# RAMAN RESEARCH INSTITUTE
Bangalore

**Annual Report 1990-91**

## Introduction

The Raman Research Institute founded by Prof. C.V. Raman in the late forties was reorganised, after his death in 1970, as a national Institute for research in basic science and it has been receiving generous grants from the Department of Science and Technology of the Government of India since 1972. The main fields of research are Astronomy and Astrophysics, and Liquid Crystals.

## 1. Astronomy and Astrophysics

Astronomy which is one of the oldest sciences is concerned with the study of heavenly bodies by investigating the radiation received on earth from them. Optical Astronomy deals with the "visible" part (wavelength 3000 Angstroms to 6500 Angstroms, 1 Angstrom= $10^{-8}$ centimeter) of the electromagnetic spectrum. Radio Astronomy, which had its beginnings in 1932 also deals with the study of these heavenly bodies, but the radiation received by radio telescopes on earth is in the radio wavelength part (30 meters to 1 millimeter) of the same electromagnetic spectrum. The lower and upper limits in wavelength of the radio spectrum are set by the earth's atmosphere and ionosphere respectively. In spite of these limitations, the radio window is very wide (30,000 to 1 compared to the 2:1 wavelength ratio in the visible part) and studies within it over the years have yielded information leading to many exciting discoveries such as the $3^0$ k cosmic background radiation, quasars, pulsars, etc.

The Raman Research Institute has observational programmes in Radio Astronomy extending over most of the available radio spectrum. It has setup a Decameterwave Radio Telescope at Gauribidanur jointly with the Indian Institute of Astrophysics. Operating at a wavelength of 10 meters, it is among the largest telescopes in the world and is being used to study the radio emission from various types of celestial objects such as the Sun, Jupiter, radio sources of various kinds in our Galaxy, and external Galaxies. Moving to somewhat shorter wavelengths, members of the Institute use the Ooty Radio Telescope operated by the Tata Institute of Fundamental Research, Bombay.

This instrument operates at a wavelength of approximately 1 meter and is used for carrying out observations of pulsars, and nebulae of various kinds in the Galaxy.

During the past two decades, millimeterwave astronomy has assumed great importance because of the discovery of numerous molecules (combinations of Hydrogen, Carbon, Nitrogen, Oxygen, Silicon, etc.) by their emitted line radiations in the shortest wavelength region of the radio spectrum. These molecules are generally found in dense molecular clouds in our own and other Galaxies where star formation is thought to be taking place. The Raman Research Institute has setup two millimeterwave telescopes of diameters 1.5 and 10.4 meters, which are being used for the study of these radiations.

In addition, the Institute has theoretical research programmes in many 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 is continuing along the lines indicated in the reports of previous years.

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

## THEORETICAL PHYSICS

*Crystallographic phase problem*: Variational approaches to the crystallographic phase problem, such as the maximum entropy method, were explored. An analogy between the phase problem and the spin-glass family of optimisation problems was suggested. A preliminary study of the landscape (i.e., maxima and minima) of an exponential entropy function was carried out broadly confirming this feature.

*Geometric Phases and Optics*: 'Spinor interferometry' using the light polarization system was pursued further to demonstrate experimentally (i) the noncyclic geometric phase, (ii) the dependence of the spinor phase on the orientation of the precession axis, and (iii) the possibility of unlimited enhancement of the geometric phase implying large frequency shifts by use of a series of counter-rotating halfwave plates in a Michelson interferometer configuration.

It was found that the SU(2) part of the phase in an evolving polarization state can show discontinuous behaviour in the form of $\pm\Pi$ phase jumps. These jumps were explained in terms of the geometric part of the phase change.

### General Relativity

A modified equation of motion preserving covariance, but containing terms with the Riemann tensor coupled to the spin of the particle was considered. The effect of these extra terms on light rays of different polarizations was investigated, and the results applied to astronomical situations.

*Post Newtonian Generation of Gravitational Waves*: New alternative forms have been explicitly obtained for postnewtonian spin dipole and spin quadrupole source moments. The transformation of these moments under shifts of the spatial origin have been obtained and used to verify their correctness. The notion of quasi-conservation laws for quasi-linearized metrics were introduced and their implications for the moments investigated.

The question of the separability of the Dirac equation in spacetimes with local rotational symmetry was re-examined. A generalized treatment involving a suitable choice of local coordinates and spinor frame makes separation possible in a class of metrics for which earlier analysis had left the issue open. Exact solutions of Einstein's equations that fall in this category were obtained. Besides the vacuum solutions, there are other solutions satisfying the equation of state $P + \rho = 0$.

## LIQUID CRYSTALS

The electromechanical coupling which results from the chiral symmetry of cholesteric liquid crystals was discovered in our laboratory a couple of years ago, using stress-free boundary conditions on specially prepared drops. New experiments were set up last year to study this effect in samples with *strong anchoring* at the boundaries. The material in this case has to be carefully chosen to overcome other distracting electrical and optical effects. A linear electro-optic effect has been found due to the electromechanical coupling in such samples.

Rigorous calculations taking into account the boundary conditions have confirmed that electro-hydrodynamic instability patterns propagate if the symmetry of the cell is changed by incorporating a small tilt angle at the boundaries, in agreement with the predictions of a simple one-dimensional analysis which was made in the previous year.

Ferronematics are nematic liquid crystals in which needle-like ferromagnetic particles are suspended. An external magnetic field produces planar linear soliton states in such a medium. If the background nematic has positive diamagnetic anisotropy, the $2\Pi$ planar soliton which is stable at lower fields splits into two $\Pi$ linear solitons above a threshold field. If the diamagnetic anisotropy is negative a linear soliton can appear at low fields which becomes unstable above a threshold value of the field, leading to two new types of linear solitons. The structure of the latter are quite sensitive to the elastic anisotropy of the medium. These ideas have been extended to mixtures of nematics with different diamagnetic anisotropies.

Geometrical theory of diffraction is an elegant and a simple technique for working out Fresnel diffraction patterns theoretically. Our recent studies in this area have yielded many new results. For example, in rectangular and elliptic discs, it was found that the 'Poisson Spot' intensity fluctuates as the distance from the diffracting object is increased. This is in contrast to the monotonic intensity decrease with distance associated with a circular disc. With linearly polarized incident light the diffraction symmetry is in general less than that of the diffracting object. Diffraction fringes in the shadow regions of a strip and a wire have many new features which were hitherto unexplained.

