RAMAN RESEARCH INSTITUTE
Bangalore

Annual Report 2003-2004

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 (radio-astronomy, 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
Physics in Biology
Optics, Quantum Mechanics
General Physics
Gravitation

CONDENSED MATTER AND STATISTICAL PHYSICS

Quantum statistics: The existence of anyons in two-dimensional systems is a well-known example of non-permutation group statistics. In higher dimensions, however, it is expected that statistics is dictated solely by representations of the permutation group. Using basic elements from representation theory it was shown that this expectation is false in three-dimensions for a certain non-gravitational system. Namely, the existence of "cyclic", or Z_n, non-permutation group statistics was demonstrated for a system of $n>2$ identical, unknotted rings embedded in three dimensions. Crucial use was made of a theorem due to Goldsmith in conjunction with the Fuchs Rabinovitch relations for the automorphisms of the free product group on n elements. [Sumati Surya].

Phase transition in the vector spin glass models: The *n*-component spin model with random interactions is one of the simplest models for studying the spin glass transition. In the limit of large number of components, the problem can be treated by the saddle point method and this basically reduces the problem to that of studying the properties of large random matrices. This problem is numerically studied to determine the nature of the glass transition and also see what this tells one about the finite-*n* system. [Abhishek Dhar + Likwee Lee and Peter Young (University of California, Santa Cruz)].

Return point memory in antiferromagnets: The phenomenon of return point memory is well known in the context of ferromagnetic systems which have hysteresis loops. When the magnetic field is changed from an initial value to a new value and then returned to the old value, the magnetization returns to exactly its initial value. In the present work systems with antiferromagnetic interactions were examined. It is shown that return point memory holds for one dimensional chains with either random exchange interactions or random fields. [Abhishek Dhar + Joshua Deutsch and Onuttom Narayan, (University of California, Santa Cruz)].

Caging dynamics in vibrated grains: Motivated by observations made during recent experimental work in vibrated grains the dynamics of caging in dense grain mixtures was investigated theoretically. Preliminary analysis based on generalized hydrodynamics in hard sphere mixtures predicts that a few large spheres get jammed more effectively in a fluid of small spheres, compared to, a few small spheres in a fluid of large spheres. [Supurna Sinha].

Non-equilibrium physics: In the last few years there have been important new results in non-equilibrium statistical physics. In particular, the so-called Jarzynski equality relates an ensemble average of the work done by a system (isolated or weakly coupled to a heat bath) which is out of equilibrium, to its end point equilibrium free energies. The quantum version of this inequality (and a related fluctuation theorem) is currently under investigation for a simple system of a particle in a box with moving walls. A longer term goal is to see if this can be used to understand non-equilibrium black hole thermodynamics. [Sumati Surya and Abhishek Dhar].

Driven diffusive Heisenberg systems: Extensive additions to research on a class of many-body systems whose dynamics and late time steady state behaviour arises as a complex interplay between driving, dissipation and inertia have been made. The driven dynamics of the classical Heisenberg magnet leads to novel critical behaviour and a unique low temperature phase which exhibits spatio-temporal chaos. Several lattice models whose continuum version is in the same universality class as the driven Heisenberg model have been proposed. [Madan Rao + Jayajit Das (University of California, Berkeley, USA) and Sriram Ramaswamy (IISc., Bangalore)].

Dynamics of solid-solid transformations: A mesoscopic description of a two dimensional (2d) model system which exhibits exactly two distinct equilibrium solid phases — square and triangular (rhombic unit cell) using an MD simulation on particles ('atoms') interacting with an *effective* potential has been developed. This is directly applicable to 2d transformations such as in In-Tl or $YBa_2Cu_3O_7$, solids in confined geometries and solid films on surfaces or solid wetting layers. This mesoscopic simulation has the added virtue that the motion of individual particles, may be followed, as the transformation proceeds. An important outcome of this work is that the selection of the final crostructure, *e.g.*, ferrite or martensite, is dictated by dynamics and not by

energetics alone. The theory successfully reproduces the essential characteristics of the time-temperature-transformation curves. [Madan Rao + Surajit Sengupta (S.N. Bose National Centre for Basic Sciences, Kolkata)].

PHYSICS IN BIOLOGY

Topology of self-avoidance in twist storing polymers: In recent years there has been a surge of research activity in the area of statistical mechanics of semiflexible polymers. This has been triggered by experiments in which single DNA molecules are stretched and twisted to probe their elastic properties. A proper analysis of the experimental results leads to issues related to self-avoidance of these polymers. This project is to construct a theoretical model which captures the essential topological aspects of self-avoidance of a twist storing polymer. In polymer physics the effects of self avoidance are very hard to incorporate because of the non-local nature of the interaction. For ordinary polymers, one can get reasonable agreement with experiment by simply ignoring the self interaction of the polymer. For twist storing polymers, this problem becomes more serious. The problem is that neglecting self avoidance effects changes the topology of the polymer configuration space and leads to a spurious periodicity in the twist elastic property of the polymer. This problem could be solved by replacing the difficult constraint of self avoidance by the easier and local constraint of south avoidance. This provides a mathematical justification for earlier work on the properties of twist storing polymers, and leads to a better understanding of the theoretical models describing the elegant experiments of Strick *et al*. [J. Samuel, Supurna Sinha and Abhijit Ghosh].

The writhe distribution of stretched polymers: Motivated by experiments in which single DNA molecules are stretched and twisted, a perturbative approach has been considered around very high forces, where the writhe distribution is determined in a simple, analytically tractable model. The results are in agreement with recent simulations and experiments. [Supurna Sinha].

Statistical mechanics of two-component artificial membranes: The equilibrium statistical mechanics of a two-component monolayer/bilayer membranes have been studied. The mean field theory shows a wide variety of modulated phases which are destabilised by thermal fluctuations. This field is seeing a revival following recent experiments on lateral compositional heterogeneity on the surface of living cells. [Madan Rao + P.B. Sunil Kumar (IIT-M, Chennai)].

Active fission-fusion of membranes: The phenomena of fission and fusion of membranes in the internal membrane components of the cell are 'active processes' requiring the hydrolysis of ATP and a complex protein machinery. The dynamics, shape instabilities and steady states of a *closed* membrane subject to *anisotropic* active fission and fusion events have been studied using analytical and simulational approaches. This work is currently being completed. An extension of these ideas to multi-component membranes have revealed that such active fission and fusion can give rise to *phase segregation leading to sorting into different morphological regions of the membrane* and *partitioning of membrane components in two distinct membranal compartments*. These issues are still under investigation. Recently an investigation of the non-equilibrium dynamics of membranes interacting with each other via trafficking of lipids and proteins was initiated. This leads naturally to a study of the dynamics of the trafficking network and to the related concept of interacting networks. [Madan Rao, Sarasij R.C., G. Kripa + S. Mayor (NCBS, Bangalore)].

