RAMAN RESEARCH INSTITUTE
Bangalore

Annual Report 1992-93

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, Liquïd 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 meters to 1 millimeter) of the same electromagnetic spectrum. The lower and upper limits in wavelength of the radio spectrum are set by the earth's atmosphere and ionosphere respectively. In spite of these limitations, the radio window is very wide (30,000 to 1 compared to the 2:1 wavelength ratio in the visible part) and studies within it over the years have yielded information leading to many exciting discoveries such as the 3^0 K cosmic background radiation, quasars, pulsars, etc.

The Raman Research Institute has observational programmes in Radio Astronomy extending over most of the available radio spectrum. It has setup a Decameterwave Radio Telescope at Gauribidanur jointly with the Indian Institute of Astrophysics. It is one of the few largest among the telescopes in the world operating at 10 m 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 meter 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 new Giant Metre wavelength Radio Telescope (GMRT) being built by TIFR near Pune.

During the past two decades, millimeterwave astronomy has assumed great importance because of the discovery of numerous molecules (combinations of Hydrogen, Carbon, Nitrogen, Oxygen, Silicon, etc.) by their emitted line radiations in the shortest wavelength region of the radio spectrum. These molecules are generally found in dense molecular clouds in our own and other Galaxies where star formation is thought to be taking place. The Raman Research Institute has set up a millimeterwave telescope of diameter 10.4 meters, 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, phase transitions, defects, X-ray and light scattering and synthesis of new materials. Work on the 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 more technical specific and detailed account of the work carried out in the past year is given in the following pages.

THEORETICAL PHYSICS

Quantum gravity in lower dimensions : Topological geons, *i.e.*, vacuum solutions with a nontrivial spatial topology, were investigated in 2+1 dimensional canonical quantum gravity in the Ashtekar-Witten formalism. The possibility of fractional spin for such objects, suggested by analogy with other 2+1 dimensional systems, was analysed in detail and proved by constructing the corresponding quantum state.

Quantum measurement and optics : The role of the geometric phase in a "welcher-weg" thought experiment (in which one seeks information on which slit was traversed by a quantum particle) was brought out. This showed that the concept is necessary to enforce the uncertainty principle and its existence could even have been inferred from that fact. This example also clarifies other such thought experiments in the literature. Studies of the phase variable in optical interferometric analogues of quantum systems were continued with emphasis on singularities and the rapid nonlinear behaviour of the phase near them. Experimental demonstrations of these effects were given using a modified metrological interferometer

Gravitational radiation reaction to higher order: The problem of developing equations of motion in powers of (v/c) in general relativity is an old one, acquiring fresh interest from the application to coaelescing neutron star binaries. Gravitational radiation reaction effects first appear at order $(v/c)^5$. The next order, $(v/c)^7$, terms were analysed indirectly via known results at this order for energy and angular momentum flux at infinity. Apart from gauge dependent terms, this balance argument seems to fix the near field effects from the far field ones. A direct attack on the equations of motion at this order is more difficult and has not yet been carried out.

Formalism for precession in General Relativity : A study of gyroscopic precession in stationary axisymmetric spacetimes was carried out using the Serret-Frenet formalism.

LIQUID CRYSTALS

Continuing our studies on growth of smectic A liquid crystals in binary systems, compositions in which the interfacial tension anisotropy ($\Delta\gamma$) changes sign during the growth of a smectic drop have recently been investigated. Many novel structures like ellipsoidal drops which develop hemispherical caps, spherical drops with a radial defect, etc., have been observed in this regime. The formation of some of these structures can be understood on the basis of simple energy considerations.

A new experimental technique has been devised to compare the anchoring energies of a nematic at the two surfaces of a hybrid aligned cell by exploiting the fact that the flexoelectric effect produces only a surface torque on the director field in such cells.Using this technique, a comparative study of anchoring energies of a few different compounds has been completed. The flexoelectric coefficients of several compounds have also been measured and are found to depend on the molecular structures of the nematogens.

The electromechanical coupling coefficient of a compensated cholesteric mixture across the compensation temperature T_c was recently measured using a technique developed by us earlier. We have demonstrated that the sign of the coupling coefficient changes across T_c in agreement with the predictions of the hydrodynamic models. We have also measured the electroclinic coefficients of a number of ferroelectric liquid crystals synthesised in our laboratory. This measurement probes the soft-mode for the paraelectric-ferroelectric transition and in the systems studied the mean field theory is satisfied.

Our theoretical model for highly polar compounds has been extended to get solutions corresponding to a nematic to nematic transition in such systems. The two nematics differ in the relative proportion of nearest neighbours with mutually parallel and antiparallel configurations.

A cholesteric which is subjected to a magnetic field transverse to the helical axis results in 180° twisted regions separated by untwisted nematic-like regions. Consequently the biaxiality of the medium which is a consequence of the twist fluctuates along the helical axis. This leads to the result that an incident plane wavefront with its electric vector *parallel* to the helical axis will also give rise to a diffraction pattern which can be used to detect even small biaxilities of the order of 10^{-3} or 10^{-4}.

Calculations have been made on the optical reflection coefficient from a Fibonacci stacking of three element units with different optical constants. If one of the elements is absorbing, the Friedel law is violated, i.e., the reflection coefficients on opposite sides of the stack are different, demonstrating that the structure is non-centrosymmetric. New features have been found in the Borrman transmission of such a stack and in the dependence of the reflection spectrum on sample thickness and absorption coefficient.

The optical properties of a ferrocholesteric, i.e., a cholesteric with transparent magnetic grains, have been studied for propagation along the helical axis. Depending on the Faraday rotation and the pitch of the medium, such a system placed between appropriately aligned polarizers can act as an optical isolator, allowing light transmission in one direction and blocking it in the opposite direction.

The diffraction of light by a chiral smectic C phase has been investigated experimentally. Several orders of diffraction are found in this case and the intensity and polarization features are being analysed using a rigorous model.

Theoretical investigation on the bistability of nematic director orientation under an external magnetic field was continued and it has been found that for a certain range of parameters, the bistability extends over the entire range of magnetic tilts with respect to the sample plane. If the material has negative diamagnetic anisotropy, in certain planes the deformations have to be described using two angles rather than a single angle.

Using a general expression for the Maxwell stress in nematic and cholesteric liquid crystals subjected to an external electric field, it has been shown that the force arising from the spatial gradients in the electric field may become important when the perturbations are non-linear, i.e., in regimes lying above instability thresholds.

Dielectric dispersion studies have been made on a number of ferroelectric liquid crystals synthesised in our chemistry laboratory, which have a large polarization-tilt coupling. These show a monotonic variation of both the strength and relaxation frequency of the Goldstone (or phason)

mode. The soft mode has also been studied in the smectic A phase of these compounds. Studies under high pressure show that both soft and Goldstone modes slow down with pressure. The ratio of electroclinic to elastic coefficients is found to decrease rapidly with pressure.