Recent experimental studies on the Freedericksz transition in nematic samples subjected to an external electric field have led to some very interesting results. Detailed theoretical calculations have been made to explain some of these phenomena and to predict some new features. It is found that while the transition is continuous for the twist geometry, it is discontinuous for the bend geometry if the dielectric anisotropy is sufficiently large. The effects of an ad-

ditional magnetic field and a pretilt angle have been investigated in reference to orientational bistability in such cells.

A sudden application of a magnetic field above a threshold can induce transient periodic dissipative structures in nematics. Detailed theoretical calculations on such structures have been made for very general geometrical configurations of the director orientations and the applied field. In the twist geometry, the critical point separating periodic and non-periodic regimes has been located *analytically* by an evaluation of the energy dissipation rate.

The Raman-Nath theory has been extended to study the diffraction from periodic helical structures in both cholesteric and smectic C* liquid crystals. In the former, most of the diffraction intensity appears in higher rather than the lower orders of diffraction. In the smectic C* phase the molecules are tilted in a layered structure. The azimuthal angle of the tilted molecules varies continuously to give rise to a macroscopic helical arrangement. In this case, the diffraction pattern shows extra 'odd' orders of diffraction which are always *linearly polarized.* Further the azimuth of the incident linearly polarized beam affects the odd and even orders of diffraction very differently. Introduction of absorption suppresses some strong peaks while enhancing some weak ones. Experiments are being now set up to study the diffraction phenomena in these liquid crystals.

Theoretical calculations show that in oblique incidence the higher order Bragg reflections are found to be more intense than lower orders if the molecules forming the cholesteric and smectic C* phases are linearly dichroic. The Borrmann effect in such a geometry is also being investigated.

X-ray studies on a homologous series of compounds with a weak transverse dipole moment have been taken up, which show that the strength of the smectic A - smectic C transition can be varied by reducing the range of the smectic A phase.

Detailed measurements of polarization and tilt angle of the ferroelectric smectic C* liquid crystals have shown that the coupling parameters between these two 'order parameters' are not temperature-independent, as implied by Landau type of theories.

Some compounds with tilted molecules exhibit the smectic I phase which has a 3-dimensional bond orientational order. It has been suggested that smectic I has the same symmetry as the smectic C phase and thus there could be a critical point in the transition between I and C phases. Detailed X-ray, dielectric and polarization experiments have been conducted to show that the nature of the I-C transition depends on the temperature range of the hexatic phase.

In continuation of the synthetic work on liquid crystalline substances containing transition metals, a number of chelates with copper, palladium and nickel have been prepared during this period. With a view to obtaining enantiotropic nematic phase, a large number of metal $\beta$-diketonates were investigated and quite a number of them exhibited such a phase. Several homologous series of metallomesogenic compounds have been synthesised. It was found that many of the ligands used to complex with metal ions are themselves mesogenic. The ligands used in one such synthetic effort belong to N-(2-hydroxy-4'-n-alkyloxybenzylidene)4"-n- dodecylphenyl anilines. The copper and palladium complexes of these have been prepared. All the thirty nine compounds synthesised exhibit enantiotropic mesophases.

A large number of different types of ferroelectric liquid crystalline compounds have been synthesised. These include compounds containing one or two chiral centres. Polarization values as high as 160 nc/cm have been obtained for some compounds. Compounds with lateral hydroxy groups have also been investigated. Some copper complexes have been prepared and these represent the first examples of paramagnetic ferroelectric liquid crystals.

A detailed study of the X-ray structure analysis of the transition metal containing discogen bis[1,3-di(p-n-octylphenyl) propane-1,3-dionato] copper(II) which crystallises in the triclinic space group $P\bar{1}$ was completed.

## ASTRONOMY AND ASTROPHYSICS

*Galaxy dynamics*: An oscillating model of a stellar distribution function proposed earlier was investigated further. The differential equations governing the time evolution of the model parameters (e.g.velocity dispersions, elliptical boundary) were put into a Hamiltonian form. This allowed some general conclusions to be drawn concerning the evolution of the model.

*Pulsars*: A detailed statistical analysis of the observed pulsar population was undertaken. This analysis largely centered around the distribution of the *current* of pulsars as a function of their magnetic fields, periods and distances from the galactic plane.

Various selection effects were taken into account to construct the *current* distribution of the *true galactic population* of pulsars from the observed distribution. Several significant results emerged from this study:

1. *Field evolution*: The *current* weighted average magnetic fields of pulsars as a function of their characteristic ages clearly shows that

there is no evidence for the decay of magnetic fields of pulsars in timescales less than $\sim$ 20 million years. This conclusive evidence is in disagreement with earlier assertions in the literature that the observed population of pulsars cannot be understood without their fields decaying in timescales of the order of a few million years. An independent detailed study of the statistics of radio pulsars taking into account the modification of the pulsar distance scale necessitated by the recent discovery of many pulsars in globular clusters also shows that there is no evidence for the decay of the magnetic field strength of isolated pulsars.

2. *Initial periods of pulsars*: An important conclusion of the above study is that a substantial fraction of pulsars are "injected" with fairly long initial periods, in agreement with a similar conclusion arrived at earlier. A new result of the above analysis is that the majority of these injected pulsars have a very narrow range of magnetic fields around $10^{12.5}G$. In addition, there is another population of injected pulsars (with a much smaller birth rate) whose fields lie in the range $10^{11} to 10^{11.5}G$. Both these populations are born at a variety of distances from the galactic plane ranging up to 600 to 800 parsecs. This enables one to identify these injected pulsars, for the first time, as *recycled pulsars* from binary systems which were disrupted during the second supernova explosion.

3. *Velocities of pulsars*: The current analysis shows that the injected pulsars constitute roughly 50% of the total population. This lends support to the earlier conjectures that most pulsars may have had their origin in binary systems. This interpretation leads one to the following conclusion, viz., the velocities of roughly 50% of the pulsars should be traced to an asymmetric kick during their birth (these are the second-born pulsars in binaries), while the velocities of the remaining half of the population should be attributed to their orbital velocities at the time of the second supernova explosion (these are the first- born pulsars).