Rheology of active-particle suspensions: The interplay between active polymerisation and processes involving active membrane deformation, as encountered in endocytosis, cell rheological response and cell motility is a topic of current interest. For instance, living cells respond actively to mechanical stresses and stress gradients with phenotypic implications in cell motility, endocytosis and snarling. The interest is in formulating a theoretical framework for analysing experiments probing the mechanical consequences of biological activity. These problems involve understanding the interplay between membrane hydrodynamics and the dynamics of active (polymerizing) elements such as actin-myosin suspensions. As a first step, the interplay of activity, order and flow in a suspension of active, energy dissipating particles has been studied. Predictions from this study for the rheology of such systems can be tested in experiments on bacterial suspensions, cell extracts with motors and filaments, or micro- or nano-machines in a fluid. The phenomena of cytoplasmic streaming in crawling amoebae, elastotaxis and active mechanosensing find natural explanations within this model. Extension of this work to study the effects of shear banding in the nonlinear rheology of active systems is being carried out. [Madan Rao, Y. Hatwalne, Sudipto Muhuri + Sriram Ramaswamy (IISc., Bangalore) and R.A. Simha (MPI-KS, Dresden, Germany)].

Statistical mechanics of random heteropolymers: The statistical mechanics of a random, semiflexible heteropolymer such as DNA, has been studied for possible sequence dependence of thermally averaged elastic quantities. Elastic quantities reveal a broad exponential distribution for short chains with a cross-over to a gaussian distribution for longer. This study has interesting implications to the binding-unbinding kinetics of

DNA-bound proteins such as RNA-polymerase, histones and bacterial proteins such as IHF (integration host factor). [Madan Rao and Sudipto Muhuri].

Chirality discrimination in symmetric auto-catalytic reactions: Enantiomeric selectivity can arise from dynamical equilibrium fluctuations in completely symmetric autocatalytic chemical reactions without specific antagonism. While a mean field description does not break chiral symmetry, incorporating stochasticity via a Gillespie algorithm leads to chirality discrimination and amplification. Introducing spatial heterogeneity and diffusive transport of the chemical reactants, a "phase-diagram" exhibiting global chirality discrimination has been established; this is a novel realisation of dynamical fluctuation induced growth of spatial order in chemical reactions. [Madan Rao and V.S. Gayathri].

Elucidation of the structure and functionality of membrane rafts in living cells: In recent years there has been a radical rethinking of the concept of the plasma membrane embodied by the classical fluid mosaic model, wherein a multi-component lipid bilayer provides a passive pool for the active membrane proteins embedded in it. This picture of the passive lipid component of the plasma membrane is being replaced by a more active involvement of lipids via the concept of *rafts*, defined as lateral heterogeneities on the cell surface, rich in cholesterol, sphingolipids and lipid-anchored proteins such as glycosyl-phosphatidylinositol-anchored proteins (GPI-APs). Recent experiments at NCBS has demonstrated that the GPI-APs are internalised via a distinct cholesterol and sphingolipid mediated pathway, in striking contrast with the conventional clathrin mediated endocytic pathway. In collaboration with this group, an intensive program to study the physico-chemical mechanisms of endocytic trafficking of these lipid anchored proteins in eukaryotic cells is being carried out. A study of the organisation of diverse GPI-AP species on the surface of living cells, has provided definitive evidence for nano-scale, lipid-dependent GPI-AP functional organization, using homo and hetero-FRET microscopy, combined with theoretical modeling. These findings redefine the concept of *rafts* in living cell membranes at both a structural and functional level by providing evidence for an active organisation of the raft components at a nanometer scale. This provides a new picture of the cell surface wherein active *a priori* organisation of certain lipids and proteins can be specifically perturbed to form larger scale *induced* structures with functional consequences in endocytosis and signaling. [Madan Rao, Sarasij R.C. + P. Sharma, V. Varma, S. Mayor (NCBS, Bangalore), Ira, G. Krishnamoorthy (TIFR, Mumbai)].
S. Mayor (NCBS, Bangalore), Ira, G. Krishnamoorthy (TIFR, Mumbai)].

OPTICS, QUANTUM MECHANICS AND GENERAL PHYSICS

Flow-induced voltage and current generation in carbon nanotubes: New experimental results, and a plausible theoretical understanding thereof, were for the flow-induced currents and voltages observed in single-walled carbon nanotube samples. In the experiments, the electrical response was found to be sublinear - nearly logarithmic - in the flow speed over a wide range, and its direction could be controlled by an electrochemical biasing of the nanotubes. These experimental findings are inconsistent with the conventional idea of a streaming potential as the efficient cause. A Langevin-equation based treatment of the nanotube charge carriers, assumed to be moving in the fluctuating field of ions in the flowing liquid was presented. The resulting "doppler-shifted" force-force correlation, as seen by the charge carriers drifting in the nanotube was shown to give a sublinear response, broadly in agreement with experiments. [S. Ghosh, A.K. Sood, S. Ramaswamy (IISc) And N. Kumar].

Vogel-Fulcher law of viscosity for glass farming liquids and soft-matter showing slow dynamics: Starting with an expression, due originally to Einstein, for the shear viscosity $\eta(\delta\phi)$ of a liquid having a small fraction $\delta\phi$ by volume of solid particulate matter suspended in it at random, an effective-medium viscosity $\eta(\phi)$ was derived for arbitrary ϕ which was precisely of the Vogel-Fulcher form was derived. An essential point of the derivation was the incorporation of the excluded-volume effect at each turn of the iteration $\phi_{n+1} = \phi_n + \delta\phi$. 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 ($1-\phi$), for ϕ increasing monotonically with supercooling. [N. Kumar].

Dynamics of membrane nanotubulation and DNA self-assembly: A localized point-like force applied perpendicular to a vesicular membrane layer, using an optical tweezer, leads to membrane nanotubulation beyond a threshold force. Below the threshold, the force-extension curve shows an elastic response with a fine structure (serrations). Above the threshold the tubulation process exhibits a new reversible flow phase for the multilamellar membrane, which responds viscoelastically. Furthermore, with an oscillatory force applied during tubulation, broad but well-resolved resonances occur in the flow phase, presumably matching the time scales associated with the vesicle-nanotubule coupled system. These nanotubules, anchored to the optical

tweezer also provide, for the first time, a direct probe of the real-time dynamics of DNA self-assembly on membranes. These studies are a step in the direction of analysing the dynamics of membrane self-assembly and artificial nanofluidic membrane networks. [T. Roopa, N. Kumar, S. Bhattacharya and G.V. Shivashankar].

Decohering quantum statistics: Suppression of BEC: It is argued that the environment induced decoherence between spatially separated parts of the wavefunction for an open quantum system also classicalizes the quantum statistics which is based on indistinguishability. This may imply a suppression of the BEC upon dilution with, e.g., isotopic fermions, in that the usual phase-space density criterion $n\Lambda^3 > 2.612$ is supplemented by the condition $n\Lambda^3 > \hbar\gamma / \sqrt{4\pi}\, k_B T$, γ being the friction coefficient subtended by the environment, *i.e.*, the fermions in this case. [N. Kumar].