Detailed studies using X-ray diffraction, optical selective reflection and calorimetric techniques have been used to observe the twist grain boundary phase near a chiral nematic-smectic A-smectic C* multicritical point. Precise density measurements have been used to study the tricritical region in a binary system exhibiting the smectic A-nematic transition. Fitting the data to a power-law expression yields critical exponents in agreement with those given by calorimetric data.

By using a quarter wave plate placed between a homogeneously aligned liquid crystal cell and a mirror, a phase modulator for *unpolarised* light has been developed. This may become useful for image sharpening in astronomical telescopes.

In the applications oriented activity, some effort has gone into developing polymer dispersed liquid crystals displays. The kinetics of formation and growth of liquid crystal droplets in photopolymerisable materials were studied (in collaboration with V.G. Nazarenko of the University of Kiev, Ukraine). Some new addressing techniques of multiplexed displays which were developed at the Institute were further improved (in collaboration with Asahi Glass Co., Japan), to drive fast responding super twisted nematic displays. An amplitude modulation scheme has also been worked out for generating gray scales in such LCDs.

In the chemistry laboratory several new mesomorphic metal chelates using β-diketones and salicyladimines as ligands have been synthesised. The metal atoms used are copper, nickel, palladium, vanadium and platinum. The platinum(II) complexes are the first examples of such materials derived from salicylaldimines. Also several low melting mesogenic β-diketones with long *lateral* chains have been synthesised.

X-ray crystallographic work was undertaken on two isomorphic palladium(II) and nickel(II) complexes which were specially synthesised for that purpose.

In the electrochemistry laboratory, apart from routine plating of various metals on different components used by the radio astronomy group, a new process has been developed for depositing copper on PTFE (teflon). Corrosion inhibition coefficients of different azoles have been evaluated using the cyclic voltammetric technique. An electrochemical technique for depositing colour filters which may be useful for LCDs is being developed.

A computer controlled system for electrochemical relaxation studies has been developed. Some preliminary work on fabricating a scanning tunnelling microscope has also been started.

In the glass blowing section, a fire extinguisher has been developed in a glass enclosure, and is useful as a teaching aid.

The lab has one of the few well-maintained CHN analysers in Bangalore and it is also being used in carrying out analytical work of numerous samples prepared by scientists at other institutions like the Indian Institute of Science, the Bangalore University, etc.

ASTRONOMY AND ASTROPHYSICS

Pulsars

High Resolution Timing of the Vela pulsar: A 16-channel filter bank built recently for this purpose was installed at the Mt.Pleasant Observatory for timing studies of the Vela pulsar with a very high resolution (single pulse resolution). Real time software was written to acquire the data from the receiver and transfer it to a VAX 750 computer to dedisperse the signals and to monitor the pulse arrival times. The whole procedure is automatic and is designed to restart on its own as soon as the computer is switched on. This system is presently working successfully at Mt.Pleasant (work done in collaboration with P.M.McCulloch and P.A.Hamilton of the University of Tasmania, Australia).

Techniques for accurate estimation of arrival times of pulses: A detailed investigation was undertaken to judge systematic errors in the estimation of pulse arrival times in a variety of techniques. The technique that is commonly used, namely a cross-correlation of the observed profile with a template profile was found to introduce a small but systematic bias in the pulse phase estimations. A method was developed to correct for such a systematic bias which makes the simple method of cross-correlation as good as the best methods available but which are computationally expensive.

A technique for high-dynamic-range spectral analysis of pulsar timing residuals: Spectral analysis of the residual pulse-arrival times is a useful tool in understanding the nature of the underlying processes that may be responsible for the timing noise observed in pulsars. The power spectrum of timing residuals can be usually described by one or more power-laws. As these spectra are expected to be very steep, it is important to ensure high dynamic range in the estimation of the spectrum. This is difficult in practice since one is in general dealing with timing residual measurements made at unevenly spaced epochs. A technique based on CLEAN has been developed to obtain high dynamic range spectra from unevenly sampled time sequences. The performance of this technique was compared with the other techniques including some that were used earlier; it turns out that this new technique can be a very useful tool in dealing with unevenly sampled time sequences.

Flux and arrival time variations from the Vela pulsar: The investigation of the observed correlation between the measured flux of the Vela pulsar and the difference between the arrival times at two radio frequencies was continued. The available data collected over the last three and a half years was re-analysed with a view to refining the timing residuals by incorporating a proper correction for apparent diurnal effects which can be pronounced due to the high polarization of the signals from the Vela pulsar entering an allazimuth telescope with linear feeds. The measured slow variations were found to be quasi-periodic with a period of about 160 days. The possibility of this effect being related to free precession is being investigated (in collaboration with P.M.McCulloch).

Pulsars in globular clusters : New special purpose hardware was built to search for pulsars in globular clusters. After debugging this was used with the Parkes telescope and the analysis of the data obtained in the direction of a few globular clusters is in progress (in collaboration with J.G.Ables, D.McConnell, C.Jacka, P.M.McCulloch of the University of Tasmania, the CSIRO Division of Radio Physics and the Australia Telescope National Facility, Australia).

Neutron stars in low mass binaries : A couple of years ago it was argued that the decay of the magnetic field of neutron stars is related to their slowing down and the consequent expulsion of the field from the core to the crust. It is well established that neutron stars in massive binaries do experience a dramatic slow down before their subsequent spin-up, but the situation was not at all clear in low mass binaries which are believed to be the progenitors of millisecond pulsars. To clarify this a detailed investigation was undertaken of the coupled evolution of the spin rate and the magnetic field strength of neutron stars in low mass binaries. The main conclusion is that the stellar wind from the low mass companion of the neutron star will be quite efficient in slowing down the neutron star, just as in a massive binary system. This is the first quantitative support to the ideas advanced earlier that the low magnetic fields of millisecond pulsars may be due to their spin-down history.

Evolution of the magnetic field of an accreting neutron star: Since the electrical conductivity of the core and crustal matter in a neutron star are vastly different, the timescales for field evolution also differ significantly. For the normal matter in the core (consisting of neutrons,

protons and electrons) the conductivity has a strong dependence on the field itself and consequently it is much lower than the conductivity of the crust provided the magnetic field strength is larger than a limiting value of $10^8 - 10^9$ G. In an accreting neutron star the crustal matter is continuously pushed into the core where it dissolves and merges with the core material. In the process there is rapid decay of the crustal field due to the large magneto-resistance in the core, but eventually as the field decays the magneto-resistance decreases and the field decay slows down. This provides a possible explanation for the limiting value of neutron star magnetic fields.

Search for pulsars at high galactic latitudes : Pulsars are high velocity objects and as such they can migrate to large heights from the galactic plane. In addition, a recent statistical analysis of the observed population suggests that a fraction of the population of pulsars might be born at large heights from the galactic plane. Unfortunately, most of the sensitive pulsar surveys so far were confined to low galactic latitudes. To throw light on this question an extensive search for pulsars at high galactic latitude has been undertaken using the Ooty Radio Telescope with the new pulsar receiver. It is proposed to search over a large area of the sky (about 1000 square degrees) with a detection limit of 2.5 mJy (seven sigma detection). This will require each field to be observed for 10 minutes. The survey has just begun.

