RAMAN RESEARCH INSTITUTE

Bangalore

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Introduction

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

1. Theoretical Physics

The two main areas of theoretical physics pursued at the Institute are gravitation and optics. Einstein's general theory of relativity is of great importance in the astrophysics of compact objects like neutron stars and black holes and also in the study of the universe as a whole. While the theory has a beautiful geometrical structure, it is a challenge to analyse the behaviour of the gravitational field and its coupling to matter and other fields because of the nonlinear equations involved. Many conceptual questions and aspects of formal structure continue to be fruitfully investigated more than seventy years after the theory came into being. Over the years, the work at the Institute has ranged over topics such as perturbations, the exploitation of symmetries, rotation and the analogy with magnetic fields, a new Lagrangian formulation, gravitational radiation, etc. One of the challenges in the field is to make contact with quantum theory and some work has emerged in this area.

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

2. Experimental Optics

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

3. Liquid Crystals

Liquid Crystals the liquid and crystalline states. Many organic compounds whose molecules have pronounced shape anisotropy exhibit such phases. The unique combination of fluidity and anisotropic properties of liquid crystals has led to many applications of these materials. The Liquid Crystals Laboratory of the Raman Research Institute has contributed significantly to the development of the field over the past two decades.

The laboratory has been organised to undertake studies of most of the fundamental properties of liquid crystals. Theoretical and experimental work on liquid crystals covers areas like their unique mechanical and electrical properties, defects, X-ray and light scattering and synthesis of new materials. Work on applications such as displays is also carried out. A new dimension to our LC research has now been added – the study of soft condensed matter.

4. 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 $=10^{-8}$ centimetre) of the electromagnetic spectrum. Radio Astronomy, which had its beginnings in 1932 also deals with the study of these heavenly bodies, but the radiation received by radio telescopes on earth is in the radio range of wavelengths (30 metres to 1 millimetre) of the same electromagnetic spectrum. The lower and upper limits in wavelength of the radio spectrum are set by the earth's atmosphere and ionosphere respectively. In spite of these limitations, the radio window is very wide (30,000 to 1 compared to the 2:1 wavelength ratio in the visible part) and studies within it over the years have yielded information leading to many exciting discoveries such as the 3^0 k cosmic background radiation, quasars, pulsars, etc.

The Raman Research Institute has observational programmes in Radio Astronomy extending over most of the available radio spectrum. It has set-up a Decametrewave Radio Telescope at Gauribidanur jointly with the Indian Institute of Astrophysics. It is one of the few largest among the telescopes in the world operating at a wavelength of 10 metre wavelength and is being used to study the radio emission from various types of celestial objects such as the Sun, Jupiter, radio sources of various kinds in our Galaxy, and external Galaxies. Moving to somewhat shorter wavelengths, members of the Institute use the Ooty Radio Telescope operated by the Tata Institute of Fundamental Research (TIFR), Bombay. This instrument operates at a wavelength of approximately 1 metre and is used for carrying out observations of pulsars, and nebulae of various kinds in the Galaxy. There is an active programme under way to build instrumentation for and use the Giant Metre wavelength Radio Telescope (GMRT) being built by TIFR near Pune. Another interactive project nearing completion is the low frequency (150 MHZ) Mauritius Radio Telescope (MRT) built

at Mauritius in collaboration with the University of Mauritius and the Indian Institute of Astrophysics for a radio map of the southern sky at full resolution of 4' × 4'.

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

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

THEORETICAL PHYSICS (TP)

AREAS OF RESEARCH : Gravitation,
Quantum Physics
Optics

Gravitation. There is an on-going programme amongst a few groups in the world to calculate with increasing accuracy the gravitational radiation from binary systems consisting of two compact objects, in powers of (v/c), the ratio of the speeds of orbital motion to that of light. On the one hand, this has been a long standing and very challenging technical problem in general relativity in view of the nonlinearities and divergences encountered. On the other, there is an upsurge of interest in this problem driven by the prospects of this radiation being detected by ground-based laser interferometric systems now nearing completion. In fact, the waveforms computed are a vital input to the detection process.

In this context, the calculations extant in the literature have now been extended to order $(v/c)^4$ beyond leading, for general elliptic orbits and for both polarisations of the waves. This level of accuracy is required to make sure that the phase of the template waveform does not deviate significantly from that of the signal in the domain when the signal itself is strongest, towards the end of the inspiral.

The model problem of a free field in a flat space-time has been revisited to examine the role of arbitrary space-like slicing in the dynamics. The programme of constructing the Schroedinger functional, the functional Schroedinger equation and the expected slice dependent quantum corrections has been carried out rigorously in two dimensions, but basic obstacles to an extension to higher dimensions have been uncovered.

The classical solution space of the so called CGHS model is analysed. It has been shown that only a specific sector describes collapse to a black hole. Non-perturbative canonical quantisation of this sector is carried out. This leads to the interesting possibility of large quantum fluctuations in the metric even when the states of the matter are nearly classical. These results also could have some implications for the analysis of Hawking radiation from this collapse.

The relation of Mach's principle to general relativity has been debated from the inception of the theory. A recent controversy concerns the role of Mach's principle in the Lense Thirring effect (dragging of inertial frames by a rotating body). A careful analysis of the situation and the literature has shown that there can be as many as ten distinct though connected formulations of what has been called Mach's principle. The controversy is hence reduced to which one is chosen.

Optics. Following the basic work of Bell, and Greenberger Horne and Zeilinger (GHz), there has been considerable recent interest in formulating realisable experimental situations which bring out, in its most extreme form, the conflict between the multi-particle correlations predicted by quantum mechanics and the

constraints imposed by any local theory. A new experiment is proposed, involving four photons produced by parametric down-conversion to generate an entangled state, and their subsequent detection in multiple channels via beam splitters and combiners. It shares with the GHz experiment, the property that the quantum correlation is perfect and diametrically opposite to that required by "local realism".

The phenomenon of spatial rotation induced by successive Lorentz boosts ("Thomas precession") is well known in special relativity. A novel analogous phenomenon in polarisation optics was pointed out, with differential absorption between two orthogonal polarisations playing the role of the boosts, and the rotation manifesting itself as a geometric phase (as indeed Thomas precession itself can also be viewed).

Reflection by a random amplifying medium has been studied. Although the folding of the path by repeated scattering causes enhanced amplification, there is a clear distinction between the diffusive limit in which successive scatterings are uncorrelated, and the localised limit in which they are highly correlated and this shows in the statistics obtained for super-reflection by such a medium.

Quantum Physics. The phenomenon of high temperature superconductivity in the layered cuprates is analysed in terms of two basic ideas. Individual electron tunneling is blocked by the strong normal state correlations. Pair tunneling is however not suppressed, and hence there is a gain in energy coming from the establishment of inter-planar coherence in the superconducting state. This coherence related energy is responsible for the high critical temperature.

The role of the A-site cation size in oxides showing colossal magneto-resistance (CMR) has been analysed. The observed changes in charge and magnetic ordering cannot be explained solely in terms of size effects, and covalent mixing effects are invoked to understand the systematics.

EXPERIMENTAL OPTICS (EO)

AREAS OF RESEARCH : Imaging
Scattering
Entangled Photons
Laser Cooling and Trapping

Imaging in turbid media. A technique of imaging through turbid media by means of polarisation discrimination has been developed, and has been used to image objects with about 100 micrometer resolution, in media that are 30 transport mean-free paths thick, using a 1 mW He-Ne laser. When compared with other existing methods, this technique has the advantage that (a) it has no translating parts, (b) records two-dimensional data, and © achieves polarisation locking by software. These make the system extremely compact and portable, and the data collection very simple and rapid. An Indian patent for this technique has been applied for.

Light scattering. Scattering of light by random media has been studied both experimentally and by means of Monte-Carlo simulation and the modification of the transport mean-free paths in small systems is being examined.

Entangled photons. Generation of entangled photons by down-conversion of UV in a BBO crystal was attempted. However, the process being statistically very weak, it was felt that a cavity was needed to make the output significant.

Random amplifying media. Monte-Carlo simulations of light amplification in random media are being carried out.

