RAMAN RESEARCH INSTITUTE
Bangalore

Annual Report 2004 - 2005

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 grants from the Department of Science and Technology of the Government of India since 1972. The main fields of research have been, and continue to be, Theoretical Physics (gravitation and polarization optics), Liquid Crystals (thermotropic and polymeric), Astronomy & Astrophysics (radioastronomy, interstellar medium, and pulsars). More recently, research in high-energy astrophysics (X-rays and γ-rays) and cosmology has been initiated. Also, the Liquid Crystals research has been expanded so as to include soft-condensed matter and biological physics (studies on membranes and single-DNA segments). Also, an Optics Lab has been set up for studying laser cooling and trapping of atoms, imaging through turbid media, and ultra-fast atomic processes using femtosecond (10^{-15} s) laser pulses.

1. Theoretical Physics

Here research is focussed on two main areas – gravitation and polarization optics. Gravitation is known to be the weakest of all known forces of nature, but it dominates all structure and motion on the astronomical scale because of its attractive universality (everything gravitates everything else), its long range, and the fact that matter on the large scale is essentially neutral. The correct theory of gravitation is now believed to be Einstein's General Theory of Relativity (GTR). One of the fundamental predictions of GTR is that of gravitational waves – waves of distortion of spacetime itself – propagating at a finite speed (of light). This replaces the Newtonian gravitational force which was instantaneous. Such waves are expected to be emitted when, e.g., two massive inspiralling stars tend to coalesce under their mutual gravitational attraction. Accurate calculation of this gravitational radiation – its waveform – has been one of the major research programmes in the Theoretical Physics Group at the Institute, and is expected to be a crucial input towards its eventual detection. It is hoped that these gravitational waves, though abysmally weak in strength, will be detected by the ultra-sensitive gravitational wave detectors expected to become operational in a few years in different parts of the world.

One such detector LIGO (in the USA) is already on trial runs. Space based detectors (LISA) are also being planned internationally.
Einstein's General Theory of Relativity is central to the study of universe as a whole (cosmology) as also to the study of compact self-gravitating objects, such as the black holes – yet another prediction of Einstein's General Relativity. So intense is the Black Hole gravity that nothing, not even light can escape from its interior. There is little doubt now about their existence. While the theory has a beautiful geometrical structure, it is a challenge to analyse the behaviour of gravitational field and its coupling to matter and other fields as the equations involved are nonlinear – interactions too interact! Many conceptual questions and aspects of the 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, and a new Lagrangian formulation. One of the challenges in the field is to make contact with quantum theory, i.e., to combine consistently the two great framework theories of the twentieth century – the general theory of relativity and quantum mechanics. This is a long term programme. But some work on Quantum Gravity has already emerged at the Institute.

Coming now to optics, two of the main interests have been in propagation of light waves in periodic media (like some liquid crystals) and the associated polarization 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, bring 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 that of gravitational lensing (i.e., bending and focussing of light rays by the strong gravitational fields of massive stars and galaxies which, therefore, act as lenses), scintillation and quantum effects in radiation and detection, making the study of optics in a broad sense particularly appropriate to this Institute. Indeed, RRI has been home to Optics!

2. Optics

In view of the rapid and important recent advances happening worldwide in modern optics, its clearly enormous potential, and taking full advantage of our proven traditional strength in this field, a modern optics laboratory has been set up at the Institute with facilities to address several interesting and basic questions involving, e.g., cooling and trapping neutral atoms using laser lights,

studying fast atomic processes using ultra-short light pulses barely 10^{-15} second wide, polarization optics and geometrical phases, interferometry, and imaging through turbid media, and non-linear optics. This is expected to have substantial overlap with our research activities in the field of liquid crystals and astronomy.

3. Liquid Crystals

Liquid Crystals are states of condensed matter showing a variety of orderings of molecular positions and orientations intermediate between those of liquids and crystalline solids. Thus, for example, we may have a crystalline periodicity along one direction and a liquid-like, albeit viscous, fluidity in the planes perpendicular to that direction – the so-called smectic (soap-like) liquid crystals. We can also have the nematic liquid crystals in which the rod-like molecules are orientated parallel to a certain direction on the average, but without any positional order. Yet another kind of liquid crystal is the discotic one in which the disc-like molecules form liquid-like parallel columns which are, however, arranged periodically in the plane perpendicular to the columns. Many other complex forms of ordering are known. Many organic compounds whose molecules have pronounced shape anisotropy exhibit such phases. The unique combination of fluidity, softness and anisotropic properties of liquid crystals makes them readily respond to even a weak external stimulus, for example, an applied electric field. This has led to many technological applications of these materials, e.g., the very common liquid crystal displays. The Liquid Crystals Laboratory of the Raman Research Institute has contributed outstandingly to the development of this field over the past three 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 the liquid crystal displays is also being carried out. A new dimension has now been added to our LC research – the study of soft-condensed matter including membranes and the single-DNA molecules which are of great biological-physical significance.

4. Astronomy and Astrophysics

Astronomy, which is one of the oldest sciences, studies heavenly bodies, i.e., planets, stars, galaxies, clusters of galaxies, and the intervening matter such as gas and dust, and, indeed, the universe as a whole – its beginning, its large-

scale structures and its evolution. This, it does by investigating the radiation received on earth from or through them. Optical Astronomy deals with the visible part (wavelength 300 nm to 650 nm, 1 nm = 1 nanometre = 10^{-10} metre) of the electromagnetic spectrum. Radioastronomy, which had its beginnings in 1932 also deals with the study of these heavenly bodies, but the radiation received by the 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 degree kelvin cosmic background radiation (a relic from the hot big bang origin of the universe which is estimated to have taken place about 14 billion years ago, and which in fact, contributes some of the noise ("snow") on our TV channels even today!); quasars (very bright but very distant quasi-stellar sources of radiation), pulsars (rotating neutron stars barely 10 kilometres in diameter, but still about as massive as the Sun); and now almost certainly the black holes (gravitationally collapsed objects from which even light cannot escape).

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 about 80 km from Bangalore, 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 and is being used to study radio emission from various types of celestial objects such as the Sun, Jupiter, and the 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 (ORT) operated by the Tata Institute of Fundamental Research (TIFR), Mumbai. 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 make observations using the Giant Metre wavelength Radio Telescope (GMRT), built by TIFR near Pune. In fact, RRI was and is deeply involved in the GMRT instrumentation. Another interactive project is the low-frequency (150 MHz) Mauritius Radio Telescope (MRT) built at Mauritius by RRI in collaboration with the University of Mauritius and the Indian Institute of Astrophysics. A radio map of the southern sky at full resolution of 4 arcminute × 4 arcminute is getting ready.

During the past two decades, millimetrewave astronomy has assumed great importance because of the discovery of numerous molecules in the vastness of the interstellar space (combinations of Hydrogen, Carbon, Nitrogen, Oxygen, Silicon, etc.). These are identified by their emitted line radiation (spectra) 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 on campus, which is being used for such studies.

In addition to the above observational programmes, the Institute has theoretical research programmes in many areas of Astrophysics, e.g., Pulsars, their evolution, structure and the emission mechanism; Supernova Remnants; the Inter-Stellar Medium; Galaxies and large-scale structure in the universe and cosmology; and high-energy astrophysics – the X-ray astronomy and the gamma-ray bursts.

A detailed, but admittedly technical account of the work carried in the past year at RRI is given in the pages that follow.

THEORETICAL PHYSICS (TP)

AREAS OF RESEARCH: Condensed Matter & Statistical Physics
Gravitation
Optics, Quantum Mechanics &
General Physics
Physics in Biology

CONDENSED MATTER AND STATISTICAL PHYSICS

Work distribution functions in polymer stretching experiments. The distribution of work done in stretching a Gaussian polymer at a finite rate is computed. For a one-dimensional polymer undergoing Rouse dynamics, the work distribution is a Gaussian and its mean and width are explicitly computed. The two cases where the polymer is stretched, either by constraining its end or by constraining the force on it, are examined. Connections to Jarzynski's equality and the fluctuation theorems are discussed. [A. Dhar].

Work fluctuations in hysteresis loops for a single spin. For a small magnetic system driven by a time-dependent magnetic field the area under the hysteresis curve gives the work done on the system. A simple model system of a single Ising spin in a time-dependent field and driven by a Markovian dynamics (Glauber dynamics) is considered. The fluctuations of the work done are computed by Monte-Carlo simulations. For the special cases of slow and fast driving rates some exact results are obtained. [A. Dhar and R. Marathe].

Heat transport in disordered harmonic systems. The problem of a disordered harmonic system in two dimensions is studied. Extensive molecular dynamics simulations have been done, with two different types of reservoirs, to find the system-size-dependence of the current. A special case of a system with correlated disorder is treated analytically. We again find that Fourier's law is not valid. These studies are expected to be relevant for experimental studies on heat transport in nanotubes and molecular wires. [A. Dhar + L.W. Lee (University of California, Santa Cruz, USA)].

An alternative derivation of non-equilibrium Green function formalism for quantum transport. The non-equilibrium Green function formalism (NEGF) is commonly used to study electron transport in mesoscopic systems. An alternative derivation of the results of NEGF had earlier been obtained by A.

Dhar and S. Shastry. This involved a direct solution of the equations of motion for the system and reservoirs both of which are taken to be non-interacting. This equation-of-motion derivation of NEGF has now been simplified further and also generalized to the case of phonons. This derivation, which is exact, seems to be much more straightforward than the conventional derivations. Some subtle points such as the possibility of non-unique steady states are now being investigated for a simple model system, namely that of single Anderson impurity coupled to reservoirs. For an interacting system a mean field approach to NEGF is also being investigated. [A. Dhar + D. Sen (IISc., Bangalore)].

Viscosity of suspensions and the glass: Turning power-law divergence into essential singularity. Starting with an expression, due originally to Einstein, for the shear viscosity $\eta(\delta\varphi)$ of a liquid having a small fraction $\delta\varphi$ by volume of solid particulate matter suspended in it at random, an effective-medium viscosity $\eta(\varphi)$ for arbitrary φ is derived which is precisely of the Vogel-Fulcher form. An essential point of the derivation is the incorporation of the excluded-volume effect at each turn of the iteration $\varphi_{n+1} = \varphi_n + \delta\varphi$. The model is frankly mechanical, but applicable directly to soft matter like a dense suspension of microspheres in a liquid as function of the number density. Extension to a glass forming supercooled liquid is plausible inasmuch as the latter may be modelled statistically as a mixture of rigid, solid-like regions φ and floppy, liquid-like regions $(1 - \varphi)$, for φ increasing monotonically with supercooling. [N. Kumar].

Inequivalence of ensembles in single molecule measurements. The role of fluctuations in single molecule experimental measurements of force-extension curves was studied. The worm like chain (WLC) model was used to bring out the connection between the Helmholtz ensemble characterized by the free energy and the Gibbs ensemble characterized by the free energy. The rigid rod limit of the WLC model was considered as an instructive special case to bring out the issue of ensemble inequivalence. The need for taking into account the free energy of transition when one goes from one ensemble to another was pointed out. The "phase transition" noticed in an isometric setup for semiflexible polymers was commented on and a realization of its thermodynamic limit proposed. General arguments which rule out non-monotonic force-extension curves in some ensembles were presented and it was noted that these do not apply to the isometric ensemble.
[J. Samuel and S. Sinha].