GRAVITATION

Quantum cosmology: One of the popular approaches to quantum cosmology is Hawking's Euclidean path integral which describes the wave function of the Universe in terms of a gravitational path integral over Riemannian or positive definite metrics on a spacetime manifold. The Hartle-Hawking no boundary proposal is that there should be no initial geometry, i.e., the path integral should be evaluated for compact manifolds with only a single, connected boundary component which is totally geodesic. The wave function thus includes a sum over all such manifolds sharing the same totally geodesic boundary component. The resulting complexity of the expression for the Hartle-Hawking wavefunction typically makes it very hard to extract even qualitative information. Recently, however, there have been new mathematical results on 4-dimensional vacuum spaces obeying Einstein's equations. Modifications of these were used to show that the Hartle-Hawking wave function for negative cosmological constant develops sharp peaks on a class of spatial three geometries. These peaks are all centered on spatial 3 metrics of constant negative curvature, suggesting a new mechanism for obtaining local homogeneity in quantum cosmology. [Sumati Surya + Mike Anderson (SUNY, Stony Brook, USA), Steve Carlip (U.C. Davis, USA), J.G. Ratcliffe and S.T. Tschantz (Vanderbilt University, USA)].

Topology change in quantum gravity: In certain path integral approaches to quantum gravity, not only is the metric allowed to fluctuate, but so is the underlying spatial manifold topology. Such a change in spatial topology is often referred to as topology change. However, topology change has no simple description within the Hamiltonian framework thus leading to several interesting questions. In particular, a change of spatial topology in a causal, compact spacetime cannot occur when the metric is globally Lorentzian. One can, however, construct a causal metric from a Riemannian metric and a so-called Morse function on the background manifold, which is Lorentzian almost everywhere except that it is degenerate at each (isolated) critical point of the function. Such causal topology change may play a role in sum-over-histories formulations of quantum gravity. It is therefore of interest to understand the propagation of quantum fields on such backgrounds. The question of whether the existence of singularities in scalar field propagation is related to the underlying causal structure of the spacetime is currently under investigation. [Sumati Surya].

The graviton vacuum as a distributional state in kinematic loop quantum gravity: The quantum behaviour of weak gravitational fields admits an adequate, albeit approximate, description by graviton states in which the expectation values and fluctuations of the linearised gravitational field are small. Such states must approximate corresponding states in full quantum gravity. The nature of this approximation for the graviton vacuum state in the context of kinematical Loop Quantum Gravity (LQG) was analysed. 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. [Madhavan Varadarajan].

Path integral quantization of parametrised field theory: Free scalar field theory on a flat spacetime can be cast into a generally covariant form known as parametrised field theory in which the action is a functional of the scalar field as well as the embedding variables which describe arbitrary, in general curved, foliations of the flat spacetime. The path integral quantization of parametrised field theory was constructed in order to analyse issues at the interface of quantum field theory and general covariance in a path integral context. It was shown that the measure in the Lorentzian path integral was non-trivial and was the analog of the Fradkin-Vilkovisky measure for quantum gravity. Euclidean functional integrals were constructed in the generally covariant setting of parametrised field theory using key ideas of Schleich. The constructions were seen to imply the existence of non-standard 'Wick rotations' of the standard free scalar field 2 point function. The results were discussed in

the contexts of the path integral formulation of quantum gravity and the canonical quantization of parametrised field theory. [Madhavan Varadarajan].

The 2.5PN gravitational wave polarisations from inspiralling compact binaries in circular orbits: Using the multipolar post-Minkowskian and matching formalism the gravitational waveform of inspiralling compact binaries moving in quasi-circular orbits has been computed at the second and a half post-Newtonian (2.5PN) approximation to general relativity. The specific effect of non-linear memory was computed using a simplified model of binary evolution in the past. The "plus" and "cross" wave polarisations at the 2.5PN order are obtained in ready-to-use form, extending the 2PN results calculated earlier by Blanchet, Iyer, Will and Wiseman. The inputs include notably the mass-type quadrupole at the 2.5PN order, the mass octupole and current quadrupole at the 2PN order, the mass 2^5-pole and current 2^4-pole at 1PN. The non-linear hereditary terms come from the monopole-quadrupole multipole interactions or tails, present at the 1.5PN, 2PN and 2.5PN orders, and the quadrupole-quadrupole interaction arising at the 2.5PN level. [K. Arun, Bala R. Iyer, Moh'd S.S. Qusailah + Luc Blanchet (IAP, Paris)].

Phasing of gravitational waves from inspiralling eccentric binaries: Analytical high-accuracy templates for the gravitational wave signals emitted by compact binaries moving in inspiralling eccentric orbits were constructed. The case of *inspiralling eccentric* orbits involves *three different time scales*: orbital period, periastron precession and radiation-reaction time scales. By using an improved 'method of variation of constants', these three time scales are combined without making the usual approximation of treating the radiative time scale as an adiabatic process. The method was explicitly implemented at the 2.5PN post-Newtonian accuracy. The final results can be viewed as computing new 'post-adiabatic' short period contributions to the orbital phasing, or equivalently, new short-period contributions to the gravitational wave polarizations, that should be explicitly added to the standard 'post-Newtonian' expression for GW polarisations obtained by treating radiative effects on the orbital phasing in the usual adiabatic approximation. These results should be of importance both for the LIGO/VIRGO/GEO network of ground based interferometric gravitational wave detectors (especially if Kozai oscillations turn out to be significant in globular cluster triplets), and for the future space-based interferometer LISA. [Bala R. Iyer + T. Damour (IHES, France) and A. Gopakumar (Friedrich-Schiller-Universität Jena, Jena)].

O P T I C S

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

LASER COOLING AND TRAPPING OF ATOMS

Fluorescence from a collection of atoms at a temperature is expected to have a spectral width determined by the temperature; the width is typically 1GHz for rubidium atoms at room temperature and ~20MHz at 200microkelvin. However fluorescence widths as narrow as 30MHz were experimentally obtained from room temperature atoms when driven by two laser fields addressing two different electronic transitions. In addition, the fluorescence peaks were split, with the separation of the two parts increasing directly with the detuning of the driving lasers from their respective hyperfine transitions. These features were explained as the outcome of a velocity selection mechanism that becomes operative when the detunings of the two driving laser fields are exactly equal. This "double resonance" enables one to address exclusively, a particular velocity of atoms from a thermal ensemble. [Andal Narayanan, Hema Ramachandran, Jimmy Sebastian, N. Kamaraju, R. Srinivasan, Uday Kumar Khan].
In order to ascertain the origin of certain spectral features observed in doubly driven rubidium atoms, that were not due to velocity selective optical pumping, a theoretical investigation was carried out. Considering the Rb atoms as a four level system under the action of two driving fields, the density matrix was evaluated. The fluorescence spectrum of a Maxwellian distribution of atoms, as derived from this, explained all the experimentally observed features. These include classical effects like velocity selective displaced narrow emission, and quantum effects like Autler Townes splitting. [Andal Narayanan, Ashok Vudayagiri, Hema Ramachandran, R. Srinivasan, Uday Kumar Khan].