Magneto-optic trap. The setting up of a magneto-optic trap for rubidium has been taken up. The temperature control system for the diode lasers has been completed. The magnetic coil configurations have been calculated, and the coils wound and tested. The vacuum chamber is now being made.

LIQUID CRYSTALS (LC)

AREAS OF RESEARCH :

LC Synthesis
Phase Transition
Monolayers
Hydrodynamics
Instabilities
Non-linear Optics
Polarization Optics
LC Displays
STM Electrochemistry

Experimental Studies

Discovery of a new liquid crystalline phase. Based on the analogy between smectic A liquid crystals and superconductors, de Gennes predicted long ago that 'Type II' smectics should exhibit an analogue of the Abrikosov phase in which edge or screw dislocations are arranged in a regular lattice. Renn and Lubensky worked out the detailed structure to show that in highly chiral type II materials, a twist grain boundary (TGB) phase would result. Almost simultaneously, the TGB_A phase was discovered, in which smectic A blocks were found to be separated by grain boundaries made of screw dislocations. Later the TGB_C phase with the blocks made of smectic C layers was also discovered. Very recently the TGB_{C^*} phase in which the smectic C^* blocks have a helical arrangement along the layer normal directions in addition to the TGB helix in an orthogonal direction was discovered in the laboratory. Detailed optical and X-ray studies were made to show that the layers and the grain boundaries undulate to from a 2D square grid pattern orthogonal to the TGB helical axis. Thus the Undulating Twist Grain Boundary C* ($UTGB_{C^*}$) phase is 3 dimensionally modulated, and is one of the most non-uniform liquid crystalline structures discovered to date. Detailed electrooptic and dielectric studies have been taken up on this new liquid crystal.

Nematic-nematic transition in a highly polar compound. Liquid crystals made of compounds with strongly polar cyano or nitro end groups are known to exhibit unusual phase transitions. In experiments conducted in the laboratory during the previous year an indication of a nematic-nematic (NN) transition was found in one of the nematogens under the action of high electric fields (~600 esu). Detailed optical studies have shown that though thick cells (~20 μm) do not show any evidence for NN transition, thin cells (< 3 μm) clearly exhibit a jump of about 1% in the optical path difference implying a weak first order N-N transition. The transition temperature increases as the thickness is reduced and the bulk sample itself is likely to exhibit the transition well below the ambient temperature. The increase in T_{NN} with the reduction in cell thickness is associated with a concurrent increase in the optical path difference and hence the orientational order parameter. Further, experiments using a superconducting magnet also show that T_{NN} increases perceptibly (by ~1 K) for a 50 Tesla field, which is to be compared with the increase of ~1 mK in T_{NI} for a similar

field. The Landau-de Gennes theory of the nematic phase does not account for these results, and attempts are now being made to develop a better model.

Phase diagram of a mixed Langmuir monolayer. 4′-n-octylcyanobiphenyl (8CB) and stearic acid (SA) and their mixtures form monolayers at the air-water interface. Over a wide composition range the mixtures have been found to exhibit an induced liquid condensed (LC) phase, whereas the components exhibit only the liquid expanded (LE) phase. The LE to LC transition is a first order transition. Attempts are being made to understand the physical origin of this transition. Further, beyond 55% of SA, the LE phase itself phase separates into two LE phases, one of them richer in 8CB than the other. Both of them coexist with the gas phase at low surface densities and with the induced LC phase at higher surface densities. These results have been accounted for in terms of the Crisp's phase rule.

Pancharatnam phase studied using cholesterics. Cholesteric liquid crystal films can act as circular analysers as they reflect one of the circular components of a light beam of an appropriate wavelength. This has been exploited to demonstrate that the Pancharatnam phase is a purely geometric phase as no dynamical phases are introduced by the analysers.

Asymmetric ripple phase in lipid-water systems. The electron density maps of hydrated L as well as racemic DL DMPC have been calculated using X-ray data on oriented films, in a collaborative program with John Katsar of Chalk River Laboratories, Ontario, Canada. Both the lipid systems exhibit similar asymmetric ripple structures, showing that molecular chirality does not cause the asymmetry, in contradiction with the prediction of an available model. A model is now being developed by including higher order terms in the relevant order parameter to look for solutions with asymmetric ripples.

Synthesis of mesogenic compounds. Several new compounds exhibiting ferroelectric, anitferroelectric and ferri phases have been synthesised. In a collaborative program, the EPR spectra of some discotic copper complexes synthesised in the laboratory have been studied by scientists at the Bose Institute, Calcutta, to find interesting correlations with the molecular structures.

New addressing techniques for displaying gray shades in liquid crystal displays. Various techniques have been tried, over the years, to display gray shades in passively addressed matrix LCDs. Some examples are pulse width modulation and frame modulation technique which yield a limited number of gray shades. While the amplitude modulation technique gives a large number of gray shades, it requires real time calculations and a large number of voltage levels on the columns. A new technique is being investigated in which a few frames 'f' are used for addressing instead of just two as in the amplitude modulation technique. Apart from retaining the maximum selection ratio, the new technique removes some of the limitations of the earlier techniques.

Electrochemical studies: A scanning tunnelling microscope (STM) which was

constructed in the laboratory during the previous year is being modified to accommodate an electrochemical cell for an *in situ* investigation of electrochemical processes.

The effect of surface roughness on defect formation in self assembled octadecanethiol coatings on gold surfaces is being investigated using cyclic voltametry and scanning tunnelling microscopy. As the surface roughness is increased, the charge transfer reaction has been found to be blocked more effectively.

Theoretical Studies

An XY model for smectics made of bent molecules. A new type of molecular architecture which has bent (or bow-shaped) molecules has been found by a Japanese group to give rise to smectic liquid crystals which have transverse polarization. Further, though the molecules are achiral, both left- and right-handed helical structures have also been found in these liquid crystals. The ANNNXY model which was recently developed in the laboratory to successfully account for the physical properties of antiferroelectric liquid crystals has been adapted to construct a detailed phase diagram for the new materials. The helical structures arise from a frustrated second neighbour antiferroelectric interaction, competing with a first neighbour coupling which has been shown to be antiferroelectric at higher temperatures and ferroelectric at lower temperatures.

Hydrodynamics of smectic C liquid crystals. A general macroscopic hydrodynamic theory of smectic C liquid crystals has been developed to take into account both the layering and the C-vector as variables. This admits in particular permeative flow across the layers. The asymmetric stress tensor consists of 16 shear viscosity coefficients, three of which describe dissipative torques of the C-vector. The full equations give a proper description of the reorientation dynamics of the director in an external field, removing errors in an earlier formulation. Shear flow with layers slipping past each other along the direction of $\vec{C}$ exhibits an instability at a threshold, above which a uniform alignment of $\vec{C}$ is not possible, and further, leads to a transverse flow along the layers. When the shear is in the layers, a similar instability produces a transverse permeative flow and layer curvature. For this type of shear, permeation also leads to a very long 'inlet' section even in a simple Poiseuille flow. Further, the asymmetry of the stress tensor leads to a 'Hall effect' in flows along the layers in which a transverse pressure gradient develops for suitable orientations of the C-vector.

Non-linear optics of liquid crystals. Kinks are topological defects which are produced in a nematic when an electric or magnetic field is applied in an appropriate direction. Calculations have shown that a strong laser beam modifies the structure of the kink defect due to non-linear interactions with the laser beam. A new kink state is produced in the process and further, structural instabilities due to the nonlinear interaction generates a rich 'phase diagram'.

Periodic instabilities under external fields in nematic liquid crystals. The earlier theoretical calculations on field induced periodic instabilities in nematics have been extended for the case of initial planar alignment of the director ($\hat{n}$) when both electric (E) and magnetic (H) fields act on the sample simultaneously. If both the diamagnetic and dielectric anisotropies are positive, and $\hat{E}$ is stabilising, i.e., along $\hat{n}$, and $\hat{H}$ acts in a plane normal to $\hat{n}$, a complicated deformation pattern results, the direction of the wavevector of the periodic structure depending on the angle made by $\hat{H}$ with the plates. Detailed phase diagrams have been worked out for both ordinary nematics (with $K_1 < 3.4\ K_2$, K_1 and K_2 being splay and twist elastic constants respectively) and polymeric nematics with $K_1 > 3.4\ K_2$ for different combinations of the field directions with respect to the initial director alignment.