Birth rate of pulsars : The estimated birth rate of pulsars is fairly sensitive to the distance scale to them. Recently, Taylor and Cordes have proposed a new comprehensive model for the free electron distribution in the Galaxy. This latest model was used to re-estimate the birth rate of pulsars from an analysis of the true current of pulsars. This analysis yields a birth rate of about 2.5 pulsars per century, which is to be compared with our previous estimate of about 3.5 pulsars per century.

The Vela Supernova Remnant : This is one of the very few SNRs associated with a pulsar. From general considerations one would have expected this remnant to have the morphology of a shell with the pulsar and the synchrotron nebula produced by it located near the centre. The remnant, however, has a very asymmetric morphology which has been hard to understand. Indeed this has even resulted in the suggestion that the pulsar may not be associated with the SNR. There may, however, be a less radical resolution, viz., that the peculiar radio

morphology is a consequence of large scale inhomogeneity in the ambient medium into which the remnant is expanding. To investigate this possibility the region surrounding the SNR was mapped at 21 cm using the 26 m dish at Mt.Pleasant with a bandwidth of 2.5 MHz and a velocity resolution of about 1 km s^{-1}. The analysis of this data is in progress. Molecular line observations were also made at CO, HCN and HCO+ line frequencies with the 10.4 m millimeter wave telescope at the Raman Research Institute. The analysis of these observations is also in progress.

Pulsar-supernova remnant association : Although this has been a long studied issue new associations bring it back into focus. Two new associations that have raised interesting questions are G 5.4-1.2 with PSR 1757-24, and W 30 with PSR 1800-21. Among the important observational inputs are the true sizes of the supernova remnants and their distances. With this in view these SNRs were mapped at 330 MHz using the VLA. The observations were used to define the true boundaries of the remnants and to make a better estimate of the centre of the remnant. The 21 cm absorption spectra were used to estimate their distances. The implications of these observations are being explored (in collaboration with D.A.Frail, N.E.Kassim and K.W.Weiler of National Radio Astronomy Observatory, USA and the Naval Research Laboratory, USA).

Cometary globules : From an earlier study of the kinematics of the cometary globules in the Gum nebula it was concluded that the system of globules is expanding due to the influence of the massive stars in the central region. In order to verify if such motions are prevalent near other OB associations, a study of cometary globules in two other OB associations – Cepheus OB2 and Orion OB1 – has been undertaken using the 10.4 m telescope at the Raman Research Institute. A total of about 40 clouds were observed in the CO $J = 1 \rightarrow 0$ transition with about $5-10$ pointings towards each cloud. This should be adequate both to establish the radial velocities of the clouds, as well as the motions within them.

Circumstellar SiO masers : The observational programme of SiO maser sources was continued. In strong maser sources the main objective was to clarify the dependence of the maser emission on the phases of the stellar pulsation and also the physical conditions that obtain in the stellar atmosphere. The second objective was to detect SiO maser

emission from *semi-regular variable stars* in contrast to the earlier investigation which concentrated on Mira variables.

Gould's Belt : A detailed study of the kinematics of the local molecular clouds was undertaken with the RRI millimeter wave telescope. After taking out the effect of galactic differential rotation the distribution of residual radial velocities was studied in detail to obtain a model for the spatial distribution and the kinematical behaviour of the local system of dark clouds. The main results obtained are the following :

1. The local dark clouds appear to be in a state of expansion about a common centre with an expansion velocity of 4 km s^{-1}. The cloud-cloud velocity dispersion is 2.5 to 5 km s^{-1} depending upon the longitude.

2. Detailed simulations suggest that these clouds are distributed in an oval-shaped "doughnut" with the Sun offset from the centre. Such a distribution would suggest that these local dark clouds are indeed associated with the Gould's belt system of O and B stars and the associated HI gas. The expansion velocity, as well as the velocity dispersion are also in reasonable agreement with the observed properties of Gould's belt.

3. Whereas in most longitudes the local population of clouds are expanding about a common centre, in the longitude ranges $100° - 145°$ and $195° - 215°$ the dark clouds have negative (inward) radial velocities. The reason for this peculiar streaming motion is not clear.

Lynd's Cloud L1616 : The analysis of a preliminary effort to map this cloud in ^{12}CO and ^{13}CO with the RRI millimeter wave telescope suggested that this cloud may have a cometary morphology with a well defined tail, and the efforts to map this cloud in detail were continued, particularly in the tail region. The mass of this cloud estimated from the observations is $\sim$ 180 $M_\odot$. This would suggest a very high star formation efficiency $\sim$ 13% compared to the general average of $\sim$ 2%. The estimated virial mass assuming the cloud to be in equilibrium is 1000 $M_\odot$. This would imply that the cloud must be disintegrating as a result of active star formation within it. This conjecture is supported by the evidence found in this study for mass motions around the exciting stars. The location of a reflection nebula near the edge of the cloud facing the Orion association suggests that the stars illuminating

this nebula may have been formed due to external triggering. Epsilon Orion (a BOIa star) is the most likely trigger. The estimated mass, age and spectral type of its main sequence progenitor are 35 $M_{\odot}$, 4.3 Myr and O6, respectively. If this identification is correct, then one would expect a transverse velocity of 15 km s^{-1} for this cloud and the stars illuminating the reflection nebula.

Recombination Lines at Millimeter Wavelengths : Attempts were made to detect hydrogen recombination lines near 92 GHz from bright galactic HII regions using the 10.4 m telescope. These initial observations were aimed at evolving an observing procedure to detect weak ($T_A^* \sim 0.1 - 0.5$ K) and wide ($\Delta V \sim 30$ km/s) lines. Several switching schemes (e.g. frequency switching, position switching, combination of frequency and position switching, and beam switching) were tried. It was possible to detect the line towards Orion and W51. A varying baseline ripple made detection in other sources uncertain.

Molecular clouds towards Cas A : Using the 10.4 m telescope a $12' \times 12'$ region in the direction of Cas A was mapped in the ^{12}CO ($J = 1 \rightarrow 0$) line. The mapping was done to compare the spatial distribution of molecular, atomic (as seen in HI) and ionized gas (as seen in carbon recombination lines) in this direction. Processing of the data is in progress.

Small Scale Structures in Interstellar Neutral Hydrogen : To investigate possible small scale structures in the Interstellar Medium (10 to 100 AU) observations have been initiated using radio pulsars as probes. The method consists of comparing HI absorption measurements against pulsars made at intervals of about 4 years. The absorption spectrum towards one of the two pulsars observed initially showed a marginal difference suggesting that structures of about 1000 AU may exist in the HI clouds. In order to confirm this conclusion extensive 21 cm observations were carried out in the direction of many pulsars using the Parkes telescope in Australia. A special gating mode was used for the autocorrelation spectrometer, and the analysis of the data is in progress (work done in collaboration with P.M.McCulloch, W.Wilson, D.McConnell and E.Davis of the University of Tasmania, Austrlia and the Australia Telescope National Facility).