ULTRA FAST PROCESSES

Oxide protected silver and gold nanoparticles (prepared at IIT, Madras) were found to exhibit saturable absorption when excited with moderately energetic nanosecond pulses and strong optical limiting at higher intensities. This was explained in terms of the induced optical nonlinearities and nonlinear light scattering. [M. Anija, Jinto Thomas, Navinder Singh, A. Sreekumaran Nair, Renjis T.Tom, T.Pradeep, Reji Philip].

In order to study their suitability as active and passive photonic devices, glasses of composition 35MO-30Na_2O-(35-x) B_2O_3-xNd_2O_3 (MO=Bi_2O_3, PbO and x= 0, 1) were prepared through the melt quenching method. Fourier Transform Infrared (FTIR), optical absorption, photoluminescence and open aperture z-scan measurements have been performed. FTIR results show that the glasses have BO_3, BO_4 and nonbridging oxygens (NBO) as local structures, in addition to the [BiO_3] units. Using the Judd–Ofelt theory the theoretical oscillator strengths have been calculated. Radiative properties indicate that these glasses are potential laser materials. Z-scan measurements reveal the occurrence of nonlinear optical absorption, which is attributed to the presence of Bi^{3+} and Pb^{2+} ions in the glasses. [B. Karthikeyan, Reji Philip, S. Mohan].

The quantum size effects and associated optical nonlinearities in noble metal clusters make them promising candidates for photonic device fabrication. It has been found that the absorptive nonlinearity in them could be of the saturation or limiting type depending on the cluster size and applied laser fluence. Silver nanoclusters of different sizes, embedded in soda lime glass by the ion-exchange method, were irradiated with 100 femtosecond and 300 picosecond laser pulses. Induced thermal scattering is found to enhance optical limiting property in the picosecond excitation domain. Coefficients for nonlinear absorption, and the hot electron relaxation lifetime, have been determined from Z-scan and femtosecond pump-probe measurements respectively. It has been shown that pulsewidth is a major parameter that determines the mechanism of this switching from one type of the nonlinearity to the other. [B.Karthikeyan, Jinto Thomas, Reji Philip].

Under irradiation by ultrashort pulses, several processes take place in metal nanoparticles. The relaxation of hot electrons and surface phonons have been theoretically investigated. When the particle size is of the order of the electron mean free path, the main channel of hot electron energy loss is through surface-phonon generation, rather than bulk phonon generation. In the present calculations, the electrons and phonons are described by their equilibrium fermi and bose distribution functions. The expressions obtained for low temperature and high

temperature regimes are inversely proportional to the radius of the particle, indicting that the energy exchange is primarily a geometric effect. Another factor is the change in electron-surface-phonon screening due to spell-out of electron wave functions. [Navinder Singh].

LIGHT IN RANDOM MEDIA

It is known that fluorescence materials, when pumped with light in their long wavelength absorption tail, yield anti-Stokes emission, *i.e*., light of shorter wavelength. As more energy leaves the system than enters it, the medium cools. Such frequency up-conversion cooling has been seen in liquid dyes, notably rhodamine. This process has, in recent times, attracted considerable attention, as it makes feasible "optical refrigeration". It appeared that the cooling could be enhanced by the addition of microspheres to the dye solution. These randomly placed inhomogeneities would cause multiple scattering, enhancing path lengths of the photons in the medium, leading to better absorption of the pump, and greater amplification of spontaneous emission, resulting in a larger removal of heat. Preliminary experiments in rhodamine dyes with polystyrene microspheres indicate nearly an order of magnitude larger cooling in the presence of scatteres than without. [Divya Sharma, Hema Ramachandran].

QUANTUM COMMUNICATION

In an effort to solve the quantum measurement problem, a model was proposed in which the Hilbert space was assumed to be discrete, characterized by a parameter μ. Measurement entails an immense entanglement between the measured system, the measuring apparatus and the decohering environment. It was shown that, for sufficiently large entanglement and finite μ, there would be a statistically significant number of unresolvable amplitudes. So-called "collapse of the wave function" is viewed as an error-corrective response to this situation, transitioning the entangled system-apparatus-environment complex to a separable state. It was shown that cycles of unitary evolution and such transitions are sufficient to reproduce macroscopic classical behaviour. [R.Srikanth].

Entanglement-based attacks are usually believed to render insecure a quantum cryptographic protocol called "quantum bit commitment", which involves a party choosing a bit value and submitting public evidence thereof, which is supposed to peg a transmitter's choice without revealing it until he unveils it later. Some gaps in the argument that leads to this negative result have been pointed out. A particular protocol has been presented, and it has been proved that the protocol that allows for a composite (classical-quantum) evidence, is conducive for improved security. [R. Srikanth].

The problem of secure key distribution among trustful agents was investigated; it appears that multipartite quantum key distribution can be proven unconditionally secure by reducing the problem to the bipartite case and invoking the proof of security of the bipartite quantum key distribution. Some generalizations of quantum secret sharing were explored. Ways were sought in which some (classical or quantum) "secret" could be split into "shares", such that bringing together some shares according to certain restrictions would alone permit the reconstruction of the secret. A novel hybrid (classical quantum) generalization of this threshold scheme is being attempted. [R. Srikanth, in collaboration with S K Singh, IIT (Kanpur)].

LIQUID CRYSTALS (LC)

AREAS OF RESEARCH:

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

EXPERIMENTAL INVESTIGATIONS

Synthesis and characterization of new compounds exhibiting liquid crystalline phases: Research and scientific investigations were continued on the design, synthesis and characterization of new banana-shaped or bent-core compounds. A programme has also been initiated to synthesize new discotic liquid crystals.

One of the most interesting mesophases exhibited by compounds composed of banana-shaped molecules is the B_7 phase which exhibits beautiful and fascinating optical textures. Two new homologous series of five-ring Schiff's base esters exhibiting the non-switchable B_7 phase have been synthesized. These are derived from either 2-nitro- or 2-cyano-resorcinol. Very interestingly three higher homologues of the 2-nitro substituted compounds undergo a transition from the non-switchable B_7 mesophase to an antiferroelectric sub-phase (B_{7AF1}), which is the first example of such a transition. It was also shown in this study that the orientation of the azomethine linkage group has a strong influence on the mesomorphic behaviour of the two series of compounds. [H.N. Shreenivasa Murthy and B.K. Sadashiva].