GRAVITATION

Ricci Flows. Work was begun on the use of the Ricci flow to address problems in general relativity like the Penrose inequality. Some preliminary findings, which recover the positive energy theorem using a new method have been obtained. [J. Ahmed, S. Roychowdhury and J. Samuel].

A new class of post-Newtonian waveform templates for inspiralling test-mass in Schwarzschild spacetime. A new and simple complete adiabatic approximant is proposed using the energy and flux functions. At the leading order, it uses the 2PN energy function rather than the 0PN one in the standard approximation so that in spirit it corresponds to the complete 2PN dynamics. The complete adiabatic approximants lead to a remarkable improvement in the effectualness at lower PN (< 3PN) orders. Standard adiabatic approximants of order $\leq$3PN are nearly as good as the complete adiabatic approximants for the construction of effectual templates. Faithfulness of complete approximants is also better than that of standard approximants. [P. Ajith, B.R. Iyer + C.A.K. Robinson and B.S. Sathyaprakash (Cardiff University, U.K)].

Parameter estimation of inspiralling compact binaries using 3.5PN gravitational wave phasing. The problem of parameter estimation of gravitational-wave chirp signals from inspiralling non-spinning compact binaries is reexamined using the 3.5PN gravitational wave phasing. In both initial and advanced detectors the estimation of the chirp mass ($\mathcal{M}$) and symmetric mass ratio (η) improve at higher PN orders but oscillate with every half-a-PN order. Errors in parameter estimation at a fixed SNR are smaller for VIRGO than for both initial and advanced LIGO because of the larger bandwidth over which it observes the signals. For sources at a fixed distance it is advanced LIGO that achieves the lowest errors owing to its greater sensitivity. [K.G. Arun, B.R. Iyer + B.S. Sathyaprakash (Cardiff University, U.K.) and P. Sundararajan (BITS, Pilani)].

Inspiralling compact binaries in eccentric orbits: Instantaneous terms in energy, angular momentum and linear momentum fluxes. The instantaneous term in energy and angular momentum fluxes at 2.5PN and 3PN orders and of linear momentum flux at 1.5PN and 2PN orders have been obtained in the case of inspiralling compact binaries moving on general non-circular orbits. These results are needed to construct search templates for binaries moving in elliptical orbits to be used for matched filtering of gravitational wave signals. [K.G. Arun, B.R. Iyer, M.S.S. Qusailah + L. Blanchet (IAP, France)].

The Hereditary terms in the energy flux up to 3PN. The hereditary contributions to the GW energy flux at 2.5PN and 3PN orders are calculated. This, together with the instantaneous part up to 3PN and the hereditary contribution at 1.5PN, computed earlier, give the complete 3PN accurate expression for the GW luminosity up to 3PN order. At 2.5PN order the hereditary contribution is only due to the 'tails'. At 3PN order there are 'tails of tails' and 'tail square' contributions as well. They are worked out using the 3PN generalized quasi-Keplerian model for the binary orbit. [K.G. Arun, B.R. Iyer, M.S.S. Qusailah + L. Blanchet (IAP, France)].

Hadamard regularization of the third post-Newtonian gravitational wave generation of two point masses. The 3PN mass quadrupole and dipole moments are obtained in harmonic coordinates for binaries moving in non-circular general orbits using Hadamard regularization. The final expressions are given in terms of their core parts, resulting from the application of the pure Hadamard-Schwartz self-field regularization scheme, augmented by an ambiguous part. For the 3PN mass quadrupole, three ambiguity parameters exist. These results form the basis of the complete calculation of the 3PN radiation field of compact binaries by means of dimensional regularization. [B.R. Iyer + L. Blanchet (IAP, France)].

Surface-integral expressions for the multipole moments of an extended post-Newtonian source and the boosted Schwarzschild solution. New expressions are derived for the multipole moments of an isolated post-Newtonian source in the form of surface integrals in the outer near-zone. The third post-Newtonian source quadrupole moment of a Schwarzschild solution boosted to uniform velocity is computed as an application. A comparison with the 3PN computation of the gravitational wave generation by compact binaries uniquely determines one of the 3PN ambiguity parameters. A far-zone expansion of the boosted Schwarzschild metric, and a calculation of non-linear multipole interactions in the external metric at 3PN order reconfirms this value. [B.R. Iyer + L. Blanchet (IAP, France) and T. Damour (IHES, France)].

Dimensional regularization of the third post-Newtonian gravitational wave generation from two point masses. The general relativistic prediction for compact binary inspiral is completed up to 3.5PN order using dimensional regularization in the computation of the gravitational wave field at 3PN. The quadrupole moment of point-particle binaries in harmonic coordinates contains a pole at the 3PN order that can be renormalized away by means of the same

shifts of the particle world-lines as in the 3PN equations of motion. The renormalized quadrupole moment leads to unique values for all the three ambiguity parameters coming from the Hadamard self-field regularization at 3PN. These results should be of use for searching and deciphering the signals in the current network of gravitational wave detectors. [B.R. Iyer + L. Blanchet, G. Esposito-Farèse (IAP, France) and T. Damour (IHES, France)].

Functional evolution of cylindrical gravitational waves. Einstein-Rosen wave is perhaps the best known symmetry-reduced gravitational system with infinite degrees of freedom and is canonically equivalent to a cylindrically symmetric scalar field in 4-dimensional Minkowski space with arbitrarily parametrized time and space. Evolution of quantum states on two arbitrary spatial slices may be implemented by proving the existence of unitary operators that map the states on one slice to the other. A precise criterion is given by the well-known Hilbert-Schmidt condition on the Bogolubov coefficients. It is proved that the Bogolubov coefficients are not of Hilbert-Schmidt type for pure spatial diffeomorphism and therefore unitary maps between two quantum states on two arbitrary spatial slices do not exist. [D. Cho and M. Varadarajan].

Observables in classical stochastic models of causal set theory. A classical stochastic dynamics was formulated for causal set theory by Rideout and Sorkin in 2001, that adapts most easily to a path integral quantisation of causal sets. The set of covariant observables for a class of these theories has been completely characterised in terms of *past-sets* by Brightwell *et al*. These correspond to the past light cones of observers in continuum classical general relativity and hence have a very simple and physically accessible interpretation. This work was extended to include generalisations of the dynamics and hence the robustness of this characterisation of observables was demonstrated. [S. Surya + F. Dowker (Imperial College, London)].

Observability of spatial hypersurfaces and transitions between them. The continuum approximation arises from causal sets that *faithfully* embed *via* a random sprinkling of the elements of the causal set into a continuum spacetime geometry. In such an approximation, a proposal for a discrete analogue of a spatial hypersurfaces in a causal set is made. Using the classical stochastic models for causets, it is demonstrated that such hypersurfaces which represent a covariant *moment-of-time* can be assigned a covariant meaning, as can transitions between them. Within this class of models, the sets of histories containing these hypersurfaces are *observable* in striking contrast to the canonical framework. Moreover, because of the use of *completed histories*, the construction provides a new (non-local) way to sum perform the sum-over-

histories in quantum gravity. [S. Surya + S. Major and D. Rideout (Hamilton College, USA)].

Recovering continuum topology from causal sets. Using the discrete analogues of spatial hypersurfaces, homological information was constructed from the causal set which recovers the homology of a globally hyperbolic continuum spacetime with high probability, up to the cut-off scale. Along the way, this work used some lesser known results of algebraic topology and provided a new way of constructing a discretisation of a continuum spacetime, which derives from its causal structure. Numerical work was also carried out. This result could contribute significantly to the larger goal of obtaining the continuum approximation of a causal set. [S. Surya + S. Major and D. Rideout (Hamilton College, USA)].

The graviton vacuum as a distributional state in kinematic loop quantum gravity. The graviton vacuum state was identified with kinematically non-normalizable, distributional states in LQG by demanding that relations between linearised operator actions on the former were mirrored by those of their non-linear counterparts on the latter. A norm on the space of kinematical distributions was defined and it was shown that the identification was approximate up to distributions which were small in this norm. It was argued that the candidate states were annihilated by the linearised constraints (expressed as operators in the full theory) to leading order in the parameter characterising the approximation. This suggested the possibility, in a scheme such as this, of solving the full constraints order by order in this parameter. [M. Varadarajan].

A general solution for classical sequential growth dynamics of causal sets. A classical precursor to a full quantum dynamics for causal sets was formulated by Rideout and Sorkin in terms of a stochastic sequential growth process in which the elements of the causal set arise in a sort of accretion process. The transition probabilities of the Markov growth process satisfy certain physical requirements of causality and general covariance, and the generic solution with all transition probabilities non-zero was found by them. In this work the assumption of non-zero probabilities was removed, a reasonable extension of the physical requirements to cover the case of vanishing probabilities, was defined and the completely general solution to these physical conditions was found. The resulting family of growth processes has an interesting structure reminiscent of an *infinite tower of turtles* cosmology. [M. Varadarajan + D. Rideout (Hamilton College, USA)].

Quantum resolution of the black hole information loss problem in 1+1 black holes. Recently, Abhay Ashtekar and Martin Bojowlad have proposed a paradigm to discuss Hawking evaporation of a black hole in the context of a non-perturbative quantization of the gravitational field. To convert the paradigm into a concrete resolution of the black hole evaporation paradox, extremely technically involved calculations need to be made. Hence an appropriate toy model in which to test the paradigm before embarking on these calculations is of immense use. In this context, a non-perturbative quantization of the CGHS model of 1+1 black holes was constructed several years ago by Kuchař, Romano and Madhavan Varadarajan. Hence the CGHS model offers a good testing ground for the paradigm where all technical steps may be completed. The relevant work is in progress. [M. Varadarajan + A. Ashtekar (Penn State, USA)].

OPTICS, QUANTUM MECHANICS & GENERAL PHYSICS

Quantum measure and CP maps. It was shown that a Markovian evolution for a wavefunction on a discrete spacetime lattice can be non-trivial if unitarity is replaced with CP evolution. However, the Markovian character of the decoherence functional remains incompatible with CP evolution, hence establishing that a fully path-integral formulation of Markovian quantum theory on a discrete spacetime lattice has no immediate correspondence to a unitary process. This has potential relevance to models of causal set quantum gravity which employ CP evolution, but are intrinsically tied to moments of time descriptions. This work is in progress. [S. Surya].

PHYSICS IN BIOLOGY

Euler buckling in red blood cells: An optically driven biological micromotor. The physics of an optically-driven micromotor of biological origin was investigated. A single red blood cell, when placed in an optical trap using circularly polarized light, first folds into a rod-like shape and then rotates. A model based on the concept of buckling instabilities captures the folding phenomenon; the rotation of the cell was modeled using the Poincare sphere. Predictions made by this model were successfully tested. [A. Ghosh, J. Samuel, S. Sinha + A.K. Dharmadhikari, J.A. Dharmadhikari, D. Mathur, S. Roy and S. Sharma (TIFR, Mumbai)].

DNA elasticity: Topology of self avoidance. This work in progress since last year studies the topological effects of self avoidance in DNA elasticity. It is shown that the topological effects of self avoidance can be captured by replacing it with the much simpler notion of south avoidance. [A. Ghosh, J. Samuel and S. Sinha].