Neutral Hydrogen in clusters of galaxies : It has been recognized that galaxies in the cores of clusters differ from those in the field in their morphological type, stellar population and gas content. By studying galaxies in clusters over a moderate range of redshifts it might be possible to observe the galaxies evolving – from normal gas-rich to gas-poor old galaxies. As the beginning of a more systematic study of the HI properties of galaxies in clusters, we have observed 4 clusters at redshifts of .04, .05, .06 and .07 using the VLA. One galaxy in each cluster (except the first one) was detected with the mass in HI in the range of $(1 - 4) \times 10^9\ M_\odot$. An initial comparison with the gas content of the Virgo cluster of galaxies and the field galaxies has been made. However, a comprehensive study will require detecting more galaxies in each cluster. These observations will be pursued towards the end of this year (in collaboration with J.H. van Gorkom and P.Guhathakurta of Columbia University, New York, USA and the Institute for Advanced Studies, Princeton, USA).

Cooling flows in clusters of galaxies : X-ray observations of clusters of galaxies imply that there may be large quantities of cold HI gas ($\sim\ 10^{11-12}\ M_\odot$) in the cores of clusters of galaxies. This is consistent with the models of cooling flows in which gas drops out of the flow and cools to low temperatures, possibly on its way to making stars. If the cold gas exists in the form of HI then one should expect to see it in absorption against strong continuum sources that are usually present in these clusters. Sensitive HI observations have been made of 3 extreme cooling flow clusters. These observations were sensitive to a wide range of spin temperatures and to HI masses about 3 orders of magnitude lower than what is believed to be present in these clusters (in collaboration with J.H. van Gorkom and F.N.Owen of the Columbia University, New York, USA and the National Radio Astronomy Observatory, USA).

Stimulated emission in the Warm Ionized Interstellar Medium : The WIM is one of the important components of the Interstellar Medium. A knowledge of its electron temperature, density and distribution are crucial to understanding the energetics of the Interstellar Medium. While its local properties are fairly well known its global properties like, for example, its distribution as a function of both Galactic longitude and latitude are not known. One way to trace this gas is to look for stimulated recombination lines of hydrogen against strong extragalactic radio sources at frequencies around 100 MHz. Since the ex-

pected line-to-continuum ratio is very small the observations should have a very high spectral dynamic range. Based on the brightness distributions at 34.5 MHz and 408 MHz a region of the Galactic plane where one might expect to see a line to continuum ratio 10^{-3} at frequencies around 300 MHz was chosen. These observations are presently being carried out using the VLA near 330 MHz.

Spin temperature of the Warm Neutral Interstellar Medium: Although the existence of the WNM in our Galaxy was proposed about 3 decades ago, a good estimate of its spin temperature is not yet available. The basic difficulty is that this medium is seen only in emission and cannot be easily detected in absorption against a background source; both emission and absorption measurements are needed to determine the spin temperature. The expected optical depth in an absorption measurement is 0.0001 requiring high spectral dynamic range. An attempt was made to detect such an absorption against Cygnus A. Frequency switching against Cygnus A was employed to estimate the band pass. The resulting band pass limited the spectral dynamic range to less than 1 part in 1000. At this level no absorption was seen due to the WNM (in collaboration with J.H. van Gorkom and W.M.Goss of the Columbia University, New York, USA and the National Radio Astronomy Observatory, USA).

Methanol Masers at 6 GHz : As a trial survey run, a search was carried out over two selected longitude ranges in the Galactic plane for the 6 GHz Methanol maser line. In about half a dozen directions new detections were made with line strengths of about a few tens of Jansky (in collaboration with S.Ellingsen and P.M.McCulloch of the University of Tasmania, Australia).

Steep-spectrum sources : Sources with steep spectra are of interest for many reasons – they could be halos in clusters, old radio galaxies, short period pulsars etc. Using the VLA at 90 cm and 20 cm, about a dozen sources from the Gauribidanur low-frequency survey at 34.5 MHz chosen on the basis of their spectral indices were observed. These observations revealed that in all but one case the steep spectra between 34.5 MHz and 408 MHz were a result of confusion due to the larger beam at 34.5 MHz. However, one of these sources, 0508-1842, has a spectral index of -1.5 between 34.5 MHz and 5 GHz as has been measured by various single dishes. Several observations were made of this

source at 3.6, 6, 20, and 90 cm using the VLA in different configurations. These images show a double source in the core with two outer lobes. The VLA images recover all of the single dish fluxes measured earlier. The lobes most likely have spectra even steeper than -1.5. The implications are being explored (in collaboration with M.Rupen of the National Radio Astronomy Observatory, USA).

Imaging at 74 MHz using the VLA : A new observing system at 74 MHz providing an angular resolution of 20″ is currently being tested at the VLA. The biggest problem at such a low frequency is, of course, the ionosphere which renders the usual mapping techniques impossible over the baselines which VLA can provide. Thus new mapping techniques are required. The basic idea is to observe a given source at both 330 MHz and 74 MHz simultaneously and solve for the ionospheric phases. A few strong radio sources have been imaged using this technique. While this new technique is not crucial for imaging these sources (due to their large signal-to-noise ratio) it certainly helps in obtaining improved dynamic range. For weaker sources this technique is quite crucial. The weakest source that has been mapped so far has a peak brightness of 26 Jy/beam at 74 MHz (in collaboration with N.E.Kassim, R.A.Perley, W.C.Erickson of the National Radio Astronomy Observatory, USA, the Naval Research Laboratory, USA and the University of Tasmania, Australia).

Recombination Lines from External Galaxies : Research in this area is continuing. A more careful analysis of the data taken using the VLA towards the galaxies M83, NGC 1365, and NGC 3690 has resulted in the detection of the H92 line in their nuclear regions. The number of galaxies in which we have detected RRLs is now 7. The other galaxies are NGC 3628, IC 694, Arp 220, NGC 2146.

Using the theory of recombination lines, models were constructed to explain the observed lines towards NGC 3628, IC 694 and NGC 1365. The important constraint for these models is that the observed continuum from the nuclear region has a non-thermal spectrum and therefore the thermal gas which produces the recombination lines should not dominate the continuum spectrum. With this constraint it was found that a collection of several hundred HII regions with densities in the range $5 - 50 \times 10^3$ cm^{-3} can explain the observations. The total mass of the ionized gas is a few times 10^5 $M_\odot$ and the rate of production of Lyman

continuum photons to maintain the ionization is a few times 10^{54} s^{-1}. These models predict that the continuum spectrum of the nuclear region will be significantly modified beyond 10 GHz where the HII regions are expected to be optically thin. Observations are proposed to verify this.

The Great Annihilator 1 E1740.7-2942 : A search for Positronium recombination line near 5 GHz (Ps87α line) towards the Einstein X-ray source 1 E1740.7-2942 had yielded an upper limit of 330 μJy for an assumed width of 23.5 MHz (which is expected if the temperature of the annihilation region is 7×10^4 K). Formation of positronium by radiative recombination and charge exchange was considered. It was found that, in both processes, only a small fraction of Ps is produced in the high excited states. It was concluded that unless there is a hitherto unknown process by which the higher excited states of positronium can be highly over populated, or sources of annihilation radiation greatly exceeding the intensity observed in 1 E1740.7-2942 or the Galactic centre region are discovered, the prospects for observing radio recombination lines of positronium are very bleak.