Direct transition from a nematic phase to a polar biaxial smectic A phase: Twenty seven new compounds belonging to three homologous series and derived from 3-hydroxybenzoic acid were synthesized and examined for their mesomorphic behaviour. One of the terminal positions of the constituent molecules was substituted with a strongly polar cyano group with the other terminal position containing an n-alkyl chain attached to a biphenyl moiety. Twenty two of these compounds show the polar partial bilayer biaxial smectic A phase with antiferroelectric characteristics. In addition, a direct transition from the nematic phase to the polar partial bilayer biaxial smectic A phase which has not been seen before was observed. [R. Amaranatha Reddy and B.K. Sadashiva].

Polar biaxial smectic A phase in new unsymmetrical compounds: Several new compounds unsymmetrically substituted about two different central phenyl units were synthesized. All the compounds contain a strongly polar terminal cyano/nitro substituent. Some of the nitro-substituted compounds show a transition from the partial bilayer uniaxial smectic A (SmA_d) phase to a polar partial bilayer biaxial smectic A (SmA_dP_A) phase. The analogous cyano-substituted derivatives exhibit only a SmA_d phase. However, compounds containing a 4-cyanobiphenyl moiety in the terminal position and derived from 1,3-dihydroxybenzene show the SmA_d - SmA_dP_A transition. [H.N. Shreenivasa Murthy and B.K. Sadashiva].

Observation of filamentary growth patterns at the isotropic-SmCPA phase transition: Compounds composed of bent-core molecules unsymmetrically substituted about the central phenyl ring and containing terminal substituents such as fluoro, chloro and trifluoromethyl groups were examined for their mesomorphic properties. Many compounds containing a chloro substituent show filamentary growth pattern at the transition from isotropic to polar antiferroelectric smectic C phase which is very unusual and this is the first example of such a transition. The growth of such long cylindrical structures has been attributed to negative interfacial tension anisotropy. [H.N. Shreenivasa Murthy and B.K. Sadashiva].

Synthesis and characterization of compounds exhibiting twist grain boundary phases: Four compounds containing only one phenyl ring with a lateral fluoro substituent and cholesteryl moiety have been synthesized. The influence of the lateral fluoro substituent on the occurrence and stability of the twist grain boundary smectic A (TGB_A) phase has been examined. It is concluded that systems containing a single phenyl ring with fairly long terminal *n*-alkoxy chain and having cholesterol as the chiral moiety exhibit TGB_A phase when there is a lateral fluoro substituent *ortho* to the carboxylate group close to the chiral moiety. In addition, using the same cholesteryl moiety, the exotic and newly discovered undulating twist grain boundary smectic C*

($UTGB_{C*}$) phase obtained in some mixtures, were obtained in single component systems. [S. Shubashree and B.K. Sadashiva].

Studies on binary mixtures of compounds made of rod-like and bent-core molecules: Detailed experimental studies on binary mixtures of (i) 4-*n*-octyloxy-4-cyanobiphenyl (8OCB), which consists of rod-like molecules and (ii) 1,3-phenylene bis [4-(3-methylbenzoyloxy)] 4'-*n*-dodecylbiphenyl-4'-carboxylate (BC 12), composed of bent-core (BC) molecules have been carried out. Based on results from optical microscopy, polarized infrared spectroscopy and X-ray diffraction, two types of 2-dimensionally periodic structures in two different concentration ranges have been found. In the rod-rich range, the structure is dominated by the partial bilayer structure of the 8OCB molecules, and the BC molecules organize themselves to generate a periodic arrangement with antiparallel orientations of the arrow axes of neighbouring molecules both within the layers and across the layers. This is a new type of columnar phase found in such mixtures. In the BC-rich composition, the B_1 phase is formed, which is stabilized by the self-organization of the rods at the interfaces between the domains made of the bent-core molecules. [R. Pratibha, N.V. Madhusudana and B.K. Sadashiva].

Monolayers and 3D films of cholesteryl derivatives at the air-water interface: A systematic investigation of the two-dimensional (2D) and three-dimensional (3D) phases of cholesteryl derivatives at the air-water (A-W) interface has been carried out employing surface manometry, epifluorescence, and Brewster-angle and reflection microscopy techniques. It has been found that cholesteryl acetate forms a stable monolayer while the higher homologues yield 3D crystallites with very large area per molecule. However, cholesteryl benzoate, which contains a bulkier phenyl group instead of the flexible alkyl chain, forms a crystalline bilayer. [K.A. Suresh and P.Viswanath].

Stability of the Langmuir monolayer of octadecanethiol: It is known that octadecanethiol (ODT) forms self-assembled monolayer on noble metals and these have potential applications. The stability of the Langmuir monolayer of ODT molecules has been studied as a function of the purity of water. It was found that the monolayer is stable on ultra pure water of resistivity greater than 18mΩ-cm. The behaviour changes in the presence of small amounts of additives like NaOH in the sub-phase. Above a NaOH concentration of 10^{-3} M, the monolayer gets destabilized completely. [K.A. Suresh and Raj Kumar Gupta].

Photoinduced phase separation and miscibility in the condensed phase of a mixed Langmuir monolayer: The mixed Langmuir monolayer formed by mesogenic molecules *p*-(ethoxy) *p*-phenylazophenylhexanoate (EPPH) and 4-*n*-octyl-4-cyanobiphenyl (8CB) exhibits higher collapse pressures as compared to the individual monolayers. The photostability of the mixed monolayer under UV illumination, exhibits a large increase in the surface pressure from the initial value. In the visible region, the surface pressure decreases considerably. The *in-situ* Brewster angle microscopy studies for 0.5 MF of EPPH in 8CB show a phase separation in the UV and a miscible phase in the visible region, at low surface pressures. At higher surface pressures, under UV illumination, a phase separation was observed, which does not revert to a miscible phase under visible illumination. [K.A. Suresh and P.Viswanath].

Magnetic susceptibility studies on the micellar nematic phase of cesium perfluorooctanoate-water system: Magnetic susceptibility studies on the cesium perfluorooctanoate-water micellar system has been carried out. The variation of susceptibility with reference to temperature and concentration has been attributed to changes in the micellar shapes and sizes. The diamagnetic anisotropy in the nematic phase has also been evaluated. [D.Vijayaraghavan and K.A. Suresh].

Studies on self-assembled monolayers of aromatic thiols: A detailed study of the self-assembled monolayers (SAM) of aromatic thiols such as benzenedimethane thiol, naphthalene thiol and thiophenols has been carried out. The molecules of these compounds have the property of self-assembly on surfaces of gold and silver. The aromatic thiol SAMs have the property of molecular conductivity and hence are studied for their utility as molecular wire. The properties of these have been studied using STM, FTIR and electrochemical impedance spectroscopy. [V. Lakshminarayanan and V. Ganesh].