Active trafficking dynamics of closed membranes: Non-equilibrium steady states. It is shown that active vesicular transport drives a closed membrane to non-equilibrium steady states with distinct morphologies maintained at a non-uniform pressure and tension which have no analogue in equilibrium physics. Even under conditions of spatially isotropic activity, the closed membrane may spontaneously acquire a non-zero drift, a graphic demonstration of the Curie principle. For anisotropic activity, the generic steady state shapes are flattened sacs. There exist regimes of parameter space where quasi-spherical membrane shapes are unstable to tubular extensions with a radius inversely proportional to $\sqrt{\sigma_{eff}}$, the activity renormalised tension, leading one to believe that such active dynamical processes play an important role in determining subcellular shapes of membrane bound internal organelles. [G. Kripa and M. Rao].

O P T I C S

AREAS OF RESEARCH: Laser Cooling and Trapping of Atoms,
Quantum Optics
Ultra-fast Processes, Non-linear Optics
Light in Random Media
Quantum Communication

LASER COOLING AND TRAPPING OF ATOMS, QUANTUM OPTICS

Electromagnetically-induced Transparency (EIT) was observed by studying the fluorescence from doubly-driven room temperature rubidium atoms in a vapour cell. In this effect, the destructive quantum interference of transition probabilities of two transitions with a common level renders a medium transparent to light, which it normally would have absorbed. This is a very delicate effect requiring lasers of very narrow linewidths and high frequency stability, and is usually observed in absorption. The transition from the incoherent Autler-Townes splitting to the coherent transparency effect was demonstrated for the first time in fluorescence. [Andal Narayanan].

The phenomenon of double-resonance that was observed and explained by us last year has now been used to frequency lock lasers. Most experiments in quantum optics require lasers with high frequency stability that are actively locked, usually to a hyperfine transition in the saturation absorption spectrum. By using the spectral feature of double resonance, one may lock the laser at any frequency, up to 1GHz away from a hyperfine transition. As a spinoff, this provides a way of detuning a laser from a hyperfine transition, without the use of acousto-optic modulators that are usually used. [Hema Ramachandran].

The measurement of fluorescent emission from cold atoms in a magneto-optic

trap (MOT) as a function of detuning of the cooling laser showed a significant difference in intensity depending on whether the frequency was being ramped up or ramped down. The asymmetry was shown to arise from the different dependencies of the loading rate and the decay rates on detuning. Based on this, an asymmetry parameter was defined that was shown to be insensitive to the various parameters of the MOT and dependent only on the loading and decay rates, and thus on the lifetime of the trap, thereby providing a very simple means of estimating the lifetime of the trap based on measurements of fluorescent emission intensities as functions of frequency sweeps of the cooling laser. [Uday Kumar Khan, R. Srinivasan and Hema Ramachandran].
The various components of the Bose-Einstein condensation experiment that had been built last year, have now been assembled into a double-Magneto-Optic-Trap (MOT). The system is now maintained under differential pressure, with the upper MOT at $3x10^{-9}$ Torr, and the lower at 10^{-10} Torr. A cloud of cold atoms has been formed in the upper MOT. [Ashok Vudayagiri, Andal Narayanan, Hema Ramachandran, R. Srinivasan and Project Assistants].

A theoretical treatment of elementary excitations of a BEC near parallel plates was undertaken. Instability in surface modes are known to create vortices; the threshold velocities for vortex-formation, with and without the presence of parallel plates, were investigated. It is shown that measurable differences exist between the two geometries that may be used to experimentally verify the Casimir-Polder effect. [Andal Narayanan].

ULTRAFAST PROCESSES, NON-LINEAR OPTICS

Very small nano-particles, exhibiting quantum-size effects were investigated. Experimental studies on Au_{29} nanoparticles showed pico-second excited dynamics and relatively larger lifetimes. [Reji Philip + Pradeep (IIT-M)].

The experimental setup for studying the interaction of intense laser fields with liquid droplets is being built. [Reji Philip, Anija Matthew].

Neodymium-doped heavy-metal-borate glasses, which have potential for application in photonics devices were studied. Infra-red and optical absorption, photo-luminescence and open-aperture Z-scan measurements were performed. It was found that in the transparency region, the non-linearity exhibited is of fifth order. [Karthikeyan, Reji Philip + S. Mohan (Asian University, Malaysia)].

The non-linear characterization of Au-Ag alloy core-shell nano-particles were

undertaken, based on which a qualitative model for the alloy-core nano-particle has been proposed. [Pradeep (IIT-M), Jinto Thomas, Anija Matthew, Reji Philip + S. Nair (IIT-M), V. Suryanarayanan (IIT-M)].

Silver-polyvinyl alcohol (Ag-PVA) films have been prepared and the influence of annealing time upon the variation in cluster-size has been investigated, using optical absorption, emission and Fourier-Transform Infra-Red (FTIR) spectroscopy. [B. Karthikeyan].

Quantum diffusion on a dynamically disordered and driven lattice with static bias: **Decoherence.** The problem of quantum diffusion of a particle moving on a 1-D lattice with dynamical disorder is considered. Decoherence, essential for the diffusive motion, is introduced *via* a set of Lindblad operators, known to guarantee *per se* the positivity, Hermiticity and the trace-class nature of the reduced density matrix, derived and solved analytically for several transport quantities of interest. For the special Hermitian choice of the Lindblad operators projecting on to the lattice sites, we recover several known results, obtained by others, *e.g.,* through the stochastic Liouville equation using phenomenological damping terms for the off-diagonal density-matrix elements. An interesting new result obtained by us is the non-linear enhancement of the diffusion coefficient with increasing drive amplitude and its oscillatory behaviour as function of the drive frequency — clearly, a Wannier-Stark ladder signature. [Navinder Singh and N. Kumar].

Dissipative electron-phonon system photoexcited far from equilibrium. Generalizing the stochastic model known for a driven dissipative granular gas, we have derived the steady-state non-degenerate electron distribution for a semiconductor driven far from equilibrium by the interband photo-excitation assumed uniform over the nanoscale sample. Partitioning of the total inelastic electron scattering into dissipative electron-electron and electron-phonon components is included. The model is applicable to a photo-excited semiconducting sample with fast removal of the electrons by electron-hole recombination from the bottom of the conduction band. [Navinder Singh and N. Kumar].

LIGHT IN RANDOM MEDIA

A new kind of random, amplifying medium, the F-RAM (Fiber Random Amplifying Medium) has been devised, and its emission characteristics under nanosecond excitation experimentally studied. The F-RAM consists of

segments of amplifying fibers, randomly embedded in a passive scattering medium. The propagation of light in such a medium consists of diffusion through the scattering medium, and guided propagation with amplification within the active fiber segments. In analogy with the well-known Arrhenius Cascade model, an F-RAM with fiber segments with an exponentially falling distribution of lengths was created. In this system, long fibers, rare though they are, dominate the emission due to the exponentially large gain associated with them. The statistics of sample-to-sample fluctuation in emission intensity was shown to exhibit a Levy distribution, hitherto unknown in optics of random amplifying media. [Divya Sharma, N. Kumar, and Hema Ramachandran].

QUANTUM COMMUNICATION

Secret-sharing is a cryptographic protocol, where a secret is mathematically broken into pieces (shares) such that only specified collection of shares, and not others, may reconstruct the secret. Using inflation, compression and twin-thresholding, the role of classical shares in quantum key sharing were investigated. [R. Srikanth + Sudhir Singh (IIT-Kgp)].

A quantum-seal is a way of encoding a message into quantum states, so that anybody may read the message with little error, while authorized verifiers can detect that the seal has been broken. A simple extension of the Bechmann-Pasquinicci majority-voting scheme was devised that allows the sealed states to be non-orthogonal, and further, encompasses sealing of quantum messages by means of quantum encryption. The scheme is relatively easy to implement, requiring neither entanglement, nor controlled operations during state preparation, reading or verification stages. [R. Srikanth + Sudhir Singh (IIT-Kgp)].

Quantum cryptography essentially consists of a transmission of a key over a quantum channel, and it requires that the error rate (which results either from a noisy channel or from eavesdropping, which alters the transmitted bit) be smaller than a particular value in order that the transmitted key to be secure. Various protocols are proposed in literature that attempt to increase the permissible error rate. We have proposed a protocol that uses the Bennett-Brassard (BB84) scheme, and in addition, a twin-coding of bases sets, with some pre-shared information. This scheme results in a larger cryptokey generation rate for a given quantum bit error rate, and it is found that asymptotically, no error rate is too high to tolerate. [R. Srikanth, Ashok Vudayagiri, Andal Narayanan and Hema Ramachandran].

LIQUID CRYSTALS (LC)

AREAS OF RESEARCH:

L.C. Synthesis
Phase Transitions
Monolayers
Soft Matter Physics
Electrochemistry
Liquid Crystal Displays
Theoretical Investigations

EXPERIMENTAL INVESTIGATIONS

LIQUID CRYSTAL SYNTHESIS

Synthesis and characterization of new compounds exhibiting liquid crystalline phases: Research and scientific investigations were continued on the design, synthesis and characterization of new compounds composed of banana-shaped as well as disc-like molecules.

New phase sequences in banana-shaped mesogens: Many new homologous series of bent-core compounds derived from 2,7-dihydroxynaphthalene were synthesized and the mesomorphic properties investigated using classical techniques. The position of fluorine substitution has an influence on the nature of mesophase formed. The compounds containing fluorine on the middle phenyl ring *ortho* to the carboxylate group exhibit new phase sequences such as N to X_1 to X_2 to B_6; N to B_6 to B_1; N to B_1 and a chiral SmC_AP_A mesophase on ascending the homologous series. The corresponding isomeric compounds (fluorine at *meta* position) show N to X_1 to X_2 to B_1; N to B_1; and a racemic $SmCP_A$ phase. However, some of the unsubstituted parent compounds show a chiral SmC_AP_A phase. The fluorine substitution in the middle phenyl ring induces a new phase sequence and also changes the chiral nature of the mesophases. Fluorine substitution at the *ortho* position w.r.t. the n-alkoxy chain on the central phenyl unit completely changes the mesophase behaviour when compared with the parent compounds. [R. Amaranatha Reddy and B.K. Sadashiva].

Unusual mesomorphic behaviour in bent-core compounds derived from 5 – cyanoresorcinol: Two new homologous series of compounds containing a highly polar cyano group along the arrow axis of bent-core molecules were

synthesized and their mesomorphic behaviour investigated. The mesophase obtained for higher homologues of both series show a mixture of four different possible structures. Among these, two are chiral conglomerates with opposite tilt and polarity. The remaining two have racemic structures which arise from a synclinic tilt of bent-core molecules in adjacent layers in one case, and in the other a synclinic tilt of molecules in adjacent layers forming two different domains which alternate. The observation of tristable switching, as well as two half period polarization current peaks, confirms the ground state antiferroelectric structure for the mesophase. The spontaneously formed helical filaments and chiral circular domains with helical periodicity suggest a structure for this mesophase that is different from B_2 phase [R. Amaranatha Reddy and B.K. Sadashiva].