4. It appears that the recycled pulsars, particularly those with low fields, tend to have much smaller angles between their rotation and magnetic axes compared to the normal population. There is also an interesting correlation between the morphology of the pulsed emission and their possible history in binary systems. Further study of this intriguing correlation is in progress.

## Radio Astronomy

*Source-noise in the Radio Synthesis images*: The distribution of source and receiver-noise in radiosynthesis images was studied. It was shown that the source-noise is maximum at the position of the source, but also appears in the off-source region because of the side lobes. Analytical expressions were derived for the rms noise at any position in both "total power" and "correlation" images. It was further shown that under certain conditions deconvolution can remove the source-noise from off-source regions in a "snap-shot" image. The results were verified experimentally using data on the strong source Cas A obtained using the Very Large Array.

*Extragalactic Recombination Lines*: Using the Very Large Array (VLA) Radio Telescope a search was made for radio recombination lines towards six external galaxies. Lines were detected in the nuclear region of two galaxies (NGC 3690 and NGC 3628). Prior to this, recombination lines had been detected in only two other galaxies (NGC 253 and M82). High resolution observation of H92$\alpha$ recombination lines were made towards NGC253 to study the velocity field in the nuclear region. The ionized gas exhibits systematic velocity gradients in the central region.

*Highly excited carbon recombination lines towards Cas A*: The entire body of data from 14 MHz to 325 MHz available for this source were analysed in terms of a warm and cold gas model. It was shown that the published lowest frequency (14-30 MHz) data are underestimates of the line strength due to broad wings in the line profiles which are lost in the baseline fitting process. When correlation factors estimated from pressure and radiation broadening are included, the data is well fitted by the model wherein the lines originate in HI clouds with temperature 100K and electron density of $0.06cm^{-3}$. This is consistent with the observed similarity of HI and C272$\alpha$ optical depth maps towards Cas A.

*Radio emission from globular clusters*: The recently published results of the wide-field survey at 34.5 MHz made from the Gauribidanur Telescope were analysed to look for radio emission in the directions of the 150 or so Galactic Globular Clusters. Significant radio emission at low frequencies is expected from these objects if they contain a large number ($> 100$) of millisecond pulsars in each of them, as some scenarios predict. No radio emission beyond the detection limit of the survey could be associated with any of the Globular Clusters. This was converted into an upper limit of their radio luminosity at 34.5 MHz. For a few nearby Globular Clusters their luminosities, along with the average luminosity of millisecond pulsars, were used to estimate the

maximum number of millisecond pulsars in each of them. On the average, this number turned out to be $< 100$ consistent with theoretical predictions. For the more distant clusters this is not a very sensitive way of estimating this number.

*Carbon Recombination line*: $C578\alpha$ line towards Cas A was detected using a prototype 32 KHz filter in conjunction with the 128 channel digital correlator. The line width and intensity are consistent with measurements at other frequencies.

*The Vela Supernova Remnant*: The map of this SNR observed earlier at 34.5 MHz was analysed in detail to understand its true nature. The flux densities of different parts of the remnant (Vela X and YZ) were estimated. These values, along with those from earlier observations at higher frequencies, clearly shows that Vela X has a flat spectrum, while Vela YZ has a steeper spectrum. A detailed spectral-index distribution over the region was also obtained using the 34.5 and 408 MHz data. These spectral-index estimates, along with other known characteristics, strengthened the earlier hypothesis that Vela X is a pulsar produced nebula, while Vela YZ is a typical shell-type remnant. The implications of this to the association of the Vela SNR with PSR 0833-45 were studied.

*Point sources in the 34.5 MHz survey*: A detailed study of the point sources and their identifications has been undertaken, in particular, the identification of the sources with those seen in the earlier higher frequency surveys (like for e.g. the Molonglo 408-MHz survey, the Mills, Slee and Hill 85 MHz survey, etc.). This analysis has revealed an interesting class of point sources which did not show up in the higher frequency surveys of comparable sensitivity. This implies that these sources are either steep spectrum sources and/or extended. Further high resolution imaging at several frequencies are planned to understand their nature.

*Mira Variables*: The analysis and interpretation of SiO maser line observations at 86 GHz of Mira variables using the 10.4m millimeter wave telescope was completed. The dependence of SiO maser emission of a star on its spectral type allows its interpretation as due to the variation of the SiO abundance with the effective temperature.

*SiO Masers*: A correlation was found between the SiO emission and the stellar bolometric magnitude. This can be understood in terms of a radiatively-pumped maser. The infrared emission from the dust in the circumstellar shell

was shown to provide an extra possible source of pump photons. This dispels the mystery about the pumping mechanism responsible for very strong SiO maser sources.

Detailed comparison between existing numerical models for both SiO maser emission and circumstellar shells was done. It was shown that very good general agreement exists between the two, although some questions of details still remain to be settled.

*Cometary Globules*: $^{12}CO$ observations of cometary globules in the Gum Nebula region were made using the 10.4m millimeter wave telescope. Observations were made of several globule heads and a few points along the tails to study the kinematics of the cometary globular system as a whole, and to study the nature of the tails. Detailed maps were made in $^{12}CO$ and $^{13}CO$ of the 'head' of the globule CG22 to investigate the density and temperature distributions.

*Lynds clouds*: Four low opacity, high latitude, Lynds clouds were mapped in $^{12}CO$, and partially mapped in $^{13}CO$, to understand their morphology, structure and the nature of clumping and support in them. Lines of three other molecular species viz., CS, HCN and $HCO^+$ were also searched for at the centers of each cloud, but were not detected. This non-detection, along with the fact that $^{12}CO$ lines are both reasonably strong and wide raises several interesting questions. These are now being investigated.

*CO observations towards Cas A using the 10.4m millimeter wave telescope*: The $^{12}CO$ J=1 to J=0 transition at 115 GHz was observed over a 9'x9' region centered on Cas A. A total of 81 spectra obtained are intended for obtaining the distribution of CO at the Orion and Perseus arm velocities in the direction of Cas A. The analysis of the data is in progress.