A continuum image of the field containing the error circle of the X-ray source shows a weak radio source with a core and lobe structure similar to extragalactic double radio sources. Some possible relations between the radio and the X-ray source were explored. It was found that the X-ray and the radio sources could well be associated with each other but the nature of the object is uncertain – it could be either Galactic or extragalactic. In either case this source is a unique object. The source was further observed at 20 cm using the A- configuration of the VLA.

Imaging of Radio Sources Scatter-broadened by the Solar Wind : Data taken in 1988 with the VLA in the A-configuration towards some sources whose lines of sight pass within a few degrees of the Sun was analyzed. The resulting images show anisotropic scattering with axial ratios in the range 2-10. The orientation of the major axis is expected to be perpendicular to the radial from the Sun if the flow of the solar wind is radial. This is not found to be true especially near the poles. A five parameter model (consisting of the flux density of the source, major and minor axes and position angle of the image, and the index Beta of the power law spectrum of the density irregularities) was fitted to the measured visibilities. The index beta was found to differ significantly (generally on the low side) from the Kolmogorov value $\left(\beta = \frac{11}{3}\right)$.

Source noise in radio synthesis images of polarized sources : Analytical expressions were derived for the distribution of the rms noise in radio synthesis images as a function of the source distribution, its polarization characteristics and the spatial-frequency coverage used. These expressions should help in obtaining more realistic estimates of the uncertainties in estimating the source structure, and its polarization characteristics. A study was also made to identify suitable observables for making snap-shot images which can be profitably deconvolved to reduce the effect of source noise in the off- source region. This has enabled one to make specific suggestions for processing synthesis images of polarized radio sources.

Gravitational instability in an expanding universe : This is being investigated from two complementary viewpoints. (i) Exact results in the early, nearly linear regime, from a perturbative analysis of the BBGKY hierarchy of equations for correlation functions. These include expressions for the three particle correlation (induced by nonlinearity) and also for the feedback of this on the two particle correlation. These exact results for weak nonlinearity clarify approximation schemes for the strongly nonlinear case. (ii) An approximate, physically motivated equation for the growth of the pair correlation function bridging the linear and nonlinear regions. This expresses the correlations in terms of single scaling function which can be inferred from numerical simulation, or physical agreements (in collaboration with T. Padmanabhan of IUCAA, Pune).

Rotational Shear Interferometry : The Rotational Shear Interferometer (RSI) was used at the 40″ telescope of the Uttar Pradesh State Observatory in Nainital during three nights in February 1993. Unfortunately, the observing run was hampered by bad weather (in collaboration with A.K. Saxena and J.P.A. Samson of the Indian Institute of Physics, Bangalore).

Since lack of sufficient illumination in the pupil image has been a persistent problem with the RSI, it was decided to change the imaging optics to reduce the pupil image size and thereby achieve greater intensity values in the interferogram. The modified system was tried out at the 40″ telescope at the Vainu Bappu Observatory in Kavalur on the 12th and

13th of March 1993. Good quality data was recorded on the star Alpha-Orionis, as well as on some calibration sources. The first results from analysis of this data seem promising. Further analysis of this as well as data from previous observations is continuing.

An attempt to repeat observations with a similar setup on the 90″ Vainu Bappu Telescope was not successful. It is intended to continue observing with this modification, primarily on the VBT.

INSTRUMENTATION FOR RADIO ASTRONOMY

GMRT-Pulsar Project

The Pulsar Receiver : The pulsar receiver backend consisting of a search-preprocessor (which was under development last year) was successfully completed, tested and installed at the Ooty Radio Telescope. This receiver is a reduced version of the instrument designed for use with the GMRT. A baseband input over 8 MHz is processed to produce a spectrum every half a millisecond. The power spectrum consists of 256 spectral channels. The deviations of these spectra from a mean spectrum are computed and are recorded with quantization to 1 or 2 bits in each spectral channel. The processor is controlled by a PC-AT which allows flexibility in configuring the system in a variety of modes.

The performance of this receiver was evaluated through extensive laboratory tests and also observing about a few dozen known pulsars with parameters spanning a wide range. With the improved sensitivity of the Ooty Radio Telescope it was possible to detect even weak pulsars (flux density of a few mJy) with signal-to-noise ratios exceeding 10 in an integration time of a few minutes.

Development of software : A full software package to conduct observations and analyze data for the Ooty pulsar survey was developed. This package consists of three parts: (1) machine diagnostics and display software, (2) automation software for the observations, and (3) pulsar survey data post-processing software for fast and slow pulsars.

(1) This package includes a number of programmes such as the pulse arrival time monitoring which can diagnose the machine performance. A quick data analysis software was also developed to monitor the functioning of the machine regularly.

(2) A package was developed to automate the operation of the machine during the survey observations. This was developed partly in collaboration with the National Centre for Radio Astrophysics, Pune and the Radio Astronomy Centre, Ooty.

(3) A complete software package for post-processing the survey data has also been developed. This consists of three parts namely *(a)* a dedispersion, which compensates for the interstellar dispersion of the pulsar signal, *(b)* Fourier analysis of the data, and *(c)* candidate generation.

21 cm Receiver for GMRT

The test Receiver which was built for evaluating the performance of the 45 meter GMRT dishes was installed on the first GMRT dish and initial tests were made in November 1992 with the feed horn located at the theoretically determined primary focal length. Further observations at other locations for the feed horn and using the newly developed front-end receivers will be required for a proper assessment of the aperture efficiency of the dishes.

A scaled version (10X) of the proposed broad band corrugated horn was fabricated and tested in the band 10 to 14 GHz. It showed a shift in the peak of the beam pattern beyond 13 GHz suggesting the generation of unwanted modes in the coaxial to circular waveguide transition. In order to suppress these modes, a quad-ridged Ortho mode transducer of 2λ length was designed and is being fabricated. In addition, the design of the corrugated horn was also changed to a wideflare angle design and it is also being fabricated.

Broad band (1.0 – 1.45 GHz) low noise amplifiers using Fujitsu HEMTs are being fabricated with improved noise performance giving an average noise temperature of 32 K in the band. Ten units were tested and found to have excellent gain and phase tracking in the band. All the other sub-units of the front-end receiver have been developed and prototyped. The structural design of the front-end box is also being finalised.

Mauritius Radio Telescope Project

Installation of the 2 km by 2 m ground plane for the E-W array was completed. 16 additional trolleys were fabricated and installed on the south track. One more trolley with a 15 m rail track was installed on the Northern side of the E-W array to facilitate measurement of the low spatial frequency components.

Hardware consisting of 256 four way power combiners, 256 pre-amplifiers, 32 super-heterodyne receivers and a 2 km long low loss Heliax cable with directional couplers for the local oscillator network was installed in the field and tested. Thirty two group outputs from the E-W array were brought to the lab. A network consisting of 32 km of RF cables enclosed in pipes was installed for this purpose.