Novel columnar mesophases obtained from banana-shaped mesogens: A few novel series of bent-core compounds containing cinnamoyloxy or ∝-methylcinnamoyloxy groups in the sidearms were synthesized and the mesophases exhibited by them compared. The influence of the central angular unit on the occurrence of mesophases was investigated. The higher homologues of compounds containing a cinnamoyloxy group in the sidearms and derived from 2,7-dihydroxynaphthalene show a direct transition from nematic phase to a columnar phase with an oblique lattice. The corresponding analogues derived from 1,3-dihydroxybenzene show a columnar phase with a rectangular lattice, which interestingly shows an antiferroelectric switching behaviour. Compounds derived from a naphthylene central unit containing α-methylcinnamoyloxy group in the sidearms show a direct transition from a nematic phase to an antiferroelectric B_2 phase. In contrast, the corresponding analogues derived from 1,3-dihydroxybenzene do not show any mesophase. A fluorine lateral substituent induces an interesting phase sequence, such as direct transition from a nematic phase to an antiferroelectric B_2 phase and to a columnar B_1 phase as well. An orthogonal arrangement of molecules in the B_1 phase was found in two homologous series of compounds containing 2,7-naphthylene central unit. [R. Amaranatha Reddy, B.K. Sadashiva and V.A. Raghunathan].

Fluorine-substituted unsymmetrical bent-core mesogens derived from resorcinol: The mesomorphic properties of forty unsymmetrical achiral bent-core compounds belonging to four different homologous series were investigated. A majority of the compounds exhibited an antiferroelectric B_2 phase. X-ray diffraction studies of the mesophases of compounds with fluorine substitution at the *ortho* position w.r.t. the terminal n-alkoxy chain show a B_2 phase with larger *d*-spacings than those of compounds with fluorine at the *meta*

position. This indicates that the conformation of the n-alkoxy chain is affected by the presence of the highly electronegative fluorine substituent in the *ortho* position. It was also found that the position and number of fluorine substituents play a significant role in inducing the ferro-/antiferro-electric mesophase in these five-ring achiral bent-core compounds [H.N. Shreenivasa Murthy and B.K. Sadashiva].

Novel ferroelectric and antiferroelectric smectic and columnar mesophases in fluorinated symmetrical bent-core compounds: The synthesis and mesomorphic properties of a new homologous series of compounds derived from 2,7-dihydroxynaphthalene with a fluorine substituent on the outer phenyl rings *ortho* to the n-alkoxy chain were investigated using classical techniques. A wide variety of electrooptically switchable mesophases have been obtained by varying the terminal n-alkoxy chain length. This is the first example of a series of compounds in which ferroelectric, antiferroelectric switching smectic and columnar phases are obtained with increasing chain length, which gives a new phase sequence in banana liquid crystals. It is apparent that fluorine substitution only at this position induces the switchable columnar phases and not at any other position in these compounds with isomeric structures, which also suggests the importance of the position of the electronegative fluorine substituent. [R. Amaranatha Reddy, V.A. Raghunathan and B.K. Sadashiva].

Mesomorphic properties of seven-ring banana-shaped mesogens derived from 5-choloresorcinol: The synthesis and characterization of two new homologous series of seven-ring symmetrical bent-core esters derived from 5-chlororesorcinol were carried out. These represent the first example of BC compounds containing a chloro substituent at position 5 of the central phenyl unit. The lower homologues of both series of compounds exhibit the rectangular columnar B_1 phase. Interestingly, the higher homologues show a mixture of three different possible structures, two chiral and one racemic. Although the ground state structure of the mesophase is antiferroelectric, it is different from the usual B_2 phase and hence has been termed as B_{2X}. Since the B_{2X} mesophase shows a helical pattern, it is possible that this mesophase is among the B_7 class of materials. [S. Umadevi and B.K. Sadashiva].

Recent developments in the chemistry of triphenylene–based discotic liquid crystals: Triphenylene based discotic liquid crystals, which have already been used commercially in phase compensation films to improve the viewing angle of liquid crystal display devices, also have application potential as one-dimensional charge carrier systems useful in electrical conduction,

photoconduction, electroluminescence, photovoltaic solar cells, gas sensing, optical data storage and other devices. A summary of the advances in the chemistry of triphenylene based discotic liquid crystals since 1995 has been written as a review article. [Sandeep Kumar].

Inclusion of gold nanoparticles into a discotic liquid crystalline matrix: The thermophysical properties of mixtures of hexanethiolate capped gold nanoparticles and three types of discotic liquid crystals, investigated using polarizing optical microscopy, differential scanning calorimetry and DC conductivity measurements, indicate inclusion of gold nanoparticles into a matrix of triphenylene-based discotic liquid crystals [Sandeep Kumar and V. Lakshminarayanan].

Synthesis and characterization of novel imidazolium-based ionic discotic liquid crystals with a triphenylene moiety: Two novel triphenylene tethered imidazolium salts were synthesized either by the quaternization of 1-methylimidazole with a ω-bromo substituted triphenylene or the quaternization of a triphenylene-substituted imidazole with methyl iodide. These triphenylene based imidazolium salts with bromide or iodide as counterion show columnar mesophase properties over a wide temperature range. [Sandeep Kumar and Santanu Kumar Pal].

A convenient and economic method for the synthesis of monohydroxy-pentaalkoxy- and hexaalkoxytriphenylene discotics: A one step process for the preparation of mono-functionalized triphenylene discotics was developed. Oxidative trimerization of *ortho*-alkoxybenzenes using $FeCl_3$ in nitromethane and a catalytic amount of various acids, furnished monohydroxy pentaalkoxytriphenylene in addition to hexaalkoxytriphenylene which were separated by chromatography. [Sandeep Kumar and B. Lakshmi].

PHASE TRANSITIONS

Selective imaging of 3D director fields and study of defects in biaxial smectic A liquid crystals: The selective imaging of different director fields in a biaxial smectic A (SmA_b) liquid crystal using Fluorescence Confocal Polarizing Microscopy (FCPM) and Polarizing Microscopy (PM) was carried out. It has been shown that the two main director fields in biaxial smectic A phase, *viz*., those corresponding to the rods and the bow axes of the banana-shaped molecules can be independently mapped using two different types of fluorescent dyes in fluorescence confocal polarized microscopy. The technique

has led to direct proof of the correctness of the proposed structure of the biaxial smectic A phase. The defect patterns in the banana director field, the layer bending which leads to focal-conic domains, and the mutual influence of the two types of defects have also been studied. [R. Pratibha and N.V. Madhusudana + I.I. Smalyukh and O.D. Lavrentovich, Liquid Crystal Institute, Kent, U.S.A].

Stripe phase in binary mixtures of rod-like and banana-shaped mesogens: It was discovered in the laboratory some years ago that binary mixtures of compounds composed of rod-like and banana-shaped molecules can exhibit the biaxial smectic A phase. In some specially prepared cells, it was found that the medium spontaneously breaks up into a stripe phase in which alternate stripes have biaxial and uniaxial character. Stripe phases are known in a number of other condensed matter systems, but the present one appears to be quite different as the ground state of the mixture is one with a uniform composition. Effort is being made to understand the origin of the stripes by conducting further experiments. A simplified model for the stripe phase is also being developed. [N.V. Madhusudana and R. Pratibha].

Dynamic light scattering studies on a disc-like nematic lyotropic liquid crystal: Lyotropic liquid crystals possess structures that are very different from thermotropic liquid crystals and have attracted considerable interest. Cesium perfluorooctanoate (CsPFO) dissolved in water form disc-like micelles. In a certain range of concentrations, the CsPFO in water system exhibits an isotropic phase, a nematic phase and a lamellar phase on cooling. The twist viscoelastic coefficient in this nematic phase has been measured employing dynamic light scattering technique and it was found that the viscoelastic coefficient increases with increase in temperature. The viscoelastic response of the medium as a function of concentration of CsPFO in water has also been studied. Twist viscoelastic coefficient rapidly increases with the concentration of CsPFO in water at a given reduced temperature. The activation energy corresponding to the viscosity has been estimated and is shown to be nearly independent of the concentration of CsPFO in water. The effects of doping polyethylene glycol polymer on the viscoelasticity of CsPFO in water system has also been studied [Amit K. Agarwal and K.A. Suresh].

MONOLAYERS

Studies on the Langmuir monolayer of cholesteric acid: Cholesteric acid (CA) molecule is an optically active molecule possessing a size anisotropy in

the head and tail groups. This results in some interesting monolayer phases at the air-water interface. At low surface density, the monolayer exhibits a phase with a gradual tilt azimuth variation of the molecules. This is revealed by the stripe patterns seen in a Brewster angle microscope. Linear and concentric stripes and spirals are also observed. In addition to this loosely packed phase, CA monolayer exhibits two more phases – a uniformly tilted condensed phase and an untilted condensed phase. [Rajkumar Gupta and K.A. Suresh].

SOFT MATTER PHYSICS

Spontaneously formed monodisperse biomimetic unilamellar vesicles: Using small-angle neutron scattering and dynamic light scattering techniques, partial structural phase diagrams of lipid mixtures composed of the phosphatidylcholines dimyristoyl and dihexanoyl doped with calcium ions (Ca^{2+}) and/or the negatively charged lipid, dimyristoyl phosphatidyl glycerol (DMPG) have been constructed. For dilute solutions (lipid concentration ≤ 1 Wt %), spontaneously forming unilamellar vesicles (ULVs) were found, and their polydispersity was determined to be ~ 20%. The stability of Ca^{2+} – or DMPG doped ULVs was monitored over a period of 4 days and their structural parameters (*e.g.*, average outer radius, $< R_o >$) were found to be insensitive to the lipid concentration (C_{lp}). However, doping the dimyristoyl/dihexanoyl system with both Ca^{2+} and DMPG resulted in ULVs whose $< R_o >$ was found to be C_{lp} dependent. The $<R_o>$ of DMPG – doped ULVs remained unchanged over an extended period of time (at least 4 days), a good indication of their stability [V.A. Raghunathan + scientists at the Steacie Institute for Molecular Sciences, Ontario Canada, and the Center for Neutron Research, Gaithersburg, Maryland, USA].

Finite-size effects do not reduce the repeat spacing of phospholipid multibilayer stacks on a rigid substrate: Finite-size effects in stacks of phospholipid bilayers, in the fluid L_α phase, have been investigated using samples oriented on silicon substrates. Recently, such effects have been suggested, as the probable cause of reduced lamellar repeat spacings in very thin samples made up of a few (<10) bilayers. The systematic studies carried out on samples of different thicknesses do not support this conclusion. At full hydration all samples are found to have the same repeat spacing, irrespective of their thickness. At lower hydrations, on the other hand, very thin samples, consisting of only a few bilayers, have a slightly larger spacing. [V.A. Raghunathan + scientists at the Steacie Institute for Molecular Sciences, Ontario, Canada].

Magnetically alignable phase of phospholipid "Bicelle" mixtures is a chiral nematic made up of wormlike micelles: The phase behaviour of binary mixtures of long- and short-chain lipids, namely, dimyristoyl phosphatidylcholine (DMPC) and dihexanoyl phosphatidyl choline (DHPC), using optical microscopy and small-angle neutron scattering has been studied. Samples with a total lipid content of 25 wt %, corresponding to ratios Q ([DMPC] / [DHPC]) of 5, 3.2 and 2, are found to exhibit an isotropic (I) $\rightarrow$ chiral nematic (N*) $\rightarrow$ lamellar phase sequence on increasing temperature. The I $\rightarrow$ N* transition coincides with the chain melting transition of DMPC at Q =5 and 3.2, but the N* phase forms at a higher temperature for Q = 2. All three samples form multilamellar vesicles in the lamellar phase. These results show that disc-like "bicellar" aggregates occur only in the lower temperature isotropic phase and not in the higher temperature magnetically alignable N* phase, where they were previously believed to exist. The N* phase is found to consist of long, flexible wormlike micelles, their entanglement resulting in a very high viscosity of this phase. [V.A. Raghunathan + scientists at the Steacie Institute for Molecular Sciences, Ontario, Canada, the National Institute of Standards and Technology, Gaithersburg, Maryland, USA, and the Institute of Biophysics and X-ray Structure Research, Schmiedlstrasse, Austria].

