astrophys. Astron.*, **15**, 157 (1994)

43. "A study of the cometary globules in the Gum Nebula - Dissertation summary (T.K.Sridharan) *Publications of the Astronom. Soc. of the Pacific* **106**, 1018 (1994)

44. "Pulsar observations at decametric wavelengths using a swept-frequency dedisperser" (A.A.Deshpande) *J. Astrophys. Astron.* **15**, 329 (1994)

45. "Application of the Poincare sphere to radio astronomy" (V.Radhakrishnan) *Curr. Sci.*, **67**, 255 (1994).

In Conference Proceedings

1. "Collisionless relaxation of dark matter" (Rajaram Nityananda) *Proceedings of the International Conference on Non-Accelerator Particle Physics*, Ed. R.Cowsik (World Scientific, 1995)

2. "Ashtekar variables and the positive energy theorem in general relativity" (J. Samuel) . *Proceedings of the Conference on Physics at the Planck Scale*, Puri, 10-21 December 1994

3. "The Hubbard model as a paradigm for strongly interacting electron systems" (M.DiStasio, E.Ercolessi, G.Morandi, J.Samuel, A.Tagliacozzo and G.P.Zuchelli) in *Superconductivity and Strongly Correlated Electron Systems*, Eds. C.Noce, A.Romano, G.Scarpetta (World Scientific, 1994) p.241

4. "Spin-statistics relations for topological geons in 2+1 quantum gravity " (J.Samuel) *Proceedings of the International Colloquium on Modern Quantum Field Theory II*, Eds. S.Das, G.Mandal, S.Mukhi and S.R.Wadia (World Scientific, 1995)

5. "Pattern formation in the growth of smectic A liquid crystals in some binary mixtures" (R.Pratibha and N.V.Madhusudana) in *Spatio-Temporal Patterns*, Ed. P.E.Cladis and P.Palffy-Muhoray (Addison-Wesley, 1995)

6. "An addressing technique with reduced hardware complexity" (T.N.Ruckmongathan) . *1994 SID International Symposium Digest of Technical Papers* Vol. XXV, pp 65-68 (1994)

7. "Recent developments in addressing passive matrix LCDs" (T.N.Ruckmongathan) *Proceedings of the Conference on Emerging Optoelectronic Technologies (CEOT-94)*, Ed. A.Selvarajan *et al.* (Tata McGraw Hill, 1994) pp 302-306

8. "High pressure studies on ferroelectric liquid crystals" (S.Krishna Prasad) in *Advances in High Pressure Science and Technology*, ed. A.K.Singh (Tata McGraw-Hill, New Delhi, 1995) p.201

Papers in Press/Submitted

In Journals

1. "Gravitational radiation damping of compact binary systems to second post-Newtonian order" (L.Blanchet, T.Damour, B.R.Iyer, C.M.Will and A.G. Wiseman) *Phys. Rev. Lett.* (in press)

2. "Gravitational waves from in spiralling compact binaries: energy loss and waveform to second post-Newtonian order" (L.Blanchet, T.Damour and B.R.-Iyer) *Phys. Rev. D* (in press)

3. "Geometry, Fields and Cosmology", (Monograph) Eds. B.R.Iyer and C.V. Visveshwara (Wiley Eastern (in press)

4. "Merons and Thomas precession" (J. Samuel) *Phys. Rev.Lett.* (submitted)

5. "Universal diamagnetism of charged scalar fields" (Debnarayan Jana) *Phys. Rev. B* (submitted)

6. "Non-universality in imbibition" (P.B.Sunil Kumar and Debnarayan Jana) *Phys. Rev. E* (submitted)

7. "Perturbative growth of cosmological clustering: II. The two point correlation" (R.Bharadwaj) *Astrophys. J.* (submitted)

8. "The evolution of correlation functions in the Zeldovich approximation and its implications for the validity of perturbation theory" (R.Bharadwaj) *Astrophys. J.* (submitted).