*22 GHz VLBI*: This collaborative effort between the Institute and the Space Research Institute, Moscow was continued as a part of the Integrated Long Term Project of Indo-Soviet cooperation. The new VLBI system was used successfully for observations of galactic star forming regions, emitting $H_2O$ maser radiation. Information on source structure, sizes and internal velocities has been obtained with resolution less than 0.5 milli-arcsecond. An added bonus from the interferometric data was the determination of the geodetic coordinates of the millimeter wave telescope.

In collaboration with the Tata Institute of Fundamental Research, observations were made using the 10.4 m millimeter wave telescope to study the

spatial distribution and physical parameters of galactic star forming regions. The correlation between infrared emitting dust and line-emitting molecular gas would enable the measurement of dust temperature, gas/dust ratio and column density within the regions.

## INSTRUMENTATION

*GMRT Pulsar Receiver System*: The development of the first phase of the pulsar receiver for the Giant Meterwave Radio Telescope is well under way. This will provide the following features to begin with:

1. To be able to observe 2x16 MHz bands in each polarization with a 256 point Fourier transform. It will also be possible to make these observations by combining the array in either the coherent or incoherent mode.
2. Polarimetry to obtain the Stoke's parameters for polarization studies of Pulsars, as well as calibration of the antennas.
3. Real-time dedispersion over 512 spectral channels with a programmable interface to the control computer wherein a user defined model for dispersion can be fed, and the incoming data is dispersed based on this model.
4. On line preprocessing facilities to conduct Pulsar searches.
5. High speed acquisition, storage and retrieval of data from the above units at the rate of about 1 million samples/sec, corresponding to 1024 effective channels.

The first phase is expected to go into operation by the end of 1991.

*GMRT 21cm Receivers*: At the request of TIFR testing of the 45m GMRT antennas at 1-1.5 GHz was undertaken. A test receiver for this band has been constructed to receive 2 channels (at 1.05±0.05 and 1.45±0.05 GHz). The receiver was completed and the data acquisition system and PC interface are in the final stages of construction. A horn antenna and waveguide to coaxial transition were also constructed. System integration is expected to be completed and field tests to begin around August, 1991. Following promising results of the test, the development and construction of the receiver and feed system for the entire array of 30 telescopes will be undertaken for the 1-1.5 GHz band during 1992-93.

*A versatile spectral-line receiver for the Ooty Radio Telescope*: In collaboration with the Radio Astronomy Centre at Ooty, work has started on augmenting the existing 512 channel one-bit correlators to obtain 8 simultaneous

spectrometers of 768 channels each. This can be used to simultaneously observe four recombination lines at two adjacent positions in the sky.

*Millimeter Wave Telescope*

*Dual Polarisation Receiver*: This instrument was improved, especially the vacuum system, cryogenic system and cross polarisation response. This receiver was used for regular astronomical observations during the last season.

*L-band HEMTs*: The development of low-noise cooled IF amplifiers for the 1.2-1.6 GHz band was continued with HEMTs replacing the older FET devices. Measured noise was less than 10°K.

*K-band HEMTs*: 20-26 GHZ HEMT cooled amplifiers are being developed by one of our staff, working at the Chalmers Institute of Technology in Sweden. Broad band sources for the 33-50 GHz and 110-170 GHZ frequency bands were acquired for development of receivers for spectral lines of astrophysical interest.

*Flexible IF Processor*: A new IF processor system was designed and constructed to allow flexible use of the various filter banks and 3 acousto-optic spectrometers either for single or dual polarisation measurements using a frequency multiplexing scheme.

*VLBI System*: The 22 GHz VLBI system was improved by the addition of an ultra low-noise synthesiser for local oscillator generation, locked to the hydrogen maser frequency standard. The system, as reported above, was successfully used for observations.

*Holographic mapping*: It is planned to use this technique by transmitting a signal from the nearby TV tower to determine the phase and amplitude of the aperture field distribution and thus measure the antenna surface errors. The transmitter phase locking scheme has been tested successfully. Data acquisition and data reduction algorithms for surface mapping is in process.

*Multibeam Receiver*: A 4 feed receiver for the 3-mm wavelength band is being planned to allow parallel acquisition of data, making better use of the antenna. The optical design has been completed. Mechanical design and component fabrication is under process.

*Control and Monitor Scheme*: A distributed microprocessor-based monitor and control scheme has been designed to enable flexible automated telescope operations. Construction of some components has begun. Documentation effort for producing user manuals for the telescope was initiated.

*Decameterwave Telescope*:

*A 8-line Spectrometer for GEETEE*: Using the technique of recirculation the existing 128 channel digital correlator has been modified to provide 8 simultaneous spectrometers to observe eight adjacent recombination lines available within the 2 MHz bandwidth of GEETEE. Final testing of this instrument is in progress.

## Mauritius Radio Telescope Project

An interferometer using 32 helices operating at 150 MHz fabricated last year was finally tested and shipped to Mauritius.

Design and development of an on-line 1024 channel data acquisition and monitoring system for the CLRO correlators taken up last year was completed and testing is in progress.

At Mauritius, construction of the east-arm base has been completed and the west-arm is in progress. All the 512 helical antennas in the eastern arm and 128 helical antennas in the western arm have been installed. A 600 metre rail-track in the southern array has also been laid, and 16 mobile trolleys with four helical antennas on each one of them have been fabricated.

Fabrication of the first stage cabling and combining networks have been co mpleted and shipped to Mauritius. The design and development of the mixer module and signal processor is also complete.

## Optical Interferometry

With a view to investigating possible sites for a full-scale interferometer, 'seeing' measurements using a masked 15cm telescope were continued in and around Bangalore.

*Rotational Shear Interferometer*: A rotational shear interferometer with a $180^{o}$ fixed shear which can be mounted at the prime focus of the Vainu Bappu Memorial Telescope (VBT) has been fabricated at the Indian Institute of Astrophysics. The back-end electronics and data reduction was carried out at the

Institute. The combined instrument was successfully tested in the laboratory environment. The above instrument was also tested at both the prime focus and Cassegrain focus of the VBT.

**Computing Facilities**:Sixteen Megabytes of additional memory and a HP Laserjet printer has been added to the VAX 11/780 system. The Astronomical Image Processing System (AIPS) obtained from the National Radio Astronomy Observatory has been installed on the VAX 11/780 and is being used for processing radio interferometric data. Electronic mail facility has been made available at the Institute through a link to the Indian Institute of Science node "vigyan".