A system consisting of 48 signal pre-processors to condition the signal coming from the field and the 1024 channel correlator system were interconnected and tested. Preliminary observations using both a single channel analog correlator and the digital correlator systems were carried out on several E-W baselines. Using these observations the antenna gains in the array were adjusted to be within $\pm$ 1 db and the phase error to be less than $\pm 5^{\circ}$.

The installation and testing of the recirculator system to increase the surveying sensitivity, and Walsh function switching system to eliminate the common-mode noise picked up by the correlators is under progress. Observations with the entire E-W array and the 1024 channel correlator to estimate the array efficiency, phase stability of the system and study the ionospheric effects are in progress.

Millimeter Wave Laboratory

Improved low noise millimeter wave mixers were built and thermally cycled thrice before they were installed in the dual polarisation receiver of the millimeter wave telescope. New Ga As mixer diode chips of type 2I2-150 were tested in a standard mixer mount and the optimized performance was found to be inferior to that obtained with 1H-16 diode chips. A mixer noise temperature of 650K (SSB) at 114 GHz (for room temperature operation) was measured for 1H-16 diodes where as it was 900K for the 2I2-150 diodes.

Millimeter Wave Telescope

Several projects were undertaken to improve the operation and data acquisition capability of the telescope. A versatile data acquisition system and a telenet controller to control and monitor various voltages which characterises the health of the system was designed and is under implementation. The system is based on an SDLC link for communication with all the subsystems and single board microcomputer card using Intel 80186 as the basic building block.

A new beam switching system based on microstepping drive has been designed and will be implemented in due course. The chopper system will be also controlled by a microstepping drive.

Design specifications of a two channel spectrometer using Digital autocorrelation techniques have been drawn up and a collaborative program has been worked out between the Raman Research Institute and the Onsala Space Observatory, Sweden where the spectrometers will be built and tested. The collaborative program has been initiated and a person is being trained to take up the assignment.

A multi-line spectrometer for the Ooty Radio Telescope

A one-bit digital spectrometer based on recirculation which can simultaneously observe four recombination lines within the band of the Ooty Radio Telescope is being constructed. A prototype recirculation unit which can observe one line was constructed and tested. The H272α line was detected towards the HII region M8 and the Galactic centre, and found to have the expected strength. Printed circuit boards for the digital part and Single Sideband Converter units to produce the video signals for the four lines are awaited to complete the spectrometer.

INSTRUMENTATION FOR OPTICAL ASTRONOMY

Rotational Shear Interferometer : The beam-splitter in the RSI is being re-coated at the optics shop in the Indian Institute of Astrophysics. Two pairs of right-angled prisms with a surface accuracy of approximately $\lambda/10$ ($\lambda = 500nm$) and sub arc-second angle accuracy are being procured. These will be used to fabricate a new RSI which can incorporate phase-plates for polarization correction.

Specifications for a tip-tilt mirror mount to be interfaced to the control board built at the Raman Research Institute are being finalized.

COMPUTERS

A campus-wide Local Area Network based on thick and thin ethernet segments has been installed. This network connects a number of PCs located in various buildings to a central Novell Netware Server which is in turn connected to other systems such as a VAX 11/780, a PDP 11/84, several work stations and the mail server. Sending and receiving mail has been automated using a modem which periodically connects to the ERNET mode at IISc over local telephone lines. A powerful work station (Digital's DEC Alpha 400 AXP) meant for processing pulsar data was acquired and installed.

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

Name	Topic of Study
H.P. Padmini The National College Bangalore	Some Physical Studies on Liquid Crystals
P.R. Maheshwara Murthy Govt. Science College Bangalore	Electric and Magnetic field effects in Liquid Crystals
Sharanabasava M.Khened Laxmi Venkatesh Desai College, Raichur	Experimental studies of Phase Transitions in Ferroelectric Liquid Crystals

In addition, half a dozen projects were successfully undertaken by students from local Engineering Colleges.

Ph.D.

Awarded

Name	*Topic of Study*
B.Shivkumar	Synthesis and liquid crystalline behaviour of some chiral aromatic compounds
T.K.Sridharan	A study of the Cometary Globues in the Gum Nebula

Submitted

Name	Title of the Thesis
Usha K	X-ray analysis of the crystal and molecular structure of some discotic compounds
Geetha G.Nair	Experimental studies on liquid crystalline phases and phase transitions
Sharanabasava M.Khened	Experimental studies of physical properties of Ferroelectric Liquid Crystals

Publications

The research work done by the staff of the Institute has been published in a number of journals. A list of publications that have already appeared and those submitted and in press is given at Annexure - I (Page 35).

Conferences/Seminars and Meeting

The staff of the Institute visited various institutions in India and abroad and attended conferences and presented papers. In all, 95 lectures were given by them at other places.

Gandhi Memorial Lecture

The Gandhi Memorial Lecture for 1992 was given by Prof. J.T. Bonner on "Dividing the Labour in Cells and Societies", on 30th January 1993.

Colloquia

The scientists of the Institute and visiting scientists both from within and outside the country gave 36 colloquia at the Institute on different topics during the year.

Journal Club Meetings

Twelve 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, 3 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.

At our invitation, the Executive Committee of the International Astronomical Union held its 63rd meeting from 11th to 15h of September 1992 at the Institute.

Library

The library had a total collection of 18,254 books and 21,569 bound volumes of periodicals. 223 new books were added this year out of which 13 were received gratis. 3 more periodicals are being subscribed now, bringing the total number of periodicals subscribed to 143. Of these, 21 are being received by air mail. A software package called LIBSYS has been acquired, and is being used in many of the library routines and also for creating a database of the books and other material in the library.

Others

General

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

PLAN – RECURRING AND NON-RECURRING	Rs.260.00 Lakhs
NON PLAN – RECURRING	Rs.190.00 Lakhs
Total	Rs.450.00 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)*

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

Staff contd.

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

Research Fellows

Arun Roy*
N. Andal
Archana Ghode
Debnarayan Jana*
Geetha Basappa
Geetha Nair
C. Indrani
Jayadev Rajagopal
Mehdi Jahanmiri*[1]
Nimisha G. Kantharia[1]
R. Ramachandran
B. Ramesh[1]
D.S. Shankar Rao
T.P. Saravanan
Somnath Bharadwaj[1]
S. Sowmya Raman*[1]
T.K. Sridharan[1]
P.B. Sunil Kumar
Sushan Konar[1]
K. Usha
Veena Prasad
Yuvaraj Sah

Post-Doctoral Fellows

R. Pratibha

Visiting Professors/Scientists

Indira Rajagopalan
N. Kumar
A. Krishnan
S.R. Rajagopalan
T.G. Ramesh
A.K. Saxena

Consultant Physicians

M.R. Baliga
A.R. Pai

Staff contd.