Characterization of high surface area nickel: Very high surface area of porous nickel nanoparticle deposits synthesized by liquid crystal template technique was determined by cyclic voltammetry. These nanoparticles were characterized by electrochemical impedance technique, scanning electron microscopy and scanning tunneling microscopy. It was found that the porous nickel deposit obtained thus is the best nickel catalyst ever reported in literature for hydrogen evolution reaction. [V. Lakshminarayanan and V. Ganesh].

Magnetic field studies of nickel electrodeposition process: The growth morphology of nickel electrodeposition has been examined under a high magnetic field of 1 Tesla. The magnetic hydrodynamic effect reduces the diffusion layer thickness and enhances the mass transfer effect. It has also been found that there is a significant shift in the electrode-solution interface potential at the imposition of the magnetic field, which arises due to a magnetic field induced shift in the chemical potential of the ferromagnetic nickel. [V. Lakshminarayanan, D. Vijayaraghavan and V. Ganesh].

Phase diagram of a mixed surfactant system: The phase diagram of mixtures of the cationic surfactant cetyltrimethylammonium bromide (CTAB) and sodium hydroxynaphthoate (SHN) has been determined using polarizing light microscopy and X-ray diffraction techniques. This system is found to exhibit a novel phase behaviour, with the presence of two lamellar phases, separated by an "intermediate phase." This non-lamellar phase is characterized by a three dimensional lattice, and probably results from the ordering of curvature defects in the bilayers. [V.A. Raghunathan, Rema Krishnaswamy + A.K. Sood, Department of Physics, Indian Institute of Science].

Shape changes of giant unilamellar vesicles: Shape changes of giant unilamellar vesicles made of phospholipid-cholesterol mixtures were studied using optical phase contrast, fluorescence and confocal microscopy techniques. Most of these observations are in broad agreement with the results of the X-ray diffraction experiments carried out earlier, on the same system. Thermal shape fluctuations of these vesicles, and in some cases, budding of small vesicles from larger ones have been observed. [V.A. Raghunathan and S. Karmakar].

Finite size effects in supported lipid bilayers: Thin stacks of lipid multibilayers supported on rigid silicon and mica substrates are found to exhibit finite size effects. Using neutron diffraction, the repeat spacing (d) of stacks containing up to a few tens of bilayers, is found to depend on their thickness (D), with d increasing with decreasing D. These results contradict the general belief that thinner stacks have a lower d, due to the suppression of thermal bilayer undulations by the interfaces of the film, which lowers the steric interbilayer repulsion. [V.A. Raghunathan + scientists at the National Research Council, Chalk River Laboratories, Canada].

Phase behaviour of mixtures of long- and short-chain lipids: Aqueous solutions of mixtures of long- and short-chain lipids exhibit interesting phase behaviour, due to the tendency of the two types of lipids to form different types of aggregates; bilayers in the case of long-chain lipids and micelles in the other case. A partial phase diagram of dimyristoyl phosphatidylcholine (DMPC) and dihexanoyl phosphatidylcholine (DHPC) mixtures has been determined using optical microscopy and small angle neutron scattering techniques. A chiral nematic phase made up of ribbon-like aggregates is found in this system, which accounts for many earlier unexplained observations. [V.A. Raghunathan + scientists at the National Research Council, Chalk River Laboratories, Canada].

Dynamic force-spectroscopy of membranes and chromatin using an optical tweezer: Organization of self-assembled bio-molecular structures are driven by weak interactions. A novel dynamic force spectroscopy method has been developed using a modulating optical tweezer to understand the effects of point-like forces and their long-range correlations on membranes and chromatin higher order structures. [T. Roopa and G.V. Shivashankar].

LIQUID CRYSTAL DISPLAYS (LCD)

Application of wavelets to display gray shades in liquid crystal displays: A controller for driving a 32 x 32 matrix liquid crystal display by selecting 3 rows at a time has been designed and implemented to demonstrate the use of wavelets to displaying gray shades. Eight gray shades can be displayed using row waveforms composed of five voltage levels and column waveforms with six voltage levels. A cycle of three frames is necessary to display eight gray shades. A data acquisition system which samples 62 parameters every second or minute and has a capacity to store 24 hour data and simultaneously display the data on an LCD (320 x 240 pixels) has been developed. (T.N. Ruckmongathan with project students from an engineering college, and A.R. Shashidhara).

Reduction of power consumption in liquid crystal displays: Liquid crystal displays consume very little

power to operate and hence they are popular in portable devices. With the popularity of mobile telephones, there is a need to reduce the power consumption further down. Attempts have been made to achieve this by proposing new waveforms by using multi-step, triangular and trapezoidal shapes for both static and line-by-line addressing. It is envisaged to reduce the power consumption by 80% using a multi-step process. [T.N. Ruckmongathan, M. Govind and G. Deepak].

A controller for multi-line addressing using sparse matrix: The use of sparse orthogonal matrix to select the subgroups of a matrix display ensures full utilization of the hardware in the column drivers and simplifies the design of the controller. A controller has been designed using an 8 x 8 sparse, symmetric orthogonal matrix with a zero in each column and row. The column waveforms have eight voltage levels and they utilize all the hardware in the column drivers efficiently. [T.N. Ruckmongathan, with project students from an engineering college, and A.R. Shashidhara].

THEORETICAL INVESTIGATIONS

Rheology of active-particle suspensions: The interplay of activity, order, and flow through a set of coarse-grained equations governing the hydrodynamic velocity, concentration, and stress fields in a suspension of active, energy-dissipating particles have been studied. Several predictions for the rheology of such systems, which can be tested on bacterial suspensions, cell extracts with motors and filaments, or artificial machines in a fluid have been made. The phenomena of cytoplasmic streaming, elastotaxis, and active mechanosensing find natural explanations within this model. [Yashodhan Hatwalne + scientists at the Department of Physics, Indian Institute of Science, Bangalore, and National Centre for Biological Sciences, Bangalore].

Chiral symmetry breaking in polymer lamellae: Melt grown spherulites of achiral polymers such as polyethylene exhibit *chiral*, twisted lamellar structures. These helicoidal lamellar ribbons are typically about $10nm$ thick, $100nm$ wide, and have a remarkably uniform pitch of the order of $1\mu m$. Solution grown crystals of *achiral* 1,3-diynes which undergo polymerization also have helicoidal, lamellar morphologies with pitch as large as $2mm$, and an equal number of right- and left-handed helicoids. A mechanism for this chiral symmetry breaking, which has been a long standing problem in the field of polymer crystallization has been worked out. A remarkable effect of selection of a finite radius and pitch for the helicoidal ribbons *in equilibrium* has also been demonstrated. [Yashodhan Hatwalne + M. Muthukumar, University of Massachusetts, Amherst, USA].