In a collaborative work with the scientists at the College of Wooster, Ohio, USA, some experimental results obtained by the latter on the effect of the relative strengths of magnetic and electric fields in generating a periodic instability have been interpreted. The observations indicate that electrical conductivity of the medium has a significant effect on the observed instabilities.

Energetics of dislocation lines in smectic C liquid crystals. In a collaborative work with T.C. Lubensky, the energetics and mutual interactions of arbitrarily oriented straight dislocations occurring in smectic C liquid crystals have been worked out as functions of the tilt order parameter. The lowest energy dislocation lines have been found to have a part-screw and part-edge character which might account for the observed structure of the TGB_C phase.

ASTRONOMY and ASTROPHYSICS (AA)

AREAS OF RESEARCH : Neutron Stars, Pulsars
Inter-Stellar Matter (ISM)
Inter-Galactic Matter (IGM)
Galaxy Clusters
Radio Recombination Lines (RRL)
Cosmic Microwave Background (CMB)
Astrophysical Masers

Neutron Stars and Pulsars

Natal kicks. It was shown that B-emission (Be) star-neutron star binaries, of which there are many in our galaxy, can provide an interesting way to determine the natal kicks of neutron stars. If there is no natal kick received by the neutron star, then a strict relation is expected between the eccentricity and the systemic velocity of these binaries. For Be binaries, it is possible to determine both the 3-D systemic velocities and the orbital eccentricities from long-term astrometric and spectroscopic observations. Any deviation from the expected relation would then signify the existence of natal kicks, and the degree of deviation would provide an estimate of the magnitude of these kicks.

(+ E.P.J. van den Heuvel and S.F. Portegies-Zwart).

Kilohertz Quasi-Periodic Oscillations (QPOs). Recently the Rossi X-ray Timing Explorer satellite has discovered quasi-periodic brightness modulations at Kilohertz frequencies in several Low-Mass X-ray Binaries. These oscillations originate in the inner edge of the accretion disk around the central neutron star, and it is likely that the frequency represents the Keplerian frequency of the last stable orbit dictated by general relativity. If this is true, then the observed frequency places important constraints on the mass and the radius of the neutron star, thereby constraining the equation of state at high densities. A few estimates of these constraints have been made in the literature, based on approximate treatment of rotation in general relativity. These calculations were extended to full, self-consistent general relativistic ones, and it was demonstrated that the constraints are significantly modified when refined calculations are made.

(+ Arun Thampan and Bhaskar Datta)

Improving pulsar distances by modelling interstellar scattering. A new method was developed to study the distribution of electron density fluctuations in pulsar directions as well as to estimate pulsar distances. The method, based on a simple two-component model of the scattering medium as discussed by Gwinn *et al.* (1993), uses scintillation and proper motion data in addition to the measurements of angular broadening and temporal broadening to solve for the model parameters, namely, the fractional distance to a discrete scatterer and the associated relative scattering strength. It was shown how this method can be used to estimate pulsar distances reliably, when the location of a discrete scatterer (e.g., an HII region), if any, is known. The specific example of PSR B0736-40, illustrated how a simple

characterization of the Gum nebula region (using the data on the Vela pulsar) is possible and can now be used along with the temporal broadening measurements to estimate pulsar distances. *(+R. Ramachandran)*

Shape of pulsar beams. Analysis of a carefully selected subset of the recently available multi-frequency polarimetric observations of about 301 radio pulsars has revealed that pulsar beams have three distinct but nested cones of emission, and also there appears to be a dependence of the beam shape on the angle between the spin and the magnetic axes.

Interstellar scattering. 22 pulsars behind the Gum Nebula were observed with the ORT and their scattering parameters were determined. This has resulted in a map of the electron density fluctuations in the Gum Nebula.

Pulsar studies at 150 MHZ using MRT. The data from the observations made in the directions of about 50 southern pulsars (at 150 MHZ) using the Mauritius Radio Telescope are being analysed. *(+Nalini Issur)*

Pulsar beam kinematics – implication for neutron star models. Based on the kinematics of pulsar beams, developed here earlier, an exercise was undertaken to check the consistency among the constraints on the polar cap size due to the stellar gravitational effects, the remarkable phenomenological relation of Rankin for core component widths and the mass-radius relationship of neutron stars. Preliminary results favour softer equations of state for neutron stars (i.e., compact neutron stars). *(+ R.C.Kapoor, IIA)*

Radio Recombination Lines (RRL)

Recombination lines from starburst galaxies. Three of the starburst galaxies (Apr 220, NGC 3628 and IC 694) which were studied earlier in recombination lines near 8.5 GHz were observed near 1.4 GHz. These observations were aimed at testing whether the starburst regions of these galaxies contain only high density ionized gas which produce the lines detected near 8.5 GHz or whether there is also a lower density ionized component which can produce RRLs at lower frequencies. *(+ W.M.Goss {NRAO} and J.H. Zhao {CfA})*

New higher resolution images of RRL emission from the starburst galaxy NGC 253 were made by combining the VLA A-configuration data with the B, C, and D, configuration data. These images have sub-arcsecond resolution and reveal the distribution and kinematics of the ionized gas with a resolution of about 10 pc. These images confirm the peculiar kinematics in the central region which was found earlier using the BCD data. These images also show that stimulated emission may not be the main mechanism of RRL emission since the peaks in the line emission do not coincide with the continuum peaks. *(+W.M.Goss [NRAO])*

The well known Seyfert Mrk 231 shows a turn over in its radio continuum spectrum

near 5 GHz. High angular resolution VLBA observations revealed absence of HI in the central regions. Taken together, these two observations suggest that thermal gas of high-emission measure may be present in the direction of the Seyfert nucleus. A search was made for possible stimulated emission recombination line near 8 GHz. No line was detected to a 3 sigma limit of about 0.5 mJy. Data has been taken to search for the line near 1.4 GHz.

Recombination line and continuum observations towards the gravitationally lensed source PKS 1830-211. Observations of the possible recombination line at a redshift z = 0.2 did not confirm the line. Although a feature with a similar strength did appear in the new observations, there is some inconsistency in the velocity which makes the earlier detection doubtful. PKS 1830-211 was also observed in the continuum over a large frequency range (0.33 GHz to 44 GHz) using the VLA to determine the intrinsic spectrum. The source was also observed near 0.33 and 1.4 GHz using the Very Long Baseline Array to determine the intrinsic structure and effect of scattering. (+ W.M. Goss {NRAO})

Recombination lines from damped Lyman-alpha clouds. Damped Lyman-alpha systems are thought to be progenitors of present day galaxies. There is evidence that star-formation activity occurs in such systems. If O, B stars form in damped Ly-alpha systems, then HII regions will form around them. If one such region lie along the line of sight to a bright background radio source, then it may be possible to detect stimulated emission recombination lines from the damped Lyman-alpha clouds. Calculations showed that observations near 20 cm are most favourable. Using the VLA data recombination line data was taken towards 7 damped systems at redshifts ranging from 0.2 to 2.5. The data are being analysed. *(+ R.Srianand{IUCAA})*

Low-frequency recombination lines of carbon. Carbon recombination lines observed in absorption near 34.5 MHZ and in emission near 328 MHZ towards Cas A and 9 other direction in the galactic plane were used to obtain constraints on the partially ionized gas where these lines originate. Towards Cas A, the carbon recombination line near 330 MHZ was imaged over the face of Cas A with an angular resolution of 1' using the VLA. A comparison of these images with those of HI absorption of CO emission at similar resolution showed that the carbon lines are likely associated with neutral HI clouds. Modelling of the lines observed in other 9 directions also showed that the lines could arise in the neutral HI component. However, an origin in some other component of the ISM such as molecular clouds or photo-dissociation regions could not be ruled out. Models with gas temperatures of ~100 K and electron densities <0.1 cm^{-3} can fit the observed line parameters.
(+ Nimisha G. Kantharia)

G359.87 + 0.12 – An enigmatic object near the galactic centre. Radio images of the galactic centre region show a compact radio source which is about 15 arcminutes from SgrA*. A high resolution image near 90 cm showed this object to be about 20" in diameter whereas its size is <3" near 20 cm. This is a clear signature of angular broadening due to radio wave scattering. It is known from other observations that a strong scattering screen with an angular extent of about 1 degree is present near the

galactic centre. This scattering screen produces an angular broadening of about 20" near 90 cm for sources near the Galactic centre. The same screen is expected to produce an angular broadening of about 600" for sources at extragalactic distances. Thus the radio source G359.87+0.12 appears to be a galactic source based on its scattering diameter. High resolution images of this object was made near 3.6 cm and 2 cm using the VLA. These images revealed the object to be a triple-radio source with a morphology characteristic of a FRII radio galaxy with a redshift $z > 0.1$. Absence of strong angular broadening of this source, in spite of it being extragalactic, implies that the scattering screen near the galactic centre is inhomogeneous with "holes" in it on the scale of 5-10 pc.