Phase behaviour of dipalmitoyl phosphatidylcholine (DPPC) - cholesterol membranes: The phase behaviour of dipalmitoyl phosphatidylcholine (DPPC) – cholesterol mixtures from small angle X-ray diffraction studies of oriented multilayers has been determined. A cholesterol induced modulated phase, denoted as P_{β} is obtained at intermediate cholesterol concentrations, which is distinct from the ripple ($P_{\beta'}$) phase found in earlier studies on similar systems. Some confocal fluorescence microscopy investigations on Giant Unilamellar Vesicles (GUVs) made from these mixtures have been carried out. [Sanat Karmkar and V.A. Raghunathan + Satyajit Mayor, National Centre for Biological Sciences, Bangalore].

ELECTROCHEMISTRY

Design of a compact scanning tunneling microscope: The design of a simple and compact scanning tunneling microscope based on the principle of an inertial slider mechanism has been described. The Z feedback which adjusts the tip-sample gap separation is applied to the coarse movement piezo, unlike the conventional method of applying it to the four quadrants of the tip scanning piezo. This method produces better stability in addition to eliminating the

requirement of four high voltage amplifiers. Several simple features incorporated in the sample stage improve the stability and reliability considerably. [M. Jayadevaiah and V. Lakshminarayanan].

Fine grain growth of nickel electrodeposit effect of applied magnetic field during deposition: The electrodeposition of nickel from a nickel sulphamate bath in the presence of a magnetic field applied at an angle of 45^{o} to the cathode surface produces a nickel deposit with a fine grain structure. Scanning electron microscopy (SEM), scanning tunneling microscopy (STM) and X-ray diffraction (XRD) have been used to characterize the surface morphology of the deposit. From these studies, it is believed that magnetic field induced convection increases the mass transfer rate, reduces the concentration polarization and leads to the growth of fine grain deposit. Cyclic voltammetry (CV) has been used to determine the roughness factor and steady state current potential plots to study the hydrogen evolution reaction on the nickel electrodeposited surface. [V. Ganesh, D. Vijayaraghavan and V. Lakshminarayanan].

Assessment of liquid crystal template deposited porous nickel as a supercapacitor electrode material: The high surface area porous nickel, obtained by template electrodeposition using a hexagonal liquid crystalline phase medium as a template was evaluated as a potential material for electrochemical capacitors using cyclic voltammetry (CV) and electrochemical impedance spectroscopy (EIS) studies in 6M KOH. A single electrode double layer capacitance of 1.4 F/cm^2 (at 2*m*V/s scan rate) was obtained using CV, which corresponds to a specific capacitance of 473 F/g. EIS studies show the typical behaviour of a porous electrode and the data were analyzed in terms of complex capacitance and complex power from which the relaxation time constant (τ_o) has been determined. Nickel oxide electrode, obtained by the electrochemical oxidation of porous Ni, shows a double layer capacitance value of 171 mF/cm^2, which corresponds to a specific capacitance of 57 F/g. The values of double layer capacitance and specific capacitance of the porous nickel with fast response time are the highest values reported for nickel in the literature so far. [V. Ganesh, V. Lakshminarayanan + S. Pitchumani, Central Electrochemical Research Institute, Karaikudi, India].

LIQUID CRYSTAL DISPLAYS

Main objective of the research and developmental work in the area of applications was to reduce the hardware complexity of the drivers and the

controller in passive matrix liquid crystal displays (LCDs).

Displaying gray shades: The concept of using wavelets to display gray shades in LCDs has been extended to non-integer wavelets. We have shown that up to sixty four gray shades can be displayed by using four voltages in the row drivers and eight voltage levels in the column drivers [T.N. Ruckmongathan].

Application of sparse orthogonal matrices: A prototype based on 32 x 32 matrix LCD and driven by selecting the subgroup (each consisting of eight rows) with sparse orthogonal matrix was fabricated to demonstrate the reduction in the hardware complexity of the controller and effective use of all the eight voltages in the column driver [T.N. Ruckmongathan and A. R. Shashidhara].

Binary addressing technique with duty cycle control for LCDs: Introduction of duty cycle in the binary addressing technique is proposed to enable integration of liquid crystal display drivers with a digital system in a single chip. An analysis of this technique with duty-cycle control has been carried out. Effects of duty-cycle control on brightness uniformity of pixels in the liquid crystal display are discussed. A system on chip implementation of the technique is also demonstrated. [T.N. Ruckmongathan, M. Govind, S.V. Ashoka and G. Deepak].

THEORETICAL INVESTIGATIONS

Thermal indexing in cholesteric liquid crystals: The effects of thermal indexing in cholesteric liquid crystals has been theoretically worked out. It is observed that for light propagation parallel to the twist axis in a right (left) handed cholesteric, the right (left) circularly polarized state exhibits a large nonlinear optical (NLO) coefficient of the order of 10^{-4} cm^2/W. On the other hand, the NLO coefficient for left (right) circularly polarized state is of the order of $10^{-6}cm^2/W$. It has been observed that in both the cases, the NLO coefficient is positive or negative depending upon whether the pitch of cholesteric increases or decreases with laser intensity. Further, due to variation in the average refractive index, the NLO coefficient for the right (left) circularly polarized state changes sign as the Bragg band is approached. In the case of laser beams with a Gaussian intensity profile, self-focussing, self-divergence and self-phase modulation are obtained. In the Mauguin limit, a defect structure with a periodic array of disclination loops within the Gaussian beam is found. [Amit K. Agarwal and G.S. Ranganath].

The effects of a laser field on the nematic-isotropic phase transition: The nematic-isotropic phase transition in liquid crystals in the presence of a laser field has been considered. In some situations in non-absorbing nematics a laser induced one way transition from a paranematic to a nematic phase is obtained. In absorbing nematics, in addition to this transition, a one way transition from a nematic to a paranematic phase is obtained. Interestingly, in some range of temperatures a reentrant nematic or a reentrant paranematic *via* paranematic or nematic phase respectively, is also found [Amit K. Agarwal and G.S. Ranganath].

Spontaneous breaking of symmetry in nematic liquid crystal drops with a bipolar structure due to dissolved polymers: Nematic droplets which are suspended in anisotropic medium exhibit a variety of structures, depending on the orientation of the director at the interface. If the director is parallel to the interface, two surface point defects of strength + 1 are seen on the drops. The interaction between them is repulsive, and they lie opposite to each other, giving rise to bipolar drops. In an experimental study carried out in our laboratory some years ago it was found that when some polymeric substances are dissolved in the sample, there is a spontaneous breaking of the symmetry of the drop and the point defects are no longer in diametrically opposite positions on the drops. A detailed theoretical model has been developed now, in which the effect of the dissolved polymer on the elastic anisotropy of the nematic is explicitly taken into account. The numerical calculations on the structure of the drop clearly demonstrate the breaking of the symmetry as seen in experiments. [N.V. Madhusudana and Yashodhan Hatwalne + Anand Kumar, Centre for Mathematical Modeling and Computer Simulation, Bangalore].

Escape configuration lattice near the nematic-isotropic transition tilt analogue of blue phases: The possible existence of a new phase of liquid crystals near the nematic-isotropic transition has been predicted. This phase is an achiral, tilt-analogue of the blue phase and is composed of a lattice of *double-tilt*, escape-configuration cylinders. The stability of this phase has been discussed and an estimate of the lattice parameter provided. [Yashodhan Hatwalne, N.V. Madhusudana + B. Chakrabarti, Department of Physics, University of Massachusetts, Amherst, U.S.A].

ASTRONOMY AND ASTROPHYSICS (A&A)

AREAS OF RESEARCH:
Extragalactic Astronomy
The Galaxy and the Interstellar Medium
Neutron Stars and Pulsars
Instrumentation and Signal Processing
Others

EXTRAGALACTIC ASTRONOMY

A new mechanism was suggested for generating magnetic fields in the pre-recombination era, in which it was shown that radiation pressure that preferentially accelerates electrons as compared to protons generates a current, which could generate magnetic fields if the current is vortical. This can be achieved in the second order of perturbation theory, with adiabatic, no-vorticity initial conditions. [S. K. Sethi and Rajesh Gopal].

Investigation was carried out on detectability of the neutral hydrogen (HI) signal from pre-reionization and reionization epochs. HI can be seen in both absorption and emission in the frequency range 20 to 150 MHz with a typical average signal around 0.1 Kelvin. Detection of this signal holds the promise of determining uniquely the thermal history of the universe and the epoch of reionization. By statistical analysis it was shown how the various parameters of the underlying model, *e.g*., cosmological parameters, ionization fraction of the universe during reionization, etc., can be determined by the detection of this signal. [S. K. Sethi].

In continuation of an earlier suggestion that heating of the intracluster medium by active galactic nuclei is important, the implication of this heating process was calculated for the distortion of the cosmic microwave background radiation, *via* the Sunyaev-Zeldovich effect. Effect of thermal conduction was also considered in the calculation. It was shown that the heating decreases the anisotropy signal expected from the Sunyaev-Zeldovich effect and that the decrement is more severe than previously thought. [Biman Nath and S. Roychowdhury + M. Ruszkowski (University of Colorado, Boulder, USA)].

A model of accretion and growth of the central black holes in galaxies was worked out, where feedback from black holes regulated the accretion flow. From this it is seen that the observed correlation between the black hole mass and the halo velocity dispersion can be explained without invoking any large

scale wind from the galaxy. [Biman Nath + M.C. Begelman (JILA, Colorado, USA)].

A calculation of the effect of radiative pressure on dust grains produced in the first generation supernovae to explain some anomalous abundance patterns of metal poor stars in our galaxy was carried out. [Biman Nath + A. Venkatesan and J. M. Shull (University of Colorado, Boulder)].

Gamma Ray Bursts: The Afterglow of GRB030329 continues to be visible at GMRT radio bands. The radio follow-up has been extended to longer than two years. The late time radio evolution as observed at 1280 and 610 MHz using the GMRT has clearly shown the transition of the fireball from relativistic to non-relativistic expansion, flattening the radio light curve as a result. [D. Bhattacharya, L. Resmi and Atish P. Kamble + C. H. Ishwara Chandra (NCRA, Pune)].

X and Z shaped Galaxies: An investigation of the origin of X and Z shaped radio galaxies was carried out by assuming that they result from a major merger of two galaxies. The relativistic jet propagates along the spin axis of the central black hole of one of the galaxies. After the merger of the galaxies, the spin of the merged black hole probably points along the orbital angular momentum of the binary black hole and the jet flips into a new direction at a large angle. Thus the old and new pair of jets appear as an 'X' in the plane of sky. On the other hand, where the secondary passes through the polar regions of the primary, the primary's jet is bent into a Z-shaped symmetry. The distance where the bending of the jet happens will be dependent on the relative strength of the pressure of the jet and the ram pressure of the rotational gas motion in the wake of the secondary galaxy. By limiting this distance to a certain range, it was shown that the bent jets are of a power close to that corresponding to the transition between Fanaroff-Riley class I and II radio galaxies. [C. Zier].