Resignations

P.R. Amuda
Arun Prasad S
T.K. Babu
N. Jayaprakash
R. Madhu Krishnan
V.N. Raja
P. Ramachandran
Ravi Kulkarni
T.S. Ravishankar
G.B. Shivakumar
Sudha Srivastava
Uma Devi
Vijay Chikaramane
C.V. Vishveshwara
Vivek Dhawan
M.Vivekanand

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† On leave with the University of Tasmania, Hobart, Australia (until February 1993).

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

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

+ On deputation with the National Aeronautical Laboratory, Bangalore.

%% On leave with National Radio Astronomy Observatory, Charlottesville, VA, U.S.A. (until January 1993)

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

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

LIST OF VISITORS

G.D. Love University of Durham Durham, U.K.	Jan. 4 - Dec. 30, 1992
T.R. Ramdas Tata Inst. Fundamental Research Bombay	March 31 - April 10, 1992
R.D. Ekers Australia Telescope National Facility Sydney, Australia	April 30 - May 2, 1992
R.S. Arora National Physical Laboratory New Delhi	June 15-22, 1992
Raja Guhathakurta Institute of Advanced Studies Princeton, U.S.A.	June 18-20, 1992
Jeeva S. Anandan University of South Carolina Columbia, South Carolina, U.S.A.	July 4-8, 1992
Ramesh Narayan Harvard-Smithsonian Center for Astrophysics, Cambridge, M.A., U.S.A.	July 6-7, 1992
A. Peerally University of Mauritius, Mauritius	June 6-8, 1992
C.R. Subrahmanya National Centre for Radio Astrophysics TIFR, Pune	August 7-14, 1992
Sushila Singh Univ. of Poona, Pune	August 17-22, 1922

V.G. Nazarenko University of Kiev, Ukraine	Sept. 7 - Nov. 23, 1992
L. Woltjer Observatoire de Haute Provence France	September 5-24, 1992 December 11-18, 1992
A.A. Boyarchuk Astronomical Council Moscow, Russia	September 11-21, 1992
J.I. Smak Copernicus Astronomical Center Warsaw, Poland	September 11-21, 1992
I. Appenzeller Landessternwarte Heidelberg Heidelberg, Germany	September 11-15, 1992
Ye Shu Hua Shanghai Observatory Shanghai, China	September 11-13, 1992
F. Pacini Universita Degli Studi Firenze, Italay	September 11-15, 1992
D.S. Mathewson Mount Stromlo and Siding Springs Observatory, Australia	September 11-15, 1992
J. Bergeron Institute d'Astrophysique Paris, France	September 11-15, 1992
Y.Kozai National Astronomical Observatory Tokyo, Japan	September 11-15, 1992
M.S. Roberts National Radio Astronomy Observatory Charlottesville, U.S.A.	September 11-16, 1992

D. McNally University of London Observatory London, U.K.	September 11-17, 1992
P. Dierich Observatoire de Meudon Paris, France	September 8-13, 1992 March 17-22, 1993
Alain Omont Institute d'Astrophysique Paris, France	October 21-22, 1992
A. Beesham Inter-University Centre for Astronomy and Astrophysics Pune	Oct. 26 - Nov. 7, 1992
Alan Mackay Birkbeck College London, U.K.	November 23, 1992
Jacques Prost Groupe de Physico-Chimie Theoretique ESPCI, Paris, France	December 1992
A. Buka L. Bata Research Institute for Solid State Physics Budapest, Hungary	December 3-8, 1992 December 3-8, 1992
P.J. Lavakare U.S. Educational Foundation in India New Delhi	December 14-18, 1992
G. Swarup National Centre for Radio Astrophysics TIFR ,Pune	December 16-18, 1992
N. Kumar Indian Institute of Science Bangalore	December 14-18, 1992

Abhijit Kshirsagar Inter-University Centre for Astronomy and Astrophysics Pune	December 22-25, 1992
R.D. Cannon Anglo-Australian Observatory Sydney, Australia	December 24-27, 1992
V.F.R. Jones University of California Berkeley, California, U.S.A.	December 26-31, 1992
R.A. Vora M.S. University Baroda	Jan. 31 - Feb 2, 1993
M.G. Acharya Indian Inst. of Technology New Delhi	February 21-23, 1993
P. Hariharan University of Sydney/CSIRO Sydney, Australia	February 22-23, 1993
Amitabha Lahiri Los Alamos National Laboratory U.S.A.	February 23, 1993
Vadim Urpin Ioffe Institute St. Petersburg Russia	March 26-31, 1993

PAPERS PUBLISHED – Annexure - I

In Journals

1. "Pulsar Observations and Small-scale Structure in Interstellar HI" (A.A. Deshpande, P.M. McCulloch, V. Radhakrishnan and K.R. Anantharamaiah) *Mon. Not. Roy. ast. Soc.*, **258**, 19 (1992).

2. "Accreting White Dwarf Models for CAL 83, CAL 87 and other Ultrasoft X-ray sources in the LMC" (E.P.J. van den Heuvel, D. Bhattacharya, N. Nomoto and S.A. Rappaport) *Astron. Astrophys.*, **262**, 97, (1992).

3. "Kinematics of the Cometary Globules in the Gum Nebula" (T.K. Sridharan) *J. Astrophys. Astr.*, **13**, 217 (1992).

4. "Toward an Empirical Theory of Pulsar Emission: VI. The Geometry of the Conal Emission Regions" (Joanna M. Rankin), *Astrophys. J.*, **405**, 285 (1992).

5. "Pulsar Observations at 34.5 MHz using the Gauribidanur Telescope:I" (A.A. Deshpande and V. Radhakrishnan), *J. Astrophys. Astron.*, **13**, 151 (1992).

6. "A Sweeping Local Oscillator System for Pulsar Observations" (A.A. Deshpande), *J. Astrophys. Astr.*, **13**, 167 (1992).

7. "SiO Maser Emission and the Intrinsic Properties of Mira Variables" (Nimesh A. Patel, Antony Joseph and R. Ganesan), *J. Astrophys. Astr.*, **13**, 241 (1992).

8. "Observation of Dirac Singularities with Light Polarization–I" (R. Bhandari), *Phys. Lett. A.*, **171**, 262 (1992).

9. "Observation of Dirac Singularities with Light Polarization–II" (R. Bhandari), *Phys. Lett. A.*, **171**, 267 (1992).

10. "Decoherence due to the Geometric Phase in a 'Welcher-Weg' Experiment" (R. Bhandari), *Phys. Rev. Lett.*, **69**, 3720 (1992).

11. "Post Newtonian Gravitational Radiation Reaction for two body systems" (B.R. Iyer and Clifford M. Will), *Phys. Rev. Lett.*, **70**, 113 (1993).

12. "Fermat's principle in general relativity" (Rajaram Nityananda and J. Samuel), *Phys. Rev. D.*, **45**, 3862 (1992).

13. "Comments on 'Modified photon equation of motion as a test for the principle of equevalence' " (Rajaram Nityananda), *Phys. Rev. D.*, **46**, 871 (1992).

14. "Bianchi Cosmologies: The role of spatial topology" (J. Samuel and A. Ashtekar), *Phys. Rev. Lett.*, **71**, 215 (1993).