9. "Breakdown of universality in imbibition" (P.B.Sunil Kumar and Debnarayan Jana) *Phys. Rev. E* (submitted)

10. "Intensity and polarization features in the optical diffraction in chiral smectic C liquid crystals" (Yuvaraj Sah, P.B.Sunil Kumar and K.A.Suresh) *Phys. Rev. E* (submitted)

11. "A calculable quantum capacitance" (N.Kumar) Current Science (in press)

12. "Quantum diffusion and decoherence" (N.Kumar and A.M.Jayannavar) in *The Metal - Non-Metal Transition Revisited: A Tribute to Sir Nevill Mott*, Ed. P.P.Edwards and C.N.R.Rao (in press)

13. "On minimum metallic diffusivity in disordered conductors" (N. Kumar and A. M. Jayannavar) Current Science (in press)

14. "High-T_c superconductivity as recovery of c-axis tunneling conductivity (N.Kumar) (submitted).

15. "On the optics of twist grain boundary smectics" (N.Andal and G.S.Ranganath) *J. de Phys.* (in press)

16. "Electrooptic soft mode response of compounds exhibiting the antiferroelectric phase" (S.Sarala, Arun Roy, N.V.Madhusudana, H.T.Nguyen, C.Destrade and P.Cluzeau) *Mol. Cryst. Liq. Cryst.* (in press)

17. "Measurements of pitch of a ferroelectric liquid crystal at high pressure" (Geetha Nair, S.Krishna Prasad and S.Chandrasekhar) *Mol. Cryst. Liq. Cryst.* (in press)

18. "Pressure-induced twist grain boundary phase" (S.Krishna Prasad, Geetha G. Nair, S. Chandrasekhar and J.W.Goodby) *Mol. Cryst. Liq.Cryst.* (in press)

19. "Liquid crystals defects in a magnetic field" (G.S.Ranganath) *Int. J. Mod. Phys.* (in press)

20. "Visual illusions - Role of the eye" (G.S.Ranganath) *Horizons in Physics* (in press)

21. "Mesomorphic properties of some β-diketones containing alkoxy chain in the o- and m-positions of a terminal phenyl ring" (B.K.Sadashiva and Veena Prasad) *J. Mat. Chem.* (submitted)

22. "The optical properties of chiral liquid crystals" (K.A.Suresh) . *Int. J. Modern Phys.* (in press)

23. "Phase jumps and discontinuities in the evolution of two-state systems" (R. Bhandari), DAE Solid State Physics Symposium, Jaipur, 1994 (Indian J. Pure and App. Phys.) (to be published)

24. "Low-frequency carbon recombination lines in the central regions of the galaxy (W.C.Erickson, D.McConnel and K.R.Anantharamaiah) *Astrophys. J.* (submitted)

25. "Magnetic fields in cometary globules 1 : CG 22" (T.K.Sridharan, H.C. Bhatt and Jayadev Rajagopal) *MNRAS* (submitted)

26. "Progenitors of pulsars" (A.A.Deshpande, R.Ramachandran and G.Srinivasan) *J. Astrophys. and Astron.* (submitted)

27. "On the approach to stability of pulsar average profiles" (N.Rathnasree and Joanna M. Rankin) *Astrophys. J.* (in press)

28. "Relativistically beamed radio emission, single pulse profiles and particle energies in pulsar magnetospheres" (N.Rathnasree) *Nature* (submitted)

29. "Properties of the orthogonal polarisation modes in pulsars, a study of PSR 2110+27" (N.Rathnasree and Joanna M. Rankin) *Astrophys.Lett. & Comm.* (submitted)

30. "Geometrical constraints on pulsar emission" (R.C.Kapoor and C.S.Shukre) *Abstracts of XVI Meeting of the Astronomical Society of India* (to be published)

31. "Are many pulsars processed in binary systems?" (A.A.Deshapande, R.Ramachandran and G.Srinivasan) *J. Astrophys. Astron.* (submitted)

32. "John Gatenby Bolton" (J.P.Wild and V.Radhakrishnan) *Memoirs of Royal Society, London* (in press)

In Conference Proceedings

1. "Unusual patterns in the growth of smectic liquid crystals" (R.Pratibha, Geetha Basappa and N.V.Madhusudana) *Proceedings of the Indo-French Workshop in Instabilities and Patterning in Materials Science*, Ed. G.Ananthakrishna (Kluwer Publications) (in press)

2. "High Rydberg state recombination lines in the interstellar medium" (K.R.Anantharamaiah) Proceedings of Saha Birth Centenary International Conference on Astrophysics and Cosmology, Calcutta, December 1993 (Narosa Publishing House, Delhi, 1994) (submitted)

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