Eridanus group of galaxies: Based on about 200 hours of observations carried out using the Giant Meterwave Radio Telescope, the Tully-Fisher (TF) or the luminosity - line width relations of the galaxies in the Eridanus group were constructed. The mean baryonic TF slope is 4.1 ± 0.7 and is consistent with the predictions of dark matter models. Most (~ 70 %) of the Eridanus galaxies follow the well-known radio-FIR correlation with their star formation rates below that of the Milky Way. Those galaxies having a significant excess of radio emission are identified as low luminosity AGNs based on their radio morphologies obtained from the GMRT observations. The Eridanus group also

has two far-infrared luminous but radio-deficient galaxies. It is believed that these galaxies are observed within a few Myr of the onset of an intense star formation episode after being quiescent for at least a 100 Myr. [K.S. Dwarakanath + A. Omar (ARIES, Nainital)].

Molecular and Neutral Hydrogen Observations of nearby galaxies: It is well known that some of the active galactic nuclei (Seyfert 2) harbour thick molecular disks around the nucleus which sometimes also have associated water megamasers. Based on the observations with the Nobeyama and Mopra telescopes, a water megamaser was discovered in NGC 6926 and the variability of the one in NGC 6240 was measured. [Balasubramanyam, R + N. Sato, A. Yamaguchi, N. Kuno (NRO, Japan), Y. Ishihara (Koriyama City Fureai Science Center, Japan), K. Sorai (Hokkaido University, Japan), N. Nakai (University of Tsukuba, Japan), P. Hall (ATNF, Australia)].

From a statistical study of HI content of loose groups with and without diffuse X-ray emission based on HIPASS data it is shown that galaxies in loose groups with hot intra-group medium have lost more HI gas compared to those in loose groups without diffuse hot gas. Either tidal assisted ram-pressure stripping or thermal evaporation could cause this excess gas loss. Twelve galaxies from various groups have been imaged with the GMRT looking for evidence for the cause of the excess loss. [C. Sengupta and B. Ramesh].

Survey of the Radio Sky with the Mauritius Radio Telescope (MRT): A cross comparison of the 450 MHz MRT Catalogue (≈ 3,000 sources) with the 408 MHz Molonglo Reference Catalog (MRC) has been carried out. Almost all the MRC sources which lie in the overlapping regions are visible with the MRT. About 1000 sources which are not listed in the MRC are seen in MRT images. The images are being examined to identify interesting sources such as steep spectrum sources, relic sources, fossil galaxies, new Supernova Remnant (SNR) candidates, etc., by comparing them with other catalogues and images available in the literature.

The images of the extended sources in the survey clearly reveal that the sensitivity for extended sources is good (Brightness sensitivity $\approx 3 \times 10^{-21}$ watts/m^2/Hz). Most of the SNRs in our Galaxy have surface brightness higher than this limit. About 0.5 Sr of the sky containing the Galactic plane has been imaged and most of the SNRs expected to have been identified in the image. Detailed analysis of their properties is in progress. [V.N. Pandey and N. Udaya Shankar].

Helical jet in the gravitationally lensed system PKS1830-211: The interpretation of high resolution 43 GHz VLBA observations of the gravitationally lensed system PKS1830-211 in the context of a precessing (helical) jet with ballistically emitted plasma features or 'plasmons', hosted by a blazar-type active galactic nucleus, has had some degree of success, with the evaluation of a jet precession period. It has proven possible to determine an image-to-image transformation matrix from moving features in the data, in a way that is independent of any lens model. Combining information on the scales of milliarcseconds and tens of microarcseconds, the precession period for the jet in the underlying source is determined to be 1.08 years as observed, translating to a period of 30.8 years in the frame of the source. It has also proven possible to relate the temporal behaviour of the image-to-image flux density ratio to the evolution of synchrotron self-absorbed plasmons in the jet, yielding independent and close support for the picture of ballistically emitted features being lensed.

The rapidity of the precession period is consistent with the picture of a jet emitted from the vicinity of a black hole in a binary black hole system, with the orbital motion of the jet-emitting black hole producing an apparent helical motion for features emitted along the jet. From the jet precession period, one can infer that for typical masses of the black holes of order 10^8 solar masses, the system will have a gravitational lifetime until it collapses of about a few times 10^8 years. With a binary elemental separation of the order of less than 10^{17} cm, it may pose some questions for the evolution of binary black hole systems within the lifetime of the Universe. [(S. Nair + C. Jin (Beijing Astronomical Observatory, China), M. A. Garret, (JIVE, The Netherlands)].

THE GALAXY AND THE INTERSTELLAR MEDIUM

Studies on sites of Massive Star Formation: The progressively increasing density in a collapsing molecular core leads to adsorption of molecules onto the dust grains and hydrogenation and nitrogenation reactions on their surfaces. Subsequent formation of a massive star, with its copious heating and ionising radiation output, is expected to drive interesting time dependent chemistry, especially of endothermic nature. The study of W3(OH) and W3(IRS 5) shows clear evidence for time dependent chemistry but intrinsic molecular differences, and differences in the drivers of chemistry also play a significant role. Chemical modeling yields a fairly accurate age estimate of 10^4 yr for the molecular core W3(IRS5) supporting the idea of 'chemical chronometry' based

on line surveys and chemical modeling. [B. Ramesh + S-J. Kim, D-W. Lee (Kyunghee University, Korea), H-D. Kim (University of Wollongong, Australia), Y.C. Minh (Taeduk Radio Astronomy Observatory, Korea), M.G. Burton (University of New South Wales, Australia), T.J. Millar (UMIST, UK)].

Formyl ion is a good tracer of dynamics in the dense molecular cores. From a survey of southern massive star forming sites associated with methanol masers in methyl cyanide (CH_3CN) and formyl ion (HCO^+) using the Mopra 22m millimeterwave telescope, it has been found that both methanol and methyl cyanide are excited at very early phases and that methyl cyanide is commonly detected towards methanol maser sites; methyl cyanide emission is found to be brighter towards isolated masers associated with MSX dark clouds, indicating that these sources are internally heated. (B. Ramesh + C. R. Purcell, M. G. Burton (University of New South Wales, Australia)].

An 8.5 GHz Arecibo survey of Carbon Recombination Lines toward Ultra-compact HII regions: Physical properties of dense molecular material: From the survey carried out in August 2002 for carbon recombination lines (RLs) near 8.5 GHz toward 17 ultra-compact HII regions (UCHIIs), carbon RLs were detected in 11 out of the 17 observed directions (65 % detection), indicating the presence of dense photodissociation regions (PDRs) associated with the UCHIIs. It has been shown that the carbon RLs provide important, complementary information on the kinematics and physical properties of the ambient medium near UCHIIs. Non-LTE models for the carbon line forming region have been developed, assuming that the PDRs surround the UCHIIs, and the model parameters have been constrained using multi-frequency RL data. Modeling shows that carbon RL emission near 8.5 GHz is dominated by stimulated emission and hence we preferentially observe the PDR material that is in front of the UCHII continuum. The relative motion between ionized gas and the associated PDR is found to be about half that estimated earlier with an RMS velocity difference of 3.3 kms^{-1}. The density and pressure of the PDR derived from this model are consistent with a pressure confined HII region model where the stars are moving relative to the cloud core. The PDR pressure is estimated to be an order of magnitude larger than the pressure of the ionized gas. Further investigation is needed to understand this large pressure difference. [D. Anish Roshi + D. S. Balser, W. M. Goss (NRAO, USA) T. M. Bania (Boston University, USA), C. G. De Pree (Agnes Scott College, USA)].

Radio Recombination Lines: Spectroscopy at extremely low frequencies with radio recombination lines (RRLs) provides an effective way to study the cold

interstellar medium. A series of RRLs using the UTR2 radio telescope in Ukraine, arising from bound carbon atoms undergoing δ transitions (among them from n=1005 to 1009) in the cool tenuous medium located in the Perseus arm has been detected against the background continuum emission from the supernova remnant Cassiopeia A. They are by far the largest bound atoms (classical diameter ~ 0.1mm) occurring in ionised plasma detected in space. Further, α (around n=631), β (around n=795), and γ (around n=910) transitions arising in the same clouds have also been detected. The dependence of RRL broadening on quantum number as predicted by pressure driven and radiative mechanisms is in good correspondence with the observations, when proper account is taken of the behaviour of the galactic background and Cassiopeia A radio emission at frequencies less than 30 MHz. The data imply an upper limit to quantum levels with principal quantum number in the range 1,100 - 1,200. [N. Udaya Shankar + S. Stepkin, A. A. Konovalenko (Institute of Radio Astronomy, Ukraine), N. G. Kantharia (NCRA, Pune)].

Hα observations of NGC2024: NGC2024 is an HII region located at one of the closest sites of recent massive star formation. The nebula, considered to be a blister HII region, is bright in radio continuum as well as in optical line emission. An attempt was made to make Hα image of NGC2024 using the 1-m telescope at ARIES, Nainital, with a view to constrain the temperature of the ionized gas by combining Hα observations with existing radio recombination line data. It was, however, not possible to obtain an Hα image of required quality. [D. Anish Roshi + A. Omar (ARIES, Nainital)].

NEUTRON STARS AND PULSARS

Low frequency studies of Pulsars & Radio Recombination Lines: As a part of the Indo-Ukraine collaboration for pulsar and recombination line studies at low radio frequencies, extensive coordinated observations were conducted using the Gauribidanur & UTR-2 (Ukrainian Telescope) telescopes. Data analysis procedures were developed for high spectral and time resolution spectrometer modes as well as for pulsar-specific processing. The first-level reduction of all of the data collected at Gauribidanur was completed recently. Further analysis of the data is in progress. [A. A. Deshpande, N. Udaya Shankar, H. Aswathappa, + O.Ulyanov, S. Stepkin, V. Zakharenko (IRA, Ukraine), N. Kantharia (NCRA, Pune)].

More recently a set of coordinated observations on a few nearby pulsars were conducted using the Gauribidanur, Ooty, UTR-2 and Pushchino telescopes,

spanning a frequency range from 25 to 327 MHz. The data analysis is in progress. [A. A. Deshpande, H. Aswathappa + P.K. Manoharan (RAC, Ooty) A. Asgekar (BITS, Goa), O. Ulyanov, V. Zakharenko, V. Malofeev (IRA, Ukraine)].

Altitudes of emission regions in radio pulsars: Earlier work that provided a new method for systematic understanding of radio pulsar emission altitudes, attributing the observed longitude offsets between core and conal components to the effects of differential aberration and magnetic field line sweepback, was further extended by including the effect of light travel time (retardation). [C. S. Shukre + R. C. Kapoor (Indian Institute of Astrophysics, Bangalore)].

Equation of state of matter at high density: From a study of ground states of quark matter with chiral symmetry breaking it was found that a three-flavour state with u and d forming a spin-polarized pion condensate is a possible state at high density. This state is spontaneously magnetized and can potentially form a magnetic core of a neutron star. From a detailed computation of stellar structure with such a core, it is found that at stellar masses above a certain limit a magnetized core may appear and may explain the observed characteristics of a special category of strongly magnetized neutron stars called Magnetars. [D. Bhattacharya + V. Soni (NPL, New Delhi)].