Phenomenological Landau theory for phase transitions observed in compounds composed of bent-core molecules: As the chain length in a homologous series of bent-core (BC) molecules is decreased, the following sequence of phases is observed in a large number of cases. (i) the B_2 phase which is lamellar in which the BC molecules pack to give rise to an electric polarization in each layer; the polarization direction can be switched by an external field; (ii) a 2-dimensionally periodic B_1 phase which is non-switchable, and (iii) again a lamellar B_6 phase, but with intercalated molecules such that there is no layer polarization and the medium is non-switchable. A phenomenological Landau theory of this sequence has been developed by recognizing that the B_1 phase arises because of a frustration in the packing of the BC molecules between those occurring in the B_2 and B_6 phases. [N.V. Madhusudana and A. Roy].

ASTRONOMY AND ASTROPHYSICS (A & A)

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

EXTRAGALACTIC ASTRONOMY

Primordial magnetic fields and the structure of the universe: The implication of primordial magnetic fields in the post-recombination epoch was examined and it was shown that such fields would lead to formation of structures in the universe early enough to reionize it around a redshift of 15. In addition, slow dissipation of magnetic field from ambipolar diffusion and decaying turbulence can lead to changes in ionization and thermal

history of the universe which can potentially be detected by future probes of cosmic microwave background radiation. [S.K.Sethi + K.Subramanian (IUCAA,Pune)].

If the formation of structures in the Universe was a purely gravitational process, primordial magnetic fields would have detectable signals in the redshift space. Based on an analysis of the power spectrum (in redshift space) of matter in the presence of primordial magnetic fields, it was shown that the presently observed structure is not consistent with primordial magnetic fields. [S. K. Sethi and Rajesh Gopal].

The possibility of detectable neutral hydrogen (HI) signal from pre-reionization epoch was examined in detail. HI can be seen in both absorption and emission in the frequency range 20 to 80 MHz with a typical average signal around 0.1 Kelvin. Detection of this signal will be useful in determining uniquely the thermal history of the universe and the epoch of reionization [S. K. Sethi].

Entropy of the intracluster medium at high redshift: Recent observations of galaxy clusters show that there is an 'entropy problem' for the intracluster medium at high redshift. The evolution of the entropy-temperature relation with redshift does not fit with the simple expectations of a model in which the cluster gas is preheated before its infall, to a level that is independent of redshift. The implications of these observations and the role of active galactic nuclei as sources of heating are being studied. [Biman B. Nath].
A semi-analytic calculation of the energy deposited by buoyant bubbles of relativistic plasma emerging from active galaxies was carried out. Usually the black holes inside active galaxies feed themselves for about a hundred million years until they take a pause. This 'duty cycle' mainly depends on the supply of material that it finds in its vicinity. During this feeding time, the balloon of energetic particles is continuously blown to a large size. After the feeding stops, this cavity then slowly detaches from the galaxy, and rises to the outer parts of the cluster as a result of buoyancy. These bubbles expand as they rise and deposit energy in the ambient gas. The semi-analytic calculations were also checked using fully hydrodynamical code at the Joint Institute of Laboratory Astrophysics, University of Colorado. [(S. Roychowdhury and Biman B. Nath + M. Begelman (Univ. of Colorado, USA)].

Gamma Ray Bursts: The afterglow GRB030329 was observed at multiple optical bands from the State Observatory, Naini Tal and Himalayan Chandra Telescope, Hanle, for more than a month. The afterglow was also observed at radio wavelengths with the GMRT, leading to the first GRB afterglow detection by the GMRT. The follow-up is still continuing at frequencies of 1280 and 610 MHz. Modelling of the afterglow emission indicates that about 1.5 days after the burst a fresh supply of energy refreshed the afterglow shock wave and launched a wider, more energetic jet from an initially narrowly confined one [D. Bhattacharya and L. Resmi + Observatory teams at Naini Tal, Hanle and GMRT].

Gas content of the Eridanus group of galaxies: Detection of gas deficiency in a loose group is an important input in understanding the gas content and evolution of galaxies in different environments. The gas content of the galaxies in the nearby Eridanus loose group of galaxies was estimated from an analysis of about 200 hours of GMRT observations. It is found that the galaxies in this group are deficient in their HI content up to a factor of 2 compared to their field counterparts. Such a gas deficiency is somewhat unexpected in a loose group like Eridanus, since the gas removal mechanisms like ram-pressure stripping and evaporation that are expected to work in rich clusters are unlikely to be effective in a loose group. The HI morphologies of the Eridanus galaxies are consistent with the view that tidal interactions are the most likely cause of gas deficiency in the Eridanus group. [A. Omar and K. S. Dwarakanath].

HI observation of nearby galaxies: From the HI images of three nearby edge-on thin-disk galaxies obtained with GMRT, an attempt was made to discern the oblateness of the dark matter halo around these galaxies. The observations show that the HI disks are about 1.8 times larger in comparison to the optical disks, but the accuracy of measured scale heights was not enough to discern the structure of the dark matter halo. A comparison of the HI images with optical and near infrared images is in progress. [B. Ramesh and C. Sengupta].

MRT Survey: Full resolution images of the southern sky have been completed for the region 18^h - 24^h in right ascension and -70^o to -10^o in declination. A catalogue of about 3000 sources has been compiled from the deconvolved images. [N. Udaya Shankar and V. N. Pandey + N. Oozeer (UOM, Mauritius)].

THE GALAXY AND THE INTERSTELLAR MEDIUM

Origin of the wide HI absorption line toward Sgr A*: A region of about 5 arcmin extent surrounding Sgr A* was imaged in the 21 cm-line absorption using the Very Large Array. A Gaussian decomposition of the optical depth spectra at positions within ~2 arcmin (~5 pc at 8.5 kpc) of Sgr A* shows a wide line underlying the many narrow absorption lines. The wide line has a mean peak optical depth of $0.32 \neq 0.12$ centered at a mean velocity of $-4 \neq 15$ km s^{-1} with respect to local standard of rest. The mean full width at half maximum is $119 \neq 42$ km s^{-1}. Such a wide line is absent in the spectra at positions beyond ~2 arcmin from Sgr A*. The position-velocity diagrams in optical depth reveal that the wide line originates in various components of the circumnuclear disk (radius ~1.3 arcmin) surrounding Sgr A*. These components contribute to the optical depth of the wide line in different velocity ranges. In particular it was inferred that the wide line has no implications either to a global population of shocked HI clouds in the Galaxy or to the energetics of the interstellar medium as was earlier thought. [K. S. Dwarakanath + W. M. Goss (NRAO), J. H. Zhao (CfA), C. C. Lang (Univ. of Iowa)].