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<br>The National College<br>Bangalore | Some Physical Studies on liquid crystals |
| P.R.Maheshwara Murthy<br>Govt. Science College<br>Bangalore | Electric and magnetic field effects in liquid crystals |
| Sharanabasava M.Khened<br>Laxmi Venkatesh Desai<br>College, Raichur | Experimental studies of phase transitions in ferroelectric liquid crystals |

## Ph.D.

*Awarded*

| *Name* | *Topic of Study* |
|---|---|
| C. Nagabhushan | Experimental studies of phase dielectric properties of liquid crystals |
| V.N. Raja | High pressure and X-ray studies of liquid crystals |
| S. Somasekhar | Experimental studies of phase diagrams of liquid crystals |

*Submitted*

| | |
|---|---|
| Nimesh A. Patel | A study of circumstellar silicon monoxide Masers |

*Publications*

The research work done by the staff of the Institute has been published in a number of journals. A list of publications that have already appeared and those submitted and in press is given at Annexure - I (Page 23).

*Conferences/Seminars and Meetings*

The staff of the Institute visited various institutions in India and abroad and attended conferences and presented papers. In addition, 43 lectures were given by them elsewhere

*Gandhi Memorial Lecture*

The Gandhi Memorial Lecture for 1990 was given by Mr. Krishen Khanna on "A Pilgrim's Progress ", on 30th January, 1991.

*Colloquia*

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

*Journal Club Meetings*

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

*Visiting Scientists*

A number of scientists from institutions within the country and outside visited the Institute during the year. Their names are listed following those of the scientific and technical staff of the Institute given towards the end of the report.

*Library*

Six hundred and thirty one new books were added to the library during the year. The total book collection now is 17,731. The library presently subscribes to one hundred and fifty one periodicals and has a collection of 21,163 bound volumes. Of the periodicals subscribed, 21 are received by airmail and IAU circulars are received via electronics mail.

*General*

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

| | Rs. in lakhs |
|---|---|
| PLAN – RECURRING AND NON-RECURRING | 201.75 |
| NON PLAN – RECURRING | 159.00 |
| Total | 360.75 |

# STAFF

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

V. Radhakrishnan *(Director)*

K.R. Anantharamaiah
P.G. Ananthasubramanian
Antony Joseph
P.R. Amuda*
Arvind K. Shenai
T.K. Babu
R. Bhandari
D. Bhattacharya†
S. Chandrasekhar
K. Chandrasekhara
S. Chanthrasekharan
Chitra M. Gokhale
A.A. Deshpande††
K.S. Dwarakanath
R. Ganesan&
K. Gurukiran*
B.R. Iyer
G. Jayakumar
P.A. Johnson
U.D. Kini
S. Krishnan+
S. Krishnaprasad
V. Lakshminarayanan
Lakshmy P. Usha
N.V. Madhusudana
M. O. Modgekar
Mohd. Ateequlla
H.N. Nagaraja*
R. Nandakumar
H. Narayanan*
B.V. Nataraja
R. Nityananda
T. Prabhu*
E. Prameela*
K.B. Raghavendra Rao*
A. Raghunathan*
P. Rajasekhar
P.S. Ram Kumar
P.N. Ramachandra
C. Ramachandra Rao
S. Ramaseshan
P. Ramachandran
K. Ramesh Kumar
G.S.Ranganath
N. Ravi Sankar
D.K. Ravindra
T.S. Ravishankar
G. Rengarajan
T.N. Ruckmongathan@
B.K. Sadashiva
J. Samuel%%
G. Sarabagopalan
N.V.G. Sarma
P.S. Sasi Kumar
M. Seethalakshmi
M. Selvamani
P. Shaji
S. Shivkumar Nair
C.S. Shukre
K. Smiles Mascarenhas
G. Srinivasan
K. Subramanya

M.R. Subramanyam
Umesh S. Nayak
V. Vijay*
C.V. Vishveshwara
Vivek Dhawan
M. Vivekanand[&&]
H. Subramonyam
K. Sukumaran
K.A. Suresh
V. Suresh Rao
N. Udaya Shankar

*Research Fellows*

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

*Post-Doctoral Fellows*

R. Pratibha
V.N. Raja
L. Uma Devi
V.A. Raghunathan
Ravi Kulkarni

*Consultant Physicians*

M.R. Baliga
A.R. Pai

*Resignations*

N. Jayaprakash
Rajeev Agarwal
K.V. Ramaprasad
B.R. Ratna
Senthil Kumar
P.S. Somasundaram
V.S. Vadivel
S. Krishna
V. Rajeswari
Rani P. Rao
Reena Sharma
K. Shanti
Subash Karbelkar

S. Chandrasekhar (retired on 31.8.1990)

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

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

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

+On deputation with the National Aeronautical Laboratory, Bangalore.

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

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

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

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1 Under the UGC Faculty Improvement Programme.

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

## LIST OF VISITORS

| | |
|---|---|
| Ravi Subrahmanyan<br>Radio Astronomy Centre<br>Tata Institute of Fundamental Research<br>Ooty | 16-17 May, 1990 |
| Sanjay Wagh<br>Tata Institute of Fundamental Research<br>Bombay | 21 June -<br>23 July, 1991 |
| R.S. Arora<br>National Physical Laboratory<br>New Delhi | 19-20 June, 1990 |
| A.R.P. Rau<br>Louisiana State University<br>U.S.A. | 11-13 July, 1990 |
| W.M. Goss<br>National Radio Astronomy Observatory<br>Soccoro, New Mexico<br>U.S.A. | 13-31 July, 1990 |
| F. Biraud<br>Observatoire de Paris<br>Section de Meudon<br>Paris, France | 16-19 July, 1990 |
| J.L. Osborne<br>Department of Physics<br>University of Durham<br>Durham, U.K. | 28 July -<br>26 August 1990 |
| Bruno Bertotti<br>University of Pavia<br>Italy | 26 August -<br>7 Sept., 1990 |