(+ T.J.W.Lazio {NRL}, W.M.Goss {NRAO}, N.E.Kassim {NRL} and J.Cordes {Cornell})

Interstellar Clouds

The investigation of the true nature of the gas which produces optical absorption lines in the interstellar medium was continued. It was argued that this gas cannot be circumstellar gas associated with hot massive stars. An alternative hypothesis that the observed absorption lines arise in relics of very supernova remnants was shown to be untenable on two counts: (I) A good fraction of the more massive stars are likely to explode in rarefied regions of the interstellar medium either because previous explosions excavated the region or the strong stellar wind of the star itself created a cavity. Consequently the blast waves from the supernova explosions of massive stars – which represent the majority of supernovae – are unlikely to develop thick shells; before they attain the required radius they will intersect and/or break out of the disk of the Galaxy, (ii) the pressure of the compressed magnetic field in the swept up gas behind the shock front, and also the pressure of the cosmic rays accelerated *in situ* will prevent a dense enough shell developing.

It was argued that all the observational data could be explained under the hypothesis that the high velocity interstellar clouds are accelerated by supernova blast waves – the acceleration process naturally results in heating and evaporation of the clouds, and consequently resulting in smaller optical depths for the absorption of the 21 cm hyperfine line of hydrogen. Further observations are planned with the GMRT to prove this hypothesis.

Inter-Stellar Medium (ISM)

ISM : 21 cm absorption by WNM. HI 21 cm-line absorption by the Warm Neutral Medium (WNM) was detected using the Westerbork Synthesis Radio Telescope (WSRT). The absorption was detected toward Cygnus A at Local Standard of Rest (LSR) velocities of -40 and -70 km s^{-1}. These two velocity ranges were previously identified as being relatively free of cold absorbing clouds. The measured optical depth for the WNM along the line of sight to Cygnus A is $8.9 \pm 1.9 \times 10^{-4}$ at -70 km s^{-1}, and $8.5 \pm 2.0 \times 10^{-4}$ at -40 km s^{-1}, with corresponding spin temperatures of 6000 ± 1700 K and 4800 ± 1600 K, respectively.

(+C.L.Carilli {NRAO} and W.M.Goss {NRAO})

Galaxy clusters

Galaxy cluster Abell 2670. It has been recognized that galaxies in the cores of clusters differ from those in the field in their morphological type, stellar population, and gaseous content. Optical observations suggest that the cluster environment does speed up evolution of galaxies. Thus by studying galaxies in clusters even over a moderate range of redshifts of 0 to 0.5 it might be possible to observe the galaxies being transformed from normal to starburst to gas-poor old galaxies. With this in mind, a comprehensive study of the galaxy cluster Abell 2670 was made. This cluster is at a redshift of 0.076. There is a wealth of optical data on this cluster in the form of multi-colour photometry and spectroscopy. This cluster was observed in the 21 cm-line of HI with the Very Large Array for about 150 hours. Deep images of Abell 2670 in HI and in continuum were produced. Comparisons are now being made of the HI content, the radio continuum emission, the optical properties, and the morphological types of the galaxies in Abell 2670.

(+ J.H. van Gorkom {Columbia} and P.Guhathakurta {UC, Santa Cruz})

Galaxy clusters at low frequencies (< 300 MHZ). The possible correlation between the X-ray and the radio luminosities of galaxy clusters was studied. The images made at 34.5 MHZ from the Gauribidanur Radio Telescope were used to estimate the radio luminosities of clusters and compared with their X-ray luminosities. No correlation was found between these two quantities in accordance with earlier such studies. However, ~75% of the clusters with X-ray luminosities greater than 10^{44} erg/s were coincident with a low-frequency source while only ~10% of the lower luminosity X-ray clusters were coincident with a low-frequency radio source from the 34.5 MHZ survey (radio luminosity limit = 4×10^{26} W/Hz for z = 0.1). The reasons for this are not clear. No correlation to cooling flow clusters was found.

Inter-Galactic Medium (IGM)

IGM heating by photoelectrons from dust. Heating of gas due to photo-electrons emitted from the dust particles due to background UV photons was studied, which can be an important source of heating of the gas at redshifts Z ~ 2-3. The infrared emission from the heated dust particles was calculated keeping in mind the near-future generation of detectors.

IGM heating by UV background. Contributions from quasars and galaxies to the background radiation at redshifts Z ~ 2-3 were compared and the quasars were found to dominate the background radiation. A quasar dominated background is expected to be hard, and this has implications for reionization of the IGM and the interpretation of the heavy element abundance.

IGM heating by quasar bulk motion. Contribution of heating of IGM from the bulk motion involved with quasars (jets, etc.) at redshifts Z ~ 2-3 was calculated. The associated '*mechanical luminosity*' was found to be significant.

Anisotropy of Cosmic Microwave Background (CMB)

The data from deep searches on a pair of fields for arcminute scale CMB anisotropy taken with the Australia Telescope Compact Array (ATCA) was analysed. Any CMB anisotropy with a flat band power was shown to be limited to being less than Q-flat < 23.6 μK with 96 per cent confidence in a multipole ℓ-space range 3350 to 6050. These observations were continued with an ultra compact array at ATCA covering six additional fields with sensitivities well into the confusion limit.

MRT Sky Survey at 150 MHZ

A low resolution survey (15' x 15') covering the R.A. range 17:00 hrs to 24:00 hrs and 00:00 hrs to 05:00 hrs was complete by April 1997. Low resolution images covering the entire sky observable from Mauritius is now complete. Analysis of data on longer baseliner has been carried out to obtain a one hour image with 4' x 8' resolution covering the entire declination range of MRT (-70° to 10°). New evidence has been produced by the MRT images for the association of the pulsar 1706-44 and the SNR G343.1 - 2.3.

Methanol Masers in Milky Way

SEST observations: 107 and 157 GHz methanol masers. Forty massive young stellar candidates were observed for emission at 107 and 157 GHz methanol lines using Swedish ESO submillimeter wave telescope (SEST). Eight masers and nine thermal sources were detected. The data are being analysed in the context of massive star formation. Also, the 10.4 m telescope at RRI was equipped with a new receiver to carry out an unbiased survey of the northern galaxy for 6.7 GHz methanol masers. The survey is currently underway. (+ *Braufman, Univ of Chile*)

Using old stars to probe outer-galaxy velocity field. Usefulness of cyano-acetylene (HC_3N) line emission at 45.5 GHz from circumstellar envelopes of carbon stars to obtain the outer-Galaxy velocity field was investigated. In conclusion, CO appears a better tool than the HC_3N line.

INSTRUMENTATION FOR RADIO ASTRONOMY

AREAS OF RESEARCH : GMRT Pulsar Receiver
Digital Correlator
Signal Processing

GMRT Pulsar Receiver

Array Combiner for GMRT. GMRT Array Combiner (GAC) which caters for 8 antennas was tested successfully at GMRT site. Further production of all the hardware necessary for 30 antenna array combiner for one side band was completed. The system was tested satisfactorily in the lab with the simulated data at the input and the system was installed at GMRT site.

Efforts are on to interface the system with GMRT FFT system to do the pulsar observations.