15. "Magnetic field induced bistability in nematics and cholesterics" (U.D.Kini), *Liq. Cryst.*, **12**, 449 (1992).

16. "The Maxwell stress and theoretical models of electric field effects in nematics" (U.D.Kini), *J. de Physique II France*, **2**, 2089 (1992).

17. "High precision density studies near the smectic A - nematic tricritical point" (V.N.Raja, S.Krishna Prasad, D.S.Shankar Rao and S.Chandrasekhar), *Liq. Cryst.*, **12**, 239 (1992).

18. "Phase diagram exhibiting a smectic A - smectic C - smectic F meeting point" (V.N.Raja, D.S.Shankar Rao and S.Krishna Prasad), *Phys. Rev. A (Rapid Communications)*, **46**, 726 (1992).

19. "Dielectric studies in the vicinity of the A - C* transition" (S.Krishna Prasad, S.M.Khened, V.N.Raja, S.Chandrasekhar and B.Shivkumar), *Ferroelectrics*, **138**, 37 (1993).

20. "Optical diffraction in twisted liquid crystalline media - phase grating mode" (K.A.Suresh, P.B.Sunil Kumar and G.S.Ranganath), *Liq. Cryst.*, **11**, 73 (1992).

21. "Paradoxical networks" (G.S.Ranganath), *Curr. Sci.*, **62**, 549 (1992).

22. "Materials with negative Poisson's ratio" (G.S.Ranganath), *Curr. Sci.*, **63**, 160 (1992).

23. "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).

24. "Continuous thermodynamic path between three smectic A phases of the same symmetry" (S.Pfeiffer, G.Heppke, D.S.Shankar Rao and R.Shashidhar), *Phys. Rev. A*, **46**, 6166 (1992).

In Conference Proceedings/Books

1. "The Evolution of the Magnetic Fields of Neutron Stars" (D.Bhattacharya). in "The Magnetospheric Structure and Emission Mechanisms of Radio Pulsars", Proceedings of the IAU Colloquium No.128 (Lagow, Poland), Eds. T.H. Hankins, J.M.Rankin and J.A. Gil, Pedagogical University of Zielona Gora, Poland, p27 (1992).

2. "Pulsar observations at Decametric Wavelengths using the Gauribidanur Telescope" (A.A. Deshpande and V. Radhakrishnan), in "The Magnetospheric Structure and Emission Mechanisms of Radio Pulsars", Proceedings of the IAU Colloquium No.128 (Lagow, Poland), Eds. T.H. Hankins, J.M.Rankin and J.A. Gil, Pedagogical University of Zielona Gora, Poland,, p193 (1992).

3. "The Polarization of Pulsar Radiation" (V. Radhakrishnan), in "The Magnetospheric Structure and Emission Mechanisms of Radio Pulsars", Proceedings of the IAU Colloquium No.128 (Lagow, Poland), Eds. T.H. Hankins, J.M.Rankin and J.A. Gil, Pedagogical University of Zielona Gora, Poland, p367 (1992).

4. "Closing comments: Theory" (C.S. Shukre), in "The Magnetospheric Structure and Emission Mechanisms of Radio Pulsars", Proceedings of the IAU Colloquium No.128 (Lagow, Poland), Eds. T.H. Hankins, J.M.Rankin and J.A. Gil, Pedagogical University of Zielona Gora, Poland, p412 (1992).

5. "From low-mass X-ray Binaries to Binary and Millisecond Pulsars" (D.Bhattacharya), in *X-ray Binaries and Recycled Pulsars*, Eds. E.P.J. van den Heuvel and S.A. Rappaport, Kluwer Academic Publishers, p257 (1992).

6. "Pulsar Velocities and their Origins" (V. Radhakrishnan), in *X-ray Binaries and Recycled Pulsars*, Eds. E.P.J. van den Heuvel and S.A. Rappaport, Kluwer Academic Publishers, p257 (1992).

7. "The Magnetic Fields of Neutron Stars and their Evolution" (D. Bhattacharya and G. Srinivasan) - invited review for publication in the book "Accretion - Driven Stellar X-ray Sources" - Second Edition, Eds. W.H.G. Lewin, J.A. Van Paradijs and E.P.J. van den Heuvel.

8. "Millisecond Pulsars" (D.Bhattacharya) - invited review for publication in the book "Accretion - Driven Stellar X-ray Sources" - Second Edition, Eds. W.H.G. Lewin, J.A. Van Paradijs and E.P.J. van den Heuvel.

9. "SiO Maser Emission and the Intrinsic Properties of Mira variables" (N.A. Patel, A. Joseph, R. Ganesan and C.S. Shukre), in "Astrophysical Masers", Proceedings of the Conference held in Arlington, VA, USA, Eds. A.W. Clegg and G.E. Nedoluha, Lecture notes in Physics No.412, Springer Verlag, p445 (1993).

10. "Self Duality in Classical Gravity" (J. Samuel), in *Newman Festschrift*,eds. A. Janis and J. Proter, Birkhäuser, Boston (1992).

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1. "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 and V. Radhakrishnan), (to appear in *Astrophysical Journal*).

2. "Detection of H92α 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), (to appear in *Astrophysical Journal*).

3. "High Rydberg state carbon recombination line towards Cas A:332 MHz VLA observations and comparison with HI and Molecular lines" (K.R. Anantharamaiah, W.C. Erickson and H.E. Payne), (submitted to *Astrophysical Journal*).

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5. "On the Pumping Mechanism of circumstellar Sio Masers" (N.A. Patel and C.S. Shukre), (submitted to *Astrophysical Journal*).

6. "An experimental study of the smectic A - smectic C transition in monolayer, partially bilayer system" (D.S. Shankar Rao, V.N. Raja, S. Chandrasekhar, G. Heppke and M.E. Neubert), *Mol. Cryst. Liq. Cryst.*

7. "Optical properties of magnetically doped cholesterics" (Y. Sah, K.A. Suresh and G.S. Ranganath), *Liq. Cryst.*

8. "Mesogenic properties of nickel(II)complexes of N-(2-hydroxy-4-n-alkoxy benzylidene)-4"-n-dodecylphenylanilines" (Veena Prasad and B.K. Sadashiva), *Mol. Cryst. Liq. Cryst.*

9. "Crystal and molecular structure of isomorphous bis[1,3-di(p-n-octylphenyl)-propane- 1,3-dionato]palladium(II) and bis [1,3-di(p-n-octylphenyl)propage 1,3-dionata]nickel(II)" (K. Usha, Kalyani Vijayan and B.K. Sadashiva), *Mol. Cryst. Liq. Cryst.*

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12. "An AC electrooptical technique of comparing the two anchoring energies of a hybrid aligned nematic cell" (P.R. Maheswara Murthy, V.A.Raghunathan and N.V. Madhusudana), *Liq. Cryst.*

13. "Experimental determination of the flexoelectric coefficients of some nematic liquid crystals" (P.R.Maheswara Murthy, V.A. Raghunathan and N.V. Madhusudana), *Liq. Cryst.*

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