| | |
|---|---|
| S. Sridhar<br>Tata Institute of Fundamental Research<br>Bombay | 12 September -<br>6 Oct., 1990 |
| G. Baskaran<br>The Institute of Mathematical Sciences<br>Madras | 1-6 October, 1990 |
| N.S. Nuritdinov<br>Astronomy Department<br>Tashkent University, U.S.S.R. | 14-16 October 1990 |
| Hermann Bondi<br>Churchill College<br>Cambridge, U.K. | 26 October -<br>1 November, 1990 |
| A. Konovalenko and<br>L. Litvinenko<br>Institute of Radio Astronomy<br>Ukranian Academy of Sciences<br>Kharkov, U.S.S.R. | 2-14 December, 1990 |
| Katalin Fodor-Csorba<br>Mandor Eber<br>Central Research Institute of Physics<br>Budapest, Hungary | 11-15 December, 1991 |
| J. Ponsonby<br>Nuffield Radio Astronomy Labs.<br>Jodrell Bank, U.K. | 18 Dec. 1990 -<br>6 Jan. 1991 |
| Sam Edwards<br>Cavendish Laboratory<br>Cambridge, U.K. | 25-29 December, 1990 |
| F. Rondelez<br>University of Pierre and<br>and Marie Curie<br>Paris, France | 27-31 December, 1990 |

| | |
|---|---|
| Joanna M. Rankin<br>Department of Physics<br>University of Vermont<br>Burlington, Vermont<br>U.S.A. | 28 December, 1990 -<br>27 June, 1991 |
| A. Tsygan<br>A.I. Muslimov<br>A.F. Ioffe Institute<br>Leningrad, U.S.S.R. | 9-31 January 1991 |
| Raymond Y. Chiao<br>Department of Physics<br>University of California<br>Berkeley, California<br>U.S.A. | 10-13 January, 1991 |
| C. Devchand<br>Freiburg University<br>Germany | 23-28 January, 1991 |
| A. Kazbegi<br>G. Machabeli<br>G. Melikidze<br>Abastumani Astrophysical Observatory<br>Tbilisi, Georgia, U.S.S.R. | 8 February -<br>24 March, 1991 |
| M. Ludvigsen<br>Linkoping University<br>Linkoping, Sweden | 28 February -<br>24 March, 1991 |
| Ranjan Gupta<br>IUCAA, Pune | 17-19 March, 1991 |
| Claes-Ingvar Bjornsson<br>Stockholm Observatory<br>Sweden | 20 March -<br>22 April, 1991 |

## PAPERS PUBLISHED – Annexure - I

*In Journals*

1. "Radio studies of the Galactic Centre-II. The arc, threads and related features at 90cm (330 MHz)" (K.R. Anantharamaiah, A. Pedlar, R.D. Ekers, and W.M. Goss), *Mon. Not. R. astr. Soc.*, **249**, 262 (1991).
2. "A search for protoclusters at Z=3.3", (Ravi Subramanyam and K.R. Anantharamaiah), *J. Astrophys. Astron.*, **11**, 221 (1990).
3. "A Digital Correlation Receiver for the GEETEE Radio Telescope" (N. Udaya Shankar and T.S. Ravi Shankar), *J. Astrophy. Astron.*, **11**, 297 (1990).
4. "A modified algorithm for CLEANing wide-field maps with extended structures" (K.S.Dwarakanath, A.A. Deshpande and N. Udaya Shankar), *J. Astrophys. Astron.*, **11**, 311 (1990).
5. "A synthesis map of the sky at 34.5 MHz" (K.S. Dwarakanath and N. Udaya Shankar), *J. Astrophys. Astron.*, **11**, 323 (1990).
6. "Further 7-mm VLBI observations of 3C84 and other sources with 100 $\mu$as Angular Resolution", (V. Dhawan, N. Bartel, A.E.E. Rogers, T.P. Krichbaum, A. Witzel, D.A. Graham, I.I.K. Pauliny-Toth, B.O. Rönnäng, H. Hirabayashi, M. Ionue, C.R. Lawrence, I.I. Shapiro, B.F. Burke, R.S. Booth, A.C.S. Readhead, M. Morimoto, K.J. Johnston, J.H. Spencer and J.M. Marcaide), *Astrophys. J. Lett.*, **360**, L43 (1990).
7. "On the morphology of supernova remnants with pulsars" (D. Bhattacharya), *J. Astrophys. Astron.*, **11**, 125 (1990).
8. "Radio pulsars and the scale height of ionized hydrogen" (D. Bhattacharya and F. Verbunt), *Astron. Astrophys.*, **242**, 128 (1991).
9. "Gamma rays from millisecond pulsars" (G. Srinivasan and D. Bhattacharya), *J. Astrophys. Astron.* , **12**, (1991).
10. "The formation and evolution of binary and millisecond radio pulsars"
    (D. Bhattacharya and E.P.J. van den Heuvel), *Phys. Reports*, **203**, 17 1 (1991).
11. "Homfly, the work of Edward Witten and Quantum Groups" (Ravi Kulkarni), *Curr. Sci.*, **24**, 1301 (1990).
12. "Scalar Waves in the Witten Bubble Spacetime" (B. Bhawal and C.V. Vishveshwara), *Phys. Rev.D*, **42**, 1996 (1990).
13. "Radio Astronomy - A sky survey at 34.5 MHz" (G. Srinivasan), *Curr. Sci.*, **60**, 144 (1991).