INSTRUMENTATION

A new analysis of optics has been carried out for high frequency telescopes that lends economy and overcomes the problem of gravitational flexure. The design and analysis of the mechanical structure of a telescope based on this optics is being carried out and preliminary panel design has been completed. (Ramesh B.).

Coded Mask Imaging: Refinement of the imaging algorithm for the SSM and CZT imagers aboard ASTROSAT has been taken up and development is continuing. Several new elements including iterative windowing for source recognition and least squares solution for source flux distribution have been now incorporated in the imaging process. A maximum likelihood method is under development. Recent design changes in the camera hardware have been taken into account in the revised imaging process. [D. Bhattacharya, B.T. Ravishankar, Sushila Mishra + G. Arun (TIFR, Mumbai)].

12m PPD: The fabrication of the 12m dish was completed and static tests have

been carried out for estimating surface accuracy. A contract for the fabrication of its mount has been awarded to a fabricator in Pune. The receiver system for the telescope is ready for use -- a 4 to 8 GHz front-end receiver and a back-end spectrometer have been completed. The design and preliminary testing of a control system and development of a user-friendly control panel with a number of safety interlocks have been completed. The control system consists of two control paths - one using a commercially available DSP based programmable multi-axes controller and the other using a PC under Linux based software. The site preparation at Gauribidanur has also been completed. The construction of an RCC tower for installing the mount and buildings required for installing the receiver have been completed. Due to unforeseen/unavoidable circumstances, the fabrication of the mount is behind schedule and the commissioning of the telescope at Gauribidanur is expected to be completed by September 2005.

As part of our effort in designing broadband feeds, studies related to frequency independent antennas have been taken up. In this connection, a planar trapezoidal structure with a decade structural bandwidth (0.5 to 5 GHz) has been designed and characterized. Satisfactory VSWR and field patterns have been obtained over the bandwidth range 0.7 to 2.2 GHz. Efforts are on to improve these characteristics and also to study its cross polarization performance. [N. Udaya Shankar, C.M. Ateequlla, Durai Chelvan, B.S. Girish, A. Krishnan, Manohar Modgekar, A. Raghunathan, P.V. Rishin, K.S. Srivani].

Satellite Astrometry: The high stability frequency transfer via INSAT 3A and a system for continuous ranging of the satellite have been completed. The passive system for precise orbit estimation based on a network of 4 VSATs in the GMRT campus is undergoing final integration and tests. The originally proposed scheme for burst mode data recording at the four modes has been modified to a new system which brings the RF from all the remote modes to the central station on optical fibres. The central receiver system provides for coherent down conversion to a convenient frequency band and centralized recording/data processing. [C. R. Subrahmanya, Peeyush Prasad, G. C. Rashmi, R. Somasekhar].

OTHERS

The concept of the nonmodular topological phase was clarified and elucidated. Its significance in a range of diverse physical situations was elaborated. [R. Bhandari].

COMPUTERS

To help improving internet connectivity, services like telnet, ssh, cvs, imap and ipop to remote machines was enabled from user's desktops in the RRI local network.

An antivirus software 'ClamAV' software was installed in the mail server for scanning mails on receipt for virus infections. Steps to handle and manage SPAM in a more effective manner were explored and incorporated.

An open source digital repository system 'Dspace' was deployed for archiving and delivery of documents, in digital form for the RRI library.

Routine maintenance and improvement of computer systems and local area network was undertaken. Up-gradation of the campus network was initiated.

LIBRARY

The Library continued its basic activities and maintaining liaison with other related institutes libraries for resource sharing and for information exchange; providing need based information services and access to a wide range of information resources both in print and electronic versions.

LIBRARY RESOURCES DEVELOPMENT

During the period, the following were added to the existing collection of the library:

Books	:	682 (including 90 on gratis, and 4 e-books)
Bound volumes of journals	:	566
Scientific and technical journals	:	162
Print and online Journals	:	66
Online through consortia and Non-Cancellation Option	:	36
Online only	:	5

Procured Physics Reports Vols.1–68; 1971–1980 on gratis from University of Rochester, New York, which were gaps in our holdings.

The collection at the end of period: books – 23,419; bound volumes of journals – 32,614 and the total collection of the library stood at: 56,033.

MODERNISATION

- LIBSYS library software was up graded to ver.4 (Rel.5) on latest version of LINUX;
- Liquid Crystals database version 4.5 was procured and installed.

STRENGTHENING LIBRARY FACILITIES

- Procured one digital photocopier and installed.
- Compact Storage Racks were installed in the basement floor.

CONSORTIA ACTIVITIES

- Under Open FORSA Consortium, the Library has entered into an online subscription to Lecture Notes in Physics (Springer) for the year 2005 with option to access back volumes (1996+);

- Subscribed to "Online Nature" for the year 2004-2005 under FORSA Consortium. The other participants are: IIA, PRL, IUCAA, ARIES, SNBNCBS, TIFR and JNCASR;

- After merger of Kluwer with Springer, FORSA Consortium re-entered subscription to Kluwer/Springer Physics and Astronomy Journals, wherein RRI could access to 12 additional titles and cancelled subscription to three journals which are subscribed by other participants in the consortium, thereby RRI could save Euro 5000.00. The other participants are: IIA, PRL, ARIES and SNBNCBS.

- The IoP's "Non-Cancellation Option" for 2005 was taken up and renewed subscription where the Library can access to 19 online physics journals.

DIGITAL LIBRARY INITIATIVES

Work on digitization of audio/video cassettes is continued; scanning work of Raman Archival material is completed.

OTHER ACTIVITIES

Ph. D.

Awarded

Amitesh Omar	A GMRT synthesis survey of radio continuum and atomic hydrogen in the Eridanus group of galaxies *Jawaharlal Nehru University, New Delhi*
Surajit Dhara	Physical studies on some liquid crystals *Jawaharlal Nehru University, New Delhi*
K. Rema	Structure of surfactant-polyelectrolyte complexes *Jawaharlal Nehru University, New Delhi.*
P. Viswanath	Studies on monolayers and multilayers of mesogenic amphiphilic molecules *Jawaharlal Nehru University, New Delhi*
Rekesh Mohan	Kinematics of diffuse interstellar clouds in the galaxy *Jawaharlal Nehru University, New Delhi*
H.N. Shreenivasa Murthy	Synthesis of compounds composed of bent-core molecules: Characterization of mesophases and some physical properties *Jawaharlal Nehru University, New Delhi*
V. Manjuladevi	Experimental studies on phase diagrams of liquid crystals *Jawaharlal Nehru University, New Delhi*
Sarasij Ray Chaudhuri	The organization of rafts and its relation to the endocytosis of the cell membrane *Jawaharlal Nehru University, New Delhi*

Joint Entrance Screening Test (JEST)

Several research institutions in India jointly conduct a screening test for candidates desiring to join the Ph.D. programmes in physics. This Joint Entrance Screening Test (JEST) for Ph.D. programmes was conducted by RRI during 2005. There were 12 participating institutions. The test was conducted nationwide at 28 centres. About 5700 candidates had applied and about 4700 took the test. [C.S. Shukre].

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, as also those submitted and in press, is given at Annexure I.

Summer Programme in Physics, May - July 2004

The Summer Programme has been an important annual event in the Institute over the last few years. This year seventeen students drawn from different parts of the country representing universities, IITs and Colleges were selected. Of the seventeen students, nine were selected through JNCASR, four through the Indian Academy of Sciences, one through the KVPY program and three through direct contact with the Institute. These seventeen students were at different levels in their educational background: M.Sc. - 10, B.Tech. - 2, and B.Sc. - 5.

Contrary to the previous years, there was no lecture series arranged this year. However, three special lectures were arranged, apart from visits to the Institute museum and the laboratories. The summer students worked with the respective supervisors for periods ranging from 6 to 8 weeks.

Conferences/Seminars and Meetings

The staff of the Institute visited various institutions in India and abroad and attended conferences and presented papers. In all 153 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 colloquia at the Institute on different topics during the year.

Journal Club Meetings

Forty 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 Group meetings in Theoretical Physics, Optics, Liquid Crystals and Radio Astronomy were held on a regular basis throughout the year.

In-House Meeting

An In-House Meeting, which is an annual feature at the Institute, was held on 19-20 March 2004 where the staff and students presented their research work. In all, 47 oral presentations spread over 8 sessions chaired by Faculty Members were made. There were also 26 poster presentations. The presentations were followed by lively scientific discussions with critical comments and suggestions relevant to the reported research from the members. This year a CD and a video tape of the poster presentations were also made and are kept in the Library, in addition to including the abstracts of the presentations at the meeting on the RRI Web Page.

Visiting Scientists

A number of scientists from institutions within the country and from outside visited the Institute during the year.

General

Following grants were received from the Department of Science and

Technology during the year:

PLAN (Recurring & Non-Recurring)	Rs.1,650.00 lakh
NON-PLAN (Recurring)	Rs. 270.00 lakh
Total	Rs.1,920.00 lakh

Annexure I

PAPERS PUBLISHED

In Journals

1. "Dynamics of membrane nanotubulation and DNA self-assembly" (**T. Roopa**, **N. Kumar**, S. Bhattacharya and **G. V. Shivashankar**), *Biophys. J*., **87**, 974 (2004).

2. "Flow-induced voltage and current generation in carbon nanotubes" (S. Ghosh, A.K. Sood, S. Ramaswamy and **N. Kumar**), *Phys. Rev*. B., **70**, 205423 (2004).

3. "Viscosity of suspensions and the glass: Turning power-law divergence into essential singularity" (**N. Kumar**), *Curr. Sci*. **88**, 143 (2005).

4. "A new class of post-Newtonian approximation to the dynamics of inspiralling compact binaries: Test-mass in the Schwarzchild spacetime" (**P. Ajith**, **B.R. Iyer**, C.A.K. Robinson and B.S. Sathyaprakash), *Phys. Rev. D*, **71**, 044029 (2005).

5. "Surface-integral expressions for the multipole moments of post-Newtonian sources and the boosted Schwarschild solution" (L. Blanchet, T. Damour and **B.R. Iyer**), *Class. Quant. Grav.,* **22**, 155 (2005).

6. "Hadamard regularization of the third post-Newtonian gravitational wave generation of two point masses" (L. Blanchet and **B.R. Iyer**), *Phys. Rev. D*, **71**, 024004 (2005).

7. "Gravitational radiation from inspiralling compact binaries completed at the third post-Newtonian order" (L. Blanchet, T. Damour, G. Esposito-Farese and **B.R. Iyer**), *Phys. Rev. Lett.*, **93**, 091101 (2004).

8. "Phasing gravitational waves from inspiralling eccentric binaries" (T. Damour, A. Gopakumar and **B.R. Iyer**), *Phys. Rev. D,* **70**, 064028 (2004).

9. "The 2.5PN gravitational wave polarizations from inspiralling compact binaries in circular orbits" (**K.G. Arun**, Luc Blanchet, **B.R. Iyer** and **M.S.S. Qusailah**), *Class. Quant. Grav.*, **21**, 3771 (2004).