Polarimeter & Signal Processor for known pulsars. A polarimeter / signal processor for 8 MHZ band was taken to Ooty Radio Telescope (ORT) to perform initial field trials by observing known strong pulsars. Since, ORT is a single polarization telescope, limited testing was conducted successfully in testing the system for stability and various other functional aspects such as pulse-folding, integration in time and frequency, de-dispersion, Doppler acceleration correction etc.

After successful results of these field tests, the design of the final system was frozen and the various subsystems were re-designed using components with higher level of integration. The basic printed circuit boards are designed, fabricated and tested successfully in the lab. Production of these cards for full 32 MHZ bandwidth is under progress.

GMRT 21Cm Receiver

Further production of ten units of 21 cm Receiver was completed, tested and sent to Pune during the year thus making supply of 25 units totally. The remaining 5 units are at various stages of production.

There is a proposal to observe OH line at 1612 MHZ and to equip two of the 30 dishes of GMRT to observe this line. Development work was initiated to increase the bandwidth of the present system from 400 to 800 MHZ to observe this line. This requires development / modification of ortho mode transducer, low noise amplifier, filter etc.

A narrow band notch filter around 940 MHZ was designed and tested in the lab. Three units were sent to Pune to be used on dishes to partially overcome the interference from local cellular communication.

10.4m Millimeter-wave Telescope

With discovery of the 6.7 GHz methanol maser towards massive star forming regions, many searches based on OH maser surveys were undertaken by several groups. The Institute has initiated programme to observe methanol masers which is believed to be a potential tool of tracing massive young stellar objects. 5cm receiver was constructed and installed on 10.4m telescope with a view to carry out Northern parts of methanol maser survey. The observations are under progress.

Some modifications were underway in the receiver system to facilitate using any one of the front end systems operating at mm wave, 21 cm or 5 cm observations.

Development of a wideband digital correlator system for mm wave operation having 640 MHZ bandwidth and spectral resolution of 50 KHz was initiated in the lab. This is a hybrid system of 40 MHZ filter bank followed by an auto-correlator for each filter unit. Proto units of 40 MHZ filter bank and 100 MHZ two-bit sampler circuit were designed and tested satisfactorily. Further work in designing four channel system of these units is in progress.

A Data Acquisition System to monitor the health parameters of mm wave receiver was designed. The system comprises of 32 channel analog multiplexer followed by a 12-bit Analog to Digital Converter and is controlled by an embedded processor Intel 80186. A proto unit was built and tested on a stand alone PC. Further work to integrate a total of three such systems and interfacing to the Health Monitoring PC is in progress.

An user friendly, windows based software to prepare "observing files" was made available. This program can be used to prepare "observing files" to observe at any frequency with user specified spectrometer configurations. Further work to expand the Graphics User Interface (GUI) based main observing program on the Sun workstation is in progress.

Remote Display Unit for GMRT

A Remote Display Unit (RDU) for the display of astronomical clock data was designed, fabricated and installed at GMRT site. The unit basically reads the Local Sidereal time, Indian Standard Time, Julian day etc. from the astronomical clock and displays at a distant place using synchronous serial communication. Four such display units situated at different locations can be interfaced to the astronomical clock for simultaneous display of the clock parameters.

Signal Processing

A polarimeter capable of performing various signal processing operations on pulsar signals in real-time (such as generation of Stokes parameters, De-dispersion, Faraday rotation, Doppler correction, integration in time and frequency, folding and gating consecutive pulses) was built and installed at the Ooty Radio Telescope. Various

performance tests were completed successfully. Subsequently the mass production of various modules of the polarimeter was also completed in order to scale system for handling the entire 32 MHZ bandwidth of GMRT. Integration and testing of the full system is underway in the DSP Lab. A paper explaining the design and observational results has been submitted to IEEE for publication.

Two new signal-processing algorithms for improving the accuracy of pulsar RM measurements were developed and demonstrated using pulsar data. The possibility of using pulsars as probes to measure the ionospheric RM variations was also investigated with these methods successfully. New observations have been planned for further work in this direction. A paper explaining the methods and the results is being submitted for publication shortly.

COMPUTERS

The Computer Division acquired a colour scanner , which was used extensively in producing display material for the Golden Jubilee of the Institute. Some 125-MHZ Digital Alpha Workstations were up-graded to faster (433 MHZ) versions and a Dual-CPU Digital 1200 server was purchased to augment general computing capacity. This server will also handle automated back-up of data from our entire storage network. Upgradation of the campus network to a ATM-based fibre-optic backbone has been ordered and will be implemented shortly.

OTHER ACTIVITIES

Ph. D.

Awarded

Name	*Topic of Study*
N. Andal	Some studies on defect lattices in liquid crystals Jawaharlal Nehru University, New Delhi
Arun Roy	Theoretical and experimental studies on transversely polarized smectic liquid crystals Jawaharlal Nehru University, New Delhi
Debnarayan Jana	Numerical and field theoretic studies in low-dimensional condensed matter physics Jawaharlal Nehru University, New Delhi
C. Indrani	Timing Radio Pulsars Jawaharlal Nehru University, New Delhi
Mehdi Jahanmiri	The evolution of the magnetic fields of neutron stars: The role of the superfluid states in their interiors Indian Institute of Science, Bangalore
Nimisha Kantharia	High Rydberg state recombination lines from Interstellar carbon - An observational study Indian Institute of Science, Bangalore

Submitted

Jayadev K. Rajagopal	Some investigations of interstellar clouds Jawaharlal Nehru University, New Delhi
Sushan Konar	Evolution of the magnetic field in accreting neutron stars Indian Institute of Science, Bangalore
Geetha Basappa	Experimental studies on the relationship between order and physical properties in liquid crystals University of Mysore, Mysore
C.R.Gopalakrishnan	Synthesis and physical properties of some mesogenic chiral polysiloxanes Bangalore University, Bangalore
N. Kasthuraiah	Synthesis and liquid crystalline properties of some homologous series of optically active compounds Bangalore University, Bangalore

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 34).

Golden Jubilee Year

Calendar of scientific events planned for the Golden Jubilee Year:

• *Discussion Meeting on Gravitational Radiation and General Quantum Relativity*	*11-14 December 1997*
• *Open Day - National Science Day*	*28 February 1998*
• *Summer School in Physics & Astrophysics*	*25 May - 20 June 1998*
• *Open Days for School and College Children as well as the public*	*October 1998*
• *Formal Celebration of the Golden Jubilee*	*7 November 1998*
• *Advanced School on Liquid Crystals and Soft Condensed Matter*	*21-25 December 1998*
• *Discussion Meeting on Liquid Crystals and Other Soft Materials*	*28-31 December 1998*
• *Nineteenth Annual Meeting of the Astronomical Society of India* ***(to be hosted by RRI)***	*1-4 February 1999*

Discussion Meeting On Gravitational Radiation and Quantum General Relativity. The Golden Jubilee celebrations were begun with a Discussion Meeting on Gravitational Radiation and Quantum General Relativity. The meeting lasted for four days (11-14 December, 1997) and was attended by 74 participants, 53 from all over India and 21 from abroad. Different aspects of current research on gravitational waves were covered by Gilles-Esposito Farese, B.S. Sathyaprakash, Harald Lueck, Misao Sasaki, Luc Blanchet, Clifford Will, S.V. Dhurandhar, Bala Iyer, Nils Andersson and Ed Seidel.

Similarly, recent trends in quantum general relativity were discussed by Steven Carlip, Carlo Rovelli, Renate Loll, Domenico Guilini, Valeri Frolov, Sumati Surya and Partha Majumdar. There was also a public lecture by Clifford Will on 'Was Einstein right?'.

National Science Day. An **Open Day** feature was introduced as part of the events planned during the Golden Jubilee Year. The first of the Open Days was held on the 28 February 1998 to coincide with the National Science Day Celebrations. On that day, about 100 students from various schools in Bangalore were invited to participate. Prof. N. Kumar, Director welcomed the students and talked to them about the Institute and its present activities. Prof. S.Ramaseshan also shared his

enthusiasm and thoughts with students.