14. "Propagating electroconvection in nematic liquid crystals under DC excitation" (V.A. Raghunathan, P.R. Maheswara Murthy and N.V. Madhusudana), *Curr. Sci.*, **59**, 506 (1990).
15. "Optically condensed matter" (G.S. Ranganath), *Curr. Sci.*, **60**, 340 (1991).
16. "X-ray study of a thermotropic biaxial nematic liquid crystal" (S. Chandrasekhar, V.N. Raja and B.K. Sadashiva), *Mol. Cryst. Liquid Cryst. Lett.*, **7**, 65 (1990).
17. "Temperature range of the smectic A phase and its effect on the smectic A - smectic C transition" (S. Krishna Prasad, V.N. Raja, D.S. Shankar Rao, Geetha G. Nair and M.E. Nuebert), *Phys. Rev.*, **A42**, 2479 (1990).
18. "Ferroelectric liquid crystals derived from trans-p-n-alkoxycinnamic acids (B. Shivakumar, B.K. Sadashiva, S. Krishna Prasad and S.M. Khened), *Ferroelectrics*, **114**, 761 (1991).
19. "Spontaneous polarization and rotational viscosity measurements on ferroelectric liquid crystals derived from trans-p-n-alkoxycinnamic acids" (S.K. Prasad, S.M. Khened, S. Chandrasekhar, B. Shivakumar and B.K. Sadashiva), *Mol. Cryst. Liquid Cryst.*, **182B**, 313 (1990).
20. "Thermotropic mesomorphism in a series of copper $\beta$-diketones and their ligands" (Veena Prasad and B.K. Sadashiva), *Mol. Cryst. Liquid Cryst.*, **195**, 161 (1991).
21. "Crystal and molecular structure of the discogen bis[1,3-di-(p-n-decyl phenyl)propane 1,3-dionato]palladium(II)" (K.Usha, Kalyani Vijayan, B.K. Sadashiva and P. Rani Rao), *Mol. Cryst. Liquid Cryst.*, **185**, 1 (1990).
22. "Discontinuous orientational changes in nematics - Effects of electric and magnetic fields,, (U.D. Kini), *Liquid Crystals*, **8**, 745 (1990).
23. "Magnetic field induced transient periodic dissipative structures in nematics" (U.D. Kini), *J. de Physique II*, **1**, 225 (1991).
24. "Dielectric behaviour near a smectic $A_d$-smectic $A_2$ ritical point" (D.S. Shankar Rao, S. Krishna Prasad and V.N. Raja), *Mol. Cryst. Liquid Cryst.*, **198**, 291 (1991).

*In Conference Proceedings*

1. "Interferometric observations of HII, CII and $H_o$ regions in ORION-B" (K.R. Anantharamaiah, W.M. Goss and P.E. Dewdney), in *Radio Recombination Lines:25 years of investigations*, eds. M.A. Gordon and R.L. Sorochenko, D. Reidel, Dordrecht, p.123 (1990).

2. "Interferometric observations of Carbon Recombination Lines towards Cassiopeia A at 332 MHz" (H.E. Payne, K.R. Anantharamaiah and W.C.Erickson), in *Radio Recombination Lines: 25 years of investigations*, eds. M.A. Gorden and R.L. Sorochenko, D. Reidel, Dordrecht, p.203 (1990).
3. "Limits on the temperature and Filling Factor of the Warm ionized medium towards the galactic centre" (K.R. Anantharamaiah, H.E. Payne and D. Bhattacharya), in *Radio Recombination Lines: 25 years of investigations*, eds. M.A. Gorden and R.L. Sorochenko, D. Reidel, Dordrecht, p.259 (1990).
4. "VLA observations of Recombination lines from the Star Burst Galaxy NGC 253" (K.R. Anantharamaiah and W.M.Goss), in *Radio Recombination Lines: 25 years of investigations*, eds. M.A.Gorden and R.L. Sorochenko, D. Reidel, Dordrecht, p.267 (1990).
5. "A wide field 90cm Image around the galactic centre – Evidence for a poloidal magnetic field" (K.R. Anantharamaiah and A. Pedlar), in *Galactic and Extragalactic Magnetic Fields*, eds. R. Beck, P.P. Kromberg and R. Wielebinski, Kluwer, p.375 (1990).
6. " Gravitational Lenses" (Rajaram Nityananda), in Proc. Raman Centenary Sym. on Waves and Symmetry, Bangalore (1988), *Curr. Sci.*, p.1044 (1990).
7. "Geometric Phase Experiments in Optics – A Unified Description" (R. Bhandari), in Proc. Raman Centenary Sym. on Waves and Symmetry, Bangalore (1988), *Waves and Symmetry, Curr. Sci., 59*, p.1159 (1990).
8. "Defects in liquid Crystals" (G.S. Ranganath), in Proc. Sym. on Waves and Symmetry, Bangalore (1988), *Curr. Sci.*, **59**, 1106 (1990).
9. "Classical Light Waves and Spinors" (R. Bhandari), in *Analogies in Optics and Micro Electronics*, eds. W. van Haeringen and D. Lenstra, Kluwer (1990).
10. "Theories of liquid crystals" (N.V. Madhusudana), in *Applications of Liquid Crystals*, ed. B. Bahadur, World Scientific Publishing Co. (1990)
11. "Liquid crystals and coordination compounds" (B.K. Sadashiva), in *Prof. G.K.Narayana Reddy Felicitation Volume*, Bangalore University (1991).
12. "The Problem of Growing Science in India and Other Developing Countries: The Role of the Academies" (S. Ramaseshan), in Proc. Convocation of World Academies on *Scientific Issues of the Next Century, Ann. N.Y. Acad. Sci.*, **610**, p. 141 (1990)

## Papers in Press

*In Journals*

1. "Low-frequency observations of the Vela supernova remnant and their implications" (K.S .Dwarakanath), (submitted to *J. Astrophys. Astron.*
2. "Multipole Analysis for Electromagnetism and Linearized gravity with irreducible cartesian tensors" (T. Damour and B.R. Iyer), to appear in *Phys. Rev.D.*
3. "Post-Newtonian Generation of Gravitational Waves - The Spin Moments" (T. Damour and B.R. Iyer), to appear in *Ann. Inst. H.Poincare.*
4. "Separation and Variables for the Dirac equation in an extended class of Lorentzian metrics with Local Rotational Symmetry" (B.R. Iyer and K. Kamran), to appear in *J. Math. Phys.*
5. "New Spacetimes with local rotational symmetry in which the Dirac equation is separable" (B.R.Iyer and N.Kamran), submitted to *Cl. Q. Gravity.*
6. "Modified Photon Equation of Motion as a Test for the Principle of Equivalence" (B. Bhawal, H.S. Mani and C.V. Vishveshwara), to appear in *Phys., Rev. D.*
7. "43 GHZ-VLBI observations of 3C273 after a Flux Density outburst in 1988" (T.P. Krichbaum, R.S. Booth, A.J. Kus, B.O. Rönnäng, A. Witzel, D.A. Graham, I.I.K. Pauliny-Toth, A. Quirrenback, C.A. Hummel, J.A. Zensus, K.H. Johnston, J.H. Spencer, A.E.E. Rogers, C.R. Lawrence, A.C.S. Readhead, H. Hirabayashi, M. Inoue, V. Dhawan, N. Bartel, I.I. Shapiro, B.F. Burke and J.M. Marcaide), submitted to *Astron., Astrophys.*
8. "The evolution of the sub-parsec structure of 3C84 at 43 GHz" (T.P. Krichbaum, A. Witzel, D.A. Graham, W. Alef, I.I.K. Pauliny-Toth, C.A. Hummel, A. Quirrenbach, M. Inoue, H. Hirabayashi, M. Morimoto, A.E.E. Rogers, J.A. Zensus, C.R. Lawrence, A.C.S. Readhead, R.S. Booth, B.O. Rönnäng, A.J. Kus, K.H. Johnston, J.H. Spencer, B.F. Burke, V. Dhawan, I.I. Shapiro, N. Bartel, A. Alberdi and J.M. Marcaide), submitted to *Astron., Astrophys.*
9. "A comment on the derivation of reciprocity relations for a beam splitter from energy balance" (K. Smiles Mascarenhas). to appear in *American J. Phys.*
10. "The phase problem and the spin glass problem" (Rajeswari Venkatesan), to appear in *Acta Cryst. A.*