10. "Measuring the general relativistic curvature of wavefronts" (**Joseph Samuel**), *Class. Quantum Grav*., **21**, L83 (2004).

11. "Inequivalence of statistical ensembles in single molecule measurements" (**Supurna Sinha** and **Joseph Samuel**), *Phys. Rev. E*, **71**, 021104 (2005).

12. "Rafts: Scale-dependent, active lipid organization at the cell surface" (Satyajit Mayor and **Madan Rao**), *Traffic*, **5**, 231 (2004).

13. "A mesoscopic model of a two-dimensional solid state structural transformation: Statics and dynamics" (**Madan Rao** and Surajit Sengupta), *J. Phys.: Condens. Matter*, **16**, 7733 (2004).
14. "Path integral quantization of parametrized field theory" (**Madhavan Varadarajan**), *Phys. Rev. D*, **70**, 084013 (2004).

15. "The graviton vacuum as a distributional state in kinematic loop quantum gravity" (**Madhavan Varadarajan**), *Class. Quant. Grav.*, **22**, 1207 (2005).

16. "Cyclic statistics in three dimensions" (**Sumati Surya**), J. Math. Phys., **45**, 2515 (2004).

17. "Nonreciprocity and the second law of thermodynamics: An exact relation for non-linear media" (O. Narayan and **A. Dhar**), *Europhys. Lett.*, **67**, 559 (2004).

18. "Return to return point memory" (J.M. Deutsch, **A. Dhar** and O. Narayan), *Phys. Rev. Lett.*, **92**, 227203 (2004).

19. "Work distribution functions in polymer stretching experiments" (**A. Dhar**), *Phys. Rev. E*, **71**, 036126 (2005).

20. "Spin glasses in the limit of an infinite number of spin components" (L. W. Lee, **A. Dhar** and A.P. Young), *Phys. Rev. E*, **71**, 036146 (2005).

21. "Lanczos' generalized derivative for higher orders" (S.K. Rangarajan and S.P. Purushothaman), *J.Comput. & Appl. Math.*, **177**, 461 (2005).

22. "Writhe distribution of stretched polymers" (**Supurna Sinha**), *Phys. Rev. E*, **70**, 011801 (2004).

23. "Quantum diffusion on a dynamically disordered and harmonically driven lattice with static bias: Decoherence" (**Navinder Singh** and **N. Kumar**), *Modern Phys. Lett. B*, **19**, 379 (2005).

24. "Imaging through turbid media using polarization modulation: Dependence on scattering anisotropy" (Sushil Mujumdar and **Hema Ramachandran**), *Opt. Comm.*, **241**, 9 (2004).

25. "Observation of a fifth order optical nonlinearity in 29 kDa Au@alkanethiol clusters excited in the visible" (**Jinto Thomas**, **M. Anija**, Jobin Cyriac, T. Pradeep, and **Reji**

Philip), *Chem. Phys. Lett.*, **403**, 308 (2005).

26. "$Au_xAg_y^{@}ZrO_2$ core-shell nanoparticles: Synthesis, characterization, reactivity and optical limiting" (A. Sreekumaran Nair, V. Suryanarayanan, T. Pradeep, **Jinto Thomas**, **M. Anija** and **Reji Philip**), *Materials Sc. and Engg. B*, **117**, 173 (2005).

27. Optical and nonlinear optical properties of ND^{3+} doped heavy metal borate glasses" (**B. Karthikeyan**, **Reji Philip** and S. Mohan), Optics Comm., **246**, 153 (2005).

28. "Multiparameter segmented scan multichannel scaling system" (S.V.K. Kumar, T.S. Ananthakrishnan, E. Krishnakumar, **V.S. Ashoka** and S.K. Kataria), *Rev. Sci. Instruments*, **75**, 2711 (2004).

29. "Dissociative attachment of electrons to vibronically excited SO_2" (S.V.K. Kumar, **V.S. Ashoka** and E. Krishnakumar), *Phys. Rev. A,* **70**, 052715 (2004).

30. "Fluorescence from doubly driven four-level atoms: A density matrix approach" (**A. Narayanan**, **R. Srinivasan**, **U.K. Khan**, **A. Vudayagiri** and **H. Ramachandran**), *European Phys. J. D*, **31**, 107 (2004).

31. "Observation of narrow fluorescence from doubly driven four-level atoms at room temperature" (**U.K. Khan**, J. Sebastian, **N. Kamaraju**, **A. Narayanan**, **R. Srinivasan** and **H. Ramachandran**), *Europhys. Lett.*, **67**, 35 (2004).

32. "Condensation of bound pairs of fermionic atoms" (**R. Srinivasan** and **Andal Narayanan**), *Curr. Sci*, **86**, 1356 (2004).

33. "Slow ammonia molecules in an electrostatic quadrupole guide" (T. Junglen, T. Rieger, **S.A. Rangwala**, P.W.H. Pinkse and G. Rempe), *Eur. Phys. D*, **31**, 365 (2004).

34. "Two-dimensional trapping of dipolar molecules in time-varying electric fields" (T. Junglen, T. Rieger, **S.A. Rangwala**, W.H. Pinkse and G. Rempe), *Phys. Rev. Lett.*, **92**, 223001 (2004).

35. "Generalized quantum secret sharing" (Sudhir Kumar Singh and **R. Srikanth**), *Phys. Rev. A*, **71**, 012328 (2005).

36. "Quantum seals" (Sudhir Kumar Singh and **R. Srikanth**), *Physica Scripta,* **71,** 433 (2005).

37. "Quantum bit commitment with a composite evidence" (**R. Srikanth**), *Physica Scripta*, **70**, 343 (2004).

38. "Relaxation of femtosecond photoexcited electrons in a metallic sample" (**Navinder Singh**), *Modern Phys. Lett. B*, **18**, 979 (2004).

39. "Hot electron relaxation in a metal nanoparticle: Electron surface-phonon interaction"

(**Navinder Singh**), *Modern Phys. Lett. B*, **18**, 1261 (2004).

40. "Relaxation between electrons and surface phonons of a homogeneously photoexcited metal film" (**Navinder Singh**), *Pramana*, **63**, 1083 (2004).

41. "Enhancement of orientational order parameter of nematic liquid crystals in thin cells" (**Surajit Dhara** and **N.V. Madhusudana**), *Euro. Phys. J. E.*, **13**, 401 (2004).

42. "Two-dimensionally periodic phases in mixtures of compounds made of rod-like and bent-core molecules" (**R. Pratibha**, **N.V. Madhusudana** and **B.K. Sadashiva**), *Phys. Rev. E*, **71**, 11701 (2005).

43. "Selective imaging of 3D director fields and study of defects in biaxial smectic A liquid crystals" (I.I. Smalyukh, **R. Pratibha**, **N.V. Madhusudana** and O.D. Lavrentovich), *Eur. Phys. J. E*, **16**, 179 (2005)

44. "Influence of director fluctuations on the electric field phase diagrams of nematic liquid crystals" (**Surajit Dhara** and **N.V. Madhusudana**), *Europhys. Lett.,* **67**, 411 (2004).

45. "A polar biaxial smectic A phase in new unsymmetrical compounds composed of bent-core molecules" (**H.N. Shreenivasa Murthy** and **B.K. Sadashiva**), *Liq. Cryst.,* **31**, 567 (2004).

46. "Synthesis and mesomorphic properties of unsymmetrical bent-core compounds containing 1,3-phenylene or 2,7-naphthylene as the central unit" (**H.N. Shreenivasa Murthy** and **B.K Sadashiva**), *Liq. Cryst.,* **31**, 1347 (2004).

47. "Influence of a fluorine substituent on the mesomorphic properties of unsymmetrical five-ring bent-core compounds" (**H.N. Shreenivasa Murthy** and **B.K Sadashiva**), *J. Mater. Chem.*, **14**, 2813 (2004).

48. "New phase sequences in banana-shaped mesogens: Influence of fluorine substituent in compounds derived from 2,7-dihydroxynaphthalene" (**R. Amaranatha Reddy** and **B.K. Sadashiva**), *J. Mat. Chem.*, **14**, 1936 (2004).

49. "Unusual mesomorphic behaviour in bent-core compounds derived from 5-cyanoresorcinol" (**R. Amaranatha Reddy** and **B.K. Sadashiva**), *Liq. Cryst.,* **31**, 1069 (2004).

50. "Fluorine substituted unsymmetrical bent-core mesogens derived from resorcinol" (**H.N. Shreenivasa Murthy** and **B.K Sadashiva**), *Liq. Cryst.,* **31**, 1337 (2004).

51. "Banana-shaped mesogens derived from 2,7-dihydroxynaphthalene and 1,3-dihydroxybenzene: Novel columnar mesophases" (**R. Amaranatha Reddy**, **B.K. Sadashiva** and **V.A. Raghunathan**), *Chemistry of Materials*, **16**, 4050 (2004).

52. "Optical investigations on the biaxial smectic-A phase of a bent-core compound" (S.T.

Wang, X.F. Han, A. Cady, Z. Q. Liu, A. Kamenev, L. Glazman, **B.K. Sadashiva**, **R. Amaranatha Reddy** and C.C. Huang), *Phys. Rev. E*, **70**, 061705 (2004).

53. "Novel ferroelectric and antiferroelectric smectic and columnar mesophases in fluorinated symmetrical bent-core compounds" (**R. Amaranatha Reddy**, **V.A. Raghunathan** and **B.K. Sadashiva**), *Chemistry of Materials*, **17**, 274 (2005).

54. "Banana-shaped mesogens: Mesomorphic properties of seven-ring esters derived from 5-chlororesorcinol" (**S. Umadevi** and **B.K. Sadashiva**), *Liq. Cryst.,* **32**, 287 (2005).
55. "AFM studies on Langmuir-Blodgett films of cholesterol" (**Raj Kumar Gupta** and **K.A. Suresh**), *Eur. Phys. J. E*, **14**, 35 (2004).

56. "Phase behaviour of dipalmitoyl phosphatidylcholine (DPPC)–cholesterol membranes" (**Sanat Karmakar**, **V.A. Raghunathan** and Satyajit Mayor), *J. Phys. Cond. Matter*, **17**, S117 (2005).

57. "Binary addressing technique with duty cycle control for LCDs" (**T.N. Ruckmongathan**, **M. Govind**, **S.V. Ashoka** and **G. Deepak**), *IEEE Transactions on Electron Devices*, **52**, 345 (2005).

58. "Design of a compact scanning tunneling microscope with a feedback to coarse approach controller for low scan ranges" (**M. Jayadeviah** and **V. Lakshminarayanan**), *Measurement Science and Technology*, **15**, N35 (2004).

59. "Fine grain growth of nickel electrodeposit: Effect of applied magnetic field during deposition" (**V. Ganesh**, **D. Vijayaraghavan** and **V. Lakshminarayanan**), *Applied Surface Science*, **240**, 286 (2005).

60. "Preparation of high surface area nickel electrodeposit using a liquid crystal template technique" (**V. Ganesh** and **V. Lakshminarayanan**), *Electrochim. Acta*, **49**, 3561 (2004).

61. "Influence of secondary ion bombardment on the composition, structure and surface properties of platinum thin films" (S. Balaji, P.V. Satyam, **V. Lakshminarayanan**, and S. Mohan), *Nuclear Inst. & Methods in Phys. Res.* B, **217**, 423 (2004).

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