During the two hours before lunch and an hour or so after the lunch, the students went around the campus for viewing posters displayed in various buildings/ laboratories. A large number of posters/displays including a few demonstrations were prepared by the staff members of the Institute. These were designed to present the general themes/topics that are closely related to our research interests and supporting activities of the Institute. The staff members and the research students at the Institute were present in the poster areas to explain to the participants the details and excitement in various areas of work.

The afternoon session began with the screening of two short movies, one of which was on Raman's life. This was followed by a slide show in which the students were introduced to a variety of astronomical objects and their wonders.

The last two hours or so were devoted to a very lively Question-Answer session, wherein Faculty members responded to a variety of queries from the students.

Conferences/Seminars and Meetings

The staff of the Institute visited various institutions in India and abroad and attended conferences and presented papers. In addition, lectures were given by them at other places. In all, 81 lectures were given by them at other places.

Colloquia

The scientists of the Institute and visiting scientists both from within and outside the country, gave 53 colloquia at the Institute on different topics during the year (Annexure II, page 43).

Journal Club Meetings

Twenty meetings were held during the year. Preprints, as well as recently published papers, dealing with topics of great current interest were reviewed in the meetings. And, as in the past, several informal meetings in Theoretical Physics, Experimental Optics, Liquid Crystals and Radio Astronomy were also held.

Gandhi Memorial Lecture

The Gandhi Memorial Lecture for 1997 was given by Dr. Manmohan Singh on "Economic Reforms, Poverty Eradication, Self-Reliance and Ethical Values" on 2 October 1997.

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 members of staff of the Institute given towards the end of the report.

Library

Library added 356 books to its collection during the year. This brings its total book collection to 19,799. One hundred and thirty seven journals were subscribed to during the same period. Out of these 19 journals were received by airmail. In addition to this, library had online access to 20 journals. Library has 24,180 bound volumes of periodicals. It continued to receive preprints in Astronomy and Astrophysics from various institutions/observatories both within and outside the country. About 400 out-dated books were withdrawn from the library collection.

A new Current Awareness Service was started to disseminate the nascent scientific information that is available on the internet through services like Science Daily, Science Online, AIP Physics Update, etc. In this service information was made available to our users on the electronic bulletin board of the Institute and also displayed on the library notice board.

During the year, the library has undertaken the job of compiling the Memoirs of the Raman Research Institute (consisting of RRI publications for the last 50 years) as a part of the Golden Jubilee Celebrations.

Library participated in the Open Day activities of the Institute held on the 28 February 1998. It took initiative in compiling a booklet about the Institute and its activities. It also organized a meeting of the librarians working in Bangalore libraries to discuss matters of mutual interest and further the inter-library cooperation.

General

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

PLAN (Recurring and Non-Recurring)	Rs. 612.63 lakhs
NON PLAN (Recurring)	Rs. 278.43 lakhs
Total	Rs. 891.06 lakhs

STAFF

N. Kumar
Director

V. Radhakrishnan
Director-Emeritus
S. Ramaseshan
Distinguished Professor Emeritus (Honorary)

THEORETICAL PHYSICS

Research
N. Kumar
Rajaram Nityananda (*Chairman*)
B. R. Iyer
Joseph Samuel
Madhavan Varadarajan

Research Student
A. Gopa Kumar
Debnarayan Jana (*up to 31.7.97*)
Kanti R. Jotania (*up to 23.5.97*)

Post-Doctoral Fellow
M. Sanjay Kumar
Sukanya Sinha (*CSIR Pool Officer from 3.11.1997*)
Nivedita Deo (*up to 31.1.98*)

Visiting Professors
R. Srinivasan
S. K. Rangarajan

Secretarial
G. Manjunatha

EXPERIMENTAL OPTICS

Research
Hema Ramachandran

Research Student
Sushil Mujumdar

Visiting Professor
A K Sood

Trainee
Ranita Roy Chowdhury (*from 1.9.97*)

Technical
P. S. Sasikumar

LIQUID CRYSTALS LABORATORY

Research

N. V. Madhusudana
G. S. Ranganath
B. K. Sadashiva
K. A. Suresh
U. D. Kini
T. N. Ruckmongathan
V.A. Raghunathan
Yashodhan Hatwalne
V. Lakshminarayanan
R. Pratibha

Scientific/Technical

M. R. Subrahmanyam
K. Subramanya
P. N. Ramachandra
H. Subrahmonyam
D. Vijayaraghavan
A. Dhason
V. Nagaraja
N. Ravi Sankar
S. Seshachala
G. R. Seshadri
Mohammed Ishaq

Trainees

Rajeshree Ayangar (*from 21.7.97*)
N. G. Nagendra Prasad (*from 2.7.97*)
C. Nisha (*from 1.12.97*)
S. Sarala (*up to 31.7.97*)

Visiting Scientist

T. G. Ramesh

Research Students

R. Subramanian
Sreejith Sukumaran
P. K. Thiruvikraman
Sobha R. Warrier
Kheya Sengupta
Shubhashree S.
P. A. Pramod
Geetha Basappa (*up to 4.11.97*)
Amitabha Bhattacharyya
S. K. Srivatsa
M. S. Giridhar
K.G.Pani Kumar (*from 6.8.93*)
C. R. Gopalakrishnan
Arun Roy
N. Andal (*up to 7.8.97*)

Secretarial

K. Radhakrishna

ASTRONOMY & ASTROPHYSICS

Research

N. Kumar (*Chairman*)
G. Srinivasan
K.R. Anantharamaiah
R. Bhandari
C. S. Shukre
N. Udaya Shankar
K. S. Dwarakanath
V. Radhakrishnan
Dipankar Bhattacharya
Ravi Subrahmanyan
A.A. Deshpande
B. Ramesh
Biman Nath (*from 16.9.97*)
T.K. Sridharan

Visiting Professors
Bhaskar Datta
C. R. Subrahmanya (*from 2.1.98*)

Post-Doctoral Fellow
Mousumi Das
Sunita Nair (*from 2.1.98*)

Research Students
Jayadev K. Rajagopal
Nimisha G. Kantharia (*JAP*)*
Sushan Konar (*JAP*)
C. Indrani
Rekesh Mohan (*from 5.8.97*)
R.Ramachandran (*up to 19.5.97*)
R. Niruj Mohan (*JAP, from 1.8.97*)
Ashish Asgekar (*JAP*)
Dipanjan Mitra
Sandeep Sachadev (*from 17.7.97*)
Mehdi Jahan Miri (*up to 17.7.97*)
Raka D. Ray

Trainee
Florita D'Sa (*from 3.9.97*)

Secretarial
S. Ramasubramanian

**Joint Astronomy Programme*

RADIO ASTRONOMY LAB

Technical
D. K. Ravindra (*Head*)
G. Sarabagopalan
P. G. Ananthasubramanian
A. Raghunathan
P. S. Ramkumar
S. Kasturi
M. R. Gopala Krishna
S.Chanthrasekharan (*up to 13.3.98*)
T. Prabu
M. Seethalakshmi
K.B.Raghavendra Rao
P.A. Kamini
P. Sandhya
B.K. Udaya Shankar
B. Sridhar
S. Madhavi

Secretarial
V.Vidyamani

Trainees
B.S.Girish
K. S. Srivani
N. T. Madhusudana (*from 14.7.97*)
Jacob Rajan
K.N.Ravi Shankar (*up to 6.6.97*)
K.P.Rajesree (*up to 30.6.97*)
S.P. Raghavendra
S. Subhas Chandra (*from 13.2.98*)
G. Manjunath (*up to 15.4.98*)
Mathew P. Josesph (*up to 1.9.97*)

TELESCOPE

Technical
R. Ganesan
Antony Joseph
K. Guru Kiran
S. Swarna
E.Palanichamy (*up to 13.2.98*)
K.Ramesh Kumar (*up to 6.10.97*)

Trainees
K. Ramesh
K. R. Vinod
Bhupinder Misra (*from 30.6.97*)

ELECTRONICS & INSTRUMENTATION

Technical

M. Selvamani (*Head*)
K. Chandrashekara
M. S. Ezhilarasi
C. Vinutha
H. N. Nagaraja
A. Santhosh Kumar
S. Krishnamurthy
N. Ashwini (*up to 27.11.97*)