11. "Electromechanical effect in cholesteric liquid crystals with fixed boundary conditions" (N.V. Madhusudana, R. Pratibha and H.P. Padmini), *Mol. Cryst. Liquid Cryst.*.
12. "Propagating electrohydrodynamic instabilities in nematics" (V.A. Raghunathan, P.R. Maheswara Murthy and N.V. Madhusudana" *Mol. Cryst. Liquid Cryst.*
13. "Component order parameters in binary mixtures of liquid crystals" (R. Pratibha and N.V. Madhusudana), *Mol. Cryst. Liquid Cryst.*
14. "On some topological solitons in ferronematics" (P.B. Sunil Kumar and G.S. Ranganath), *Mol. Cryst. Liquid Cryst.*
15. "Synthesis and mesogenic properties of some $\beta$-diketones and their copper(II) and palladium(II) chelates" (B.K.Sadashiva, Archana Ghode and P. Rani Rao), *Mol. Cryst. Liquid Cryst.*
16. "Terminally chloro substituted mesogenic $\beta$-diketones" (Archna Ghode and B.K.Sadashiva), *Mol. Cryst. Liquid Cryst.*
17. "Crystal and molecular structure of the discogen bis[1,3-di(p-n-octyl-phenyl)propane-1,3-dionato]copper(II)" (K. Usha, Kalyani Vijayan and B.K. Sadashiva), *Mol. Cryst. Liquid Cryst.*
18. "On the variation of pitch and polarisation-tilt coupling in chiral smectic C" (S.K. Prasad and G.G. Nair), *Mol. Cryst. Liquid Cryst.*

*In Conference Proceedings*

1. "Source-noise in Radio Synthesis Images" (K.R.Anantharamaiah, A.A. Deshpande, V.Radhakrishnan, R.D. Ekers, T.J. Cornwell and W.M.Goss), in Proc. IAU Colloquium No.131, *Radio Interferometry - Theory, Techniques and Applications.*
2. "Spin-1/2 Interferometry with Light Beams" (R. Bhandari), in Proc. Int. Workshop on *Lasers and Laser Applications (IWOLA 90)*, Indore, India, Nov.12-20, 1990.
3. "Mixed Evolution of Light Beams in Polarization and Direction" (R. Bhandari), in Proc. Inter. Workshop on *Lasers and Laser Applications (IWOLA 90)*, Indore, India, Nov.12-30, 1990.
4. "The evolution of neutron stars in the galaxy" (D. Bhattacharya), in Proc. NATO Advanced Study Inst. on *Neutron Stars:an inter-disciplinary field*, eds. J. Ventura and D. Pines, Kluwer (1991).
5. "The formation of neutron star magnetic fields" (D.Bhattacharya and G.Srinivasan), in Proc. NATO Advanced Study Inst. on *Neutron Stars:an inter-disciplinary field*, eds. J. Ventura and D. Pines Kluwer (1991).

6. "From Low-Mass X-ray Binaries to Binary and Millisecond Pulsars" (D.Bhattacharya), in Proc. NATO Advanced Research Workshop on *X-ray Binaries and the formation of binary and millisecond radio pulsars*, eds.S.A. Rappaport and E.P.J. van den Heuvel, Kluwer, (1991).

7. "Polarisation" (V. Radhakrishnan), (Tutorial TJ delivered at the URSI General Assembly, Prague, Czechoslovakia), to appear in *Modern Radio Science 1990*, ed. J. Bach Anderson, Oxford Uni. Press, Oxford.

8. "Pulsar Velocities and their Origins" (V. Radhakrishnan), in Proc. NATO Advanced Research Workshop on *X-ray Binaries and the formation of binary and millisecond radio pulsars*, eds.S.A. Rappaport and E.P.J.van den Heuvel, Kluwer, (1991).

9. "The polarisation of Pulsar Radiation" (V. Radhakrishnan), in Proc. IAU Colloquium No.128 on *The Magnetospheric Structure and Emission Mechanisms of Radio Pulsars*, Lagow, Poland (1990).

10. "A report on the panel discussion" (C.S.Shukre), in Proc. IAU Colloquium No.128 on *The Magnetospheric Structure and Emission Mechanics of Radio Pulsars*, Lagow, Poland, (1990).

11. "Pulsars and Binary Stars" (C.S.Shukre), in Proc.Workshop on *Binary Stars and Stellar Atmospheres*, Hyderabad, *Bul. Astr. Soc. India.* (1991).

12. "Frontiers in Condensed Matter Physics" (G.Srinivasan), in Proc. Conf. on *Frontiers in Condensed Matter Physics*, a symp. in honour of Prof. Stig Lundqvist, Trieste, Italy (1990).

13. "The evolution of the magnetic field of neutron stars" (G.Srinivasan), in Proc. Texas/ESO-CERN Symp. on *Relativistic Astrophysics*, Brighton, England (1990).

14. "Dynamics of the Antonov-Nuritdinov planar galaxy model" (R. Nityananda and S. Sridhar), in Proc. IAU Colloquium No.132 on *Chaos and Instability in celestial mechanics*, ed.K.B. Bhatnagar.