Trainees

N. J. Kiran (*from 10.4.97*)
Ranganatha (*from 5.3.98*)

Secretarial

R. Mamata Bai

COMPUTERS

D. Bhattacharya (*Head*)
R. Nanda Kumar
V. Devadas
Lakshmy P. Usha (*up to 31.1.98*)
Ashima Rani (*up to 15.1.98*)

Trainees

B. S. Jayatheertha (*from 2.3.98*)
Laxmish G. Bhat

LIBRARY

A. Ratnakar (*Librarian*)
Girija Srinivasan
Geetha S.
Vrinda J. Benegal
M. N. Nagaraj
M. Manjunath

Support Staff

Hanumappa
K. Chowdasetty
C. Elumalai

MECHANICAL & ENGINEERING SERVICES

M. Selvamani (*Head*)
Manohar O. Modgekar (*In-Charge, Basement Workshop*)
C. Md. Ateequlla (*In-Charge, Precision Workshop*)
K. T. Gangadharan (*In-Charge - General Workshop*)
V. Dhamodaran
I. Henry
I. Charles Paul
N. Narayanaswamy
M. Achankunju
V. Venu
G. Gopi
P. Jayavelu
V. Gokula Chandran
R. Elumalai
S. Sunderaj
T. Puttaswamy
P. Srinivasa
S. Abdul Rahim
V. K. Muthu
K. M. Mohandas
D. Sunand
N. Gopal
K.O. Francis
M. Suresh Kumar
M. Mani

GAURIBIDANUR TELESCOPE

Technical
H.A.. Aswathappa

Support Staff
N. Raja Rao
Shivarudraradhya
Ranoji Rao
Bheema Naik
R.P. Ramji Naik
Gangaram
Prahallada Rao
Thippanna
Venkataswamy
Papanna
M. Muniyappa (*Nandi Hills*)

ADMINISTRATION

G. V. Srinivasa
K. Krishnama Raju
S. Raghavachar
Marisa D'Silva
K. Radha
L.P. Kumar
V. Raveendran
Savitha Rao
R. Manjunath (*up to 19.9.97*)
R. Ganesha

ACCOUNTS

K. R. Shankar
R. Ramesh
P.V.Subramanya
S. Srinivasa Murthy

PURCHASE

Lakshmi Rajagopal
Sowjanya Kumar
Sujatha Anil Kumar
B. Srinivasa Murthy

STORES

S. Rajasekharan Nair
C. N. Ramamurthy
M.V. Subramanya

GRAPHIC ARTS

Raju Varghese
C. Ramachandra Rao (*Consultant*)

ESTATE & BUILDINGS

R. Anantha Subba Rao (*Consultant*)
G. B. Suresh
R. Sasidharan
T. Subramaniayam Naidu
P.S.Damodara Raju
C. Haridas
S. Anantha Raman
K.N.Srinivas
Gunashekar
S. Sridhar
D. Gangappa
K. Bhoopalan
C. Sampath
K. Palani

Secretarial
V. Raghunath

CARPENTRY

K. M. Lakshmanan (*In-Charge*)
P. Navaneetha Raju
V. Muniraju
V. Ramu
T. Subramani
L. Muthu
M. Gopinath

MEDICAL

Dr. A.R. Pai (*Consultant*)
Dr. M.R.Baliga (*Consultant*)
R. Shanthamma (*Clinic*)

TRANSPORT

M. K. Raju Kutty
C. K. Mohanan
Rahamath Pasha
R. Jayaram
M. Balarama
G. Prakash
Abdul Khader
Rahamathulla Khan

AMENITIES (Canteen, Guest House and Hostels)

T. V. Janardhanan
C. V. Bharghavan
A. Raju
N. Narayanappa
N. Puttaswamy
K. Velayudhan
N. Seetharam
T. Naganna
Shivamallu
P. C. Prabhakar
Uma
Sharadamma
Mangala Singh
V. Yeshodha
Muniratna

HORTICULTURE

V. Krishnappa (*Horticulture Supervisor*)
P. N. Sachidananda (Consultant)
Munilakshmi
D. Muniraja
Thimmarayappa
Bylappa
S. Muniraju
Chikkamunivenkatappa
Mailarappa
Maiga
Marappa
Lingegowda
Lakshmamma

UPKEEP

Jayamma
Varalakshmi
K. N. Kawalappa
Ranjithamma
A. Ramanna
Hanumantha
C. Lakshamma
Saroja
T. Murali
Munihobalaiah
D. Krishna
V. Venkatesh
Rangalakshmi

SECURITY

V. Arputha Raj (*In-charge*)
Joseph Kunjachan
H. Gangaiah
H. Vaderappa
K. Govindappa
U. A. Earappa
O. M. Ramachandra
K. Krishnappa
K. Basavaraju (*up to 26.5.97*)
Suresha
M. Sannaiah
B. M. Basavarajaiah
Govind K. Kundagol
D. Mahalinga
K. Pushparaj
Keshavamurthy
G. Ramakrishna

VISITORS

Simon, R Institute of Mathematical Sciences, Chennai	15-20 April 1997
Venkatasubramanian V Radio Astronomy Centre, Ooty	22-23 April 1997
Yashwant Singh Banaras Hindu University, Varanasi	22-25 April 1997
Vijayagovindan, G V Mahatma Gandhi University, Kottayam	2 May - 27 June 1997 11 May - 10 June 1997
Pareek, T. P. Institute of Physics, Bhubaneswar	7 - 22 December 1997
Sai Iyer Physical Research Lab, Ahmedabad	1 May - 2 June 1997 10 December 1997
Jayannavar A M Institute of Physics, Bhubaneswar	16-21 May 1997 9-12 February 1998
Joanna Rankin University of Vermont in Burlington, U S A	30 May - 21 July 1997
Seshadri T R Mehta Research Institute, Allahabad	5-18 June 1997
Sridhar S IUCAA, Pune	17-20 June 1997
Touma, J University of Texas Austin, U S A	17-20 June 1997
Alladi Ramakrishnan Alladi Centenary Foundation, Chennai	15-16 July 1997

Ramachandran R Institute of Mathematical Sciences, Chennai	18-20 July 1997
Alladi Krishnaswami University of Florida, USA	22 July 1997
Bissoondoyal, S Vice-Chancellor, University of Mauritius	22 July 1997
Patrick Dierich Observatoire de Meudon, France	3 October 1997
Padmanabhan T IUCAA, Pune	3-10 October 1997
Luc Blanchet Observatoire de Meudon, France	10-15 December 1997
Engineer M H Bose Institute, Calcutta	31 December 1997 - 4 January 1998
Zbigniew Raszewski Inst.of Applied Physics, MUT, Warsaw, Poland	2-7 December 1997
Josef Zmija Inst.of Applied Physics, MUT, Warsaw, Poland	2-7 December 1997
Berry M V University of Bristol, UK	21 December 1997 - 3 January 1998
Shyamalendu Bose Drexel University, USA	17-19 December 1997
Arnold Wolfendale University of Durham, UK	10-11 January 1998
Pendry J B Imperial College, London, UK	14 February - 6 March 1998

Michael Revzen Technion, Rehovot, Israel	2 - 17 March 1998
Anshu Gupta Physical Research Lab, Ahmedabad	24 - 27 February 1998
Jogesh Pati University of Maryland, USA	9 February 1998
Sanjay Jhingan Tata Inst. of Fundamental Research Mumbai	19-22 February 1998
Sukratu Barve Tata Inst. of Fundamental Research Mumbai	21-24 February 1998
Hariharan P CSIRO Division of Applied Physics Sydney, Australia	20 June - 22 July 1997 & 15 February - 20 April 1998

Annexure I

PAPERS PUBLISHED

In Journals

1 "Normal-state c-axis resistivity of the high-T_c cuprate superconductors (N.Kumar, T.P. Pareek and A.M. Jayannavar) *Modern Phys. Lett.* **B11**, 347 (1997).

2 "Lasing in active sub-mean-free path-sized systems with dense random weak scatterers" (B.Raghavendra Prasad, Hema Ramachandran, A.K. Sood, C.K.Subramanian and N.Kumar) *Applied Optics*, **36**, 7718 (1997).

3 "c-Axis resistivity and high-T_c superconductivity" (N. Kumar, T.P.Pareek and A.M.Jayannavar*)*, *Phys. Rev. B*, **57**, 13399 (1998).

4 "Highly anisotropic layered systems: Intra-planar metallicity and inter-planar non-metallicity" (N. Kumar) *Philosophical Transactions of the Royal Society, London*, **356**, 261 (1998).

5 Coherently amplifying random medium: Statistics of super-reflection" (N. Kumar, Prabhakar Pradhan and A.M.Jayannavar) *Superlattice and Microstructures,* **23**, 853 (1998).

6 "One hundred years of the electron" (N. Kumar and E.S.Raja Gopal) *IETE Technical Review*, **14**, 231 (1997).

7 "The nature of charge ordering in rare earth manganates and its strong dependence on the size of the A-site cations" (N. Kumar and C.N.R. Rao) *J. Solid State Chem.*, **129**, 363 (1997).

8 "The Lense-Thirring effect and Mach's principle" (Hermann Bondi and J. Samuel) *Phys. Lett.*, **A228**, 121 (1997).

9 "The geometric phase and ray space isometrics" (J. Samuel) *Pramana*, **48**, 959 (1997).

10 "Thomas rotation and polarized light: A non-Abelian geometric phase in optics" (J. Samuel and Supurna Sinha), *Pramana*, **48**, 969 (1997).

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5 "Visco-elastic modes in some ferroelectric liquid crystals" (Y. Sah and K.A. Suresh) *Liquid Crystals.*

6 "Synthesis and properties of main chain discotic liquid crystalline polyethers based on rufigallol" (V.S.Raja, V.A.Raghunathan and S. Ramakrishnan) *Macromolecules.*

7 "On Geometric phase from pure projections" (R. Bhandari), *J. Mod. Opt.*

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9 "Carbon recombination lines between 34.5 MHZ and 770 MHZ towards Cas A" (N.G. Kantharia, K.R .Anantharamaiah and H.E. Payne) *Ap. J.*

10 "Contribution of galaxies to the background hydrogen-ionizing flux) (J.E.G. Devriendt, S. Sethi, B. Guiderdoni, B.B. Nath), *Mon. Not. Royal Astron. Soc.*

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Annexure - II

COLLOQUIA

Name	Title	Date
Manas Sardar University of Regensburg Germany	Parametric amplification of radiation using intrinsic Josephson effect in high T_c materials	1.4.1997
G S. Ranganath Raman Research Institute Bangalore	Dynamics of kink states	3.4.1997
Rohini Godbole Indian Institute of Science Bangalore	Leptoquarks/squarks at HERA?	15.4.1997
Simon R Institute of Mathematical Chennai	The role of Pancharatnam phase in quantization of classical orbits: Application to asymptotic form of the special functions of Mathematical Physics	16.4.1997
Narayanan K S Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore	Light emission in polymeric systems	17.4.1997
Radha Balakrishnan Institute of Mathematical Science, Chennai	Geometry and non-linearity	23.4.1997
Sriram Ramaswamy Indian Institute of Science Bangalore	Sedimentation of crystalline and liquid suspensions	1.5.1997
N.V.Madhusudana Raman Research Institute Bangalore	Liquid crystals made of strongly polar compounds	15.5.1997
R.Srinivasan Raman Research Institute Bangalore	Laser cooling atoms (*two lectures*) Traps and evaporative cooling of neutral atoms (*two lectures*)	16 & 21.5.1997 22 & 23.5.1997

Name	Title	Date
Alladi Krishnaswami University of Florida Gainesville, USA	A new companion to Ramanujan's continued fraction	23.5.1997
R. Srinivasan Raman Research Institute Bangalore	Bose-Einstein condensation and recent recent developments (*two lectures)*	27 & 28.5.1997
Nagendra Singh University of Alabama U S A	Particle-in-cell simulations of liquid crystal devices	29.5.1997
V. Nanjundiah Indian Institute of Science, Bangalore	Lamarck's ghost	29.5.1997
R. Srinivasan Raman Research Institute Bangalore	Bose-Einstein Condensation (*two lectures*)	3 & 4.6.1997
Ravi Subrahmanyan Raman Research Institute Bangalore	Cosmic microwave background radiation	12.6.1997
Sukanya Sinha CSIR Pool Officer	Quantum to classical transition of perturbations in the inflationary universe	5.8.1997
Biman Nath IUCAA, Pune	The inter-galactic medium	8.8.1997
Y. Divakara Mayya Instituto Nacional de Astrofisica, Puebla Mexico	Radial distribution of gas-to-dust ratio in galaxies	13.8.1997
A.R.P. Rau Louisiana State University U S A	Stability at saddles of potential surfaces	14.8.1997
Anil Kumar University of Florida U S A	Conducting poly-(3,4-alkenylene-dioxy-thiophene) derivatives as fast electro-chromics with high contrast ratio	27.8.1997

Name	Title	Date
N. Kumar Raman Research Institute Bangalore	The Force of Casimir	28.8.1997
R. Srinivasan Raman Research Institute Bangalore	The fountain effect	4.9.1997
Vikram Soni National Physical Lab New Delhi	Baryogenesis at the weak scale: Some aspects	16.9.1997
A.K.Raychaudhuri Department of Physics Indian Institute of Science Bangalore	Giant magnetoresistance	18.9.1997
G.V. Shivashankar Rockefeller University U S A	Single molecule studies of DNA interactions using atomic force spectroscopy and laser tweezer	7.10.1997
Fr. C. J. Saldanha Centre for Taxonomic Studies, Bangalore	The Western Ghats	16.10.1997
V.K. Gaur Indian Institute of Astrophysics, Bangalore	The ice ages of the Earth	13.11.1997
Jozef Zmija Military University of Technology, Warsaw Poland	A semi-empirical method of determining the surface interaction of nematic liquid crystal	5.12.1997
Tamas Borzsonyi Research Institute for Solid State Physics, Budapest, Hungary	Pattern forming instabilities during the nematic to smectic B phase transition	10.12.1997
M.K.Chandrasekaran Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore	Biological clocks	18.12.1997

Name	Title	Date
Michael Berry Bristol University, U K	Quantum indistinguishability	23.12.1997
	Integer, fractional and fractal talbot effects	24.12.1997
	Much ado about nothing: Phase singularities in Gaussian beams	2.1.1998
Srikanth Raghavan International Centre for Theoretical Physics Trieste, Italy	Non-linear generalizations of Josephson-like effects in Bose-Einstein condensates	9.1.1998
Robert Anderson Cambridge University U K	Sustaining effective scientific institutions in India: Reflections on the road ahead after a long detour	27.1.1998
Michael Revzen Technion, Haifa, Israel	Casimir effect - The classical limit	5.2.1998
Vidyasagar M Centre for Artificial Intelligence & Robotics Bangalore	Can a computer be intelligent?	6.2.1998
Jogesh Pati University of Maryland U S A	New aspects in unification and proton decay: Because of supersymmetry and neutrinos	10.2.1998
Dabrowski R Military University of Technology, Warsaw Poland	Induced and enhanced smectic phases	18.2.1998
Pendry J B Imperial College London, U K	Shearing the vacuum-quantum friction	19.2.1998
Mukunda N Indian Institute of Science Bangalore	What is non-classical about non-classical light?	19.2.1998

Name	Title	Date
Sanjay Jhingan Tata Institute of Fundamental Research, Mumbai	Final state of gravitational collapse in Einstein's theory of gravitation	20.2.1998
Anshu Gupta Physical Research Lab Ahmedabad	Centrifugal force and ellipticity behaviour in general relativistic framework	25.2.1998
Pendry J B Imperial College London, U K	Trapping light in solids	5.3.1998
Madhav Gadgil Indian Institute of Science Bangalore	Western Ghats: A life-scape	6.3.1998
Shukre C S Raman Research Institute Bangalore	Kinematics of pulsar beams	17.3.1998
Yashwant Singh Banaras Hindu University Varanasi	Symmetry breaking and self-replication in biophysics	18.3.1998
V. Lakshminarayanan Raman Research Institute Bangalore	Scanning tunneling microscopy	19.3.1998