G35.20-1.74 : A stellar wind driven UCHII region in W48: To resolve the lifetime problem of ultra-compact HII regions (UCHII regions), it has been suggested that these regions are pressure confined by dense molecular material in their vicinity. If such dense material is present, then photo-dissociation region formed within them will produce observable radio recombination lines of carbon. Multi-frequency observations of these carbon lines can be used to investigate whether UCHII regions are pressure confined. With this point of view, observations were carried out for G35.20-1.74, (UCHII region in W48) using the Very Large Array (VLA) near the frequencies of 4.8, 8.3 and 14.7 GHz. Analysis of the central velocities of the carbon and helium lines as well as the molecular lines indicates that G35.20-1.74 is pressure confined. The gas pressures in the photo-dissociation region and in the UCHII region are found to be dominated by turbulence. It was also shown that the dominant contribution to the total pressure in the UCHII region could arise from a stellar wind bubble. But the estimated mass loss rate is an order of magnitude larger than that expected from the star embedded in G35.20-1.74. [D. Anish Roshi + W.M. Goss (NRAO)].

Maser lines at 53 MHz: A search for the 53 MHz OH maser line was made towards $l = 48^{o}.4$ and $b = -1^{o}.4$ using the National MST Radar Facility. The portable pulsar receiver was used for this purpose by incorporating necessary software modifications. The line could not be detected to a sensitivity limit of 39 Jy. [D. Anish Roshi + Srikumar M. Menon, Manipal Institute of Technology, Manipal, & T. Rajandra Prasad, NMRF, Gadanki)].

Millimeter wave observations: The 1.2 mm continuum data obtained from Swedish-ESO submillimeter telescope towards a large number of southern high mass protostellar candidates are being combined with far infrared data from space telescopes to construct their spectral energy distributions. It is planned to model these data to obtain the dust cocoon masses and their relation to the masses of the central objects as well as Initial Mass Function. [B. Ramesh + T. K.Sridharan, J.Zhang, T.Bourke and H.Beuther(Center for Astrophysics, USA)]

NEUTRON STARS AND PULSARS

Effects of light travel time (retardation effects) were neglected in an earlier explanation of the observed longitude offsets between the core and the conal components of pulsars. Consequence of including retardation effects in this context is being investigated. [C. S. Shukre + R. C. Kapoor (IIA)].

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 unless the mass of the strange quark is less than 150 MeV a two-flavour pion condensed state would have a lower energy than a three-flavour state with up, down and strange quarks. This implies that strange quark matter and strange stars are unlikely to exist in nature. [(D. Bhattacharya + V. Soni, (NPL, New Delhi)].

OTHERS

Topological Phases: A review of earlier work on topological phases revealed that a neutron interferometer experiment with unpolarized neutrons reported in the literature can be interpreted as a partial observation of a phase singularity in mixed state interference. It was suggested that a small modification of this experiment could reveal the full singularity structure in pure as well as mixed state interference. It was also inferred that phase singularities of the type observed in earlier experiments at RRI as time-sequential phase shift

measurements can be realised in real space by means of a suitable "SU(2) screen", i.e., a screen with spatially varying birefringence followed by a polarizer placed in front of a plane wavefront. The resulting field in front of the polarizer could then have a lattice of phase singularities strongly reminiscent of flux lattices in type II superconductors. [R. Bhandari].

Gravitational perturbations of a geostationary satellite's orbit: The short-term (over several minutes) effects of the gravitational perturbations on the orbit of a near geo-stationary satellite were estimated taking into account the Earth's flattening, as well as the luni-solar tides. All these perturbations are of the similar order, about ten parts in a million when compared to the dominant Keplerian force exerted by the Earth. A Hamiltonian formulation was used, employing action-angle variables appropriate to the perturbed Kepler problem. Treating the eccentricity and inclination as small parameters, canonical perturbation theory was used to solve for the perturbations. [S. Sridhar].

INSTRUMENTATION AND SIGNAL PROCESSING

12-m Radio Telescope: A 4-8 GHz front-end receiver has been designed which includes a feed with an octave bandwidth and a HEMT based low noise amplifier. A low frequency wide band ridge horn has also been designed to operate in the frequency band 600 MHz to 1600 MHz. A cryogenic system using pulse-cooled cryo-coolers is being developed in collaboration with IISc. [A. Raghunathan & others at RAL].

A digital back-end receiver for the 12m radio telescope, capable of providing at least 1024 channels across a 200 MHz band and a high-speed data acquisition system is being developed. [T. Prabu, B. S. Girish & other at RAL].

Fabrication of the 12m dish is complete and the details of the mount have been finalized. Contract has been awarded for fabrication of the mount and erection of the dish at Gauribidanur. This antenna is expected to be commissioned by March 2004 with the first set of (uncooled) receivers. [N. Udaya Shankar & others in MES/RAL].

Spincasting Polymeric Parabolic Mirrors: Work was continued on developing a technique suitable for spincasting high quality mirrors for submillimetre wave telescopes. A 20 cm diameter polymeric parabolic mirror was cast and attempt was made to get a smooth finish in the cured polymeric surface first and later to retain this smoothness while vacuum depositing the aluminium layer. It was found that slow curing in an air-tight environment followed by a thin acrylic final layer was essential for making a smooth and lasting polymeric mirror [B. Ramesh and V. Lakshminarayanan].

Coded Mask Imaging: The CZT hard X-ray imager on board ASTROSAT employs a complex collimator design between the mask plate and the detector. The field of view at lower energies (10-30 keV) is restricted to a fraction of that at higher energies (30-150 keV) in order to limit the exposure to the sky background. A coded mask pattern has been designed to have optimal imaging quality at both high and low energies, even though the latter employs different subsets of the larger pattern meant for high energies. [D. Bhattacharya, Sushila Mishra and G. Arun (TIFR)].

Digital Backend for Ooty Radio Telescope: A modern, general purpose backend has been designed for the Ooty Radio Telescope (ORT) in collaboration with the Radio Astronomy Centre. In this system, the IF signals reaching the receiver room from each of the 22 modules of ORT will be directly digitized and the entire processing (currently being done in analog systems) will be replaced by a reconfigurable system based on high density field programmable gate arrays (FPGA) and a DSP-based controller. The system can be reconfigured in a variety of ways including those necessary to support the ongoing observational programmes. It is expected that the digitally formed beams will have a higher sensitivity compared to the existing system both due to the broader bandwidth and the possibility of complex correlators between north and south modules. In addition, it will be possible to carry out a variety of new types of spectral line observations including the incoherent addition of power spectra of signals reaching individual modules for a very sensitive search for deuterium lines.

At present, new analog systems to tap the outputs from individual modules (without disturbing the existing system) including amplifiers and filters have been built by the Ooty engineers and tested. A choice of two filters has been provided for each module - one with a 12 MHz bandwidth and the other with a narrow band filter with 800 kHz bandwidth. The digital systems have been designed at RRI and most of the PCBs required

for the system have been fabricated and being tested in Bangalore. [C.R. Subrahmanya, R. Somashekar T. Prabu + P.K. Manoharan, A. J. Selvanayagam (RAC, Ooty)].

Satellite Astrometry: The high stability frequency transfer system via INSAT has been enhanced to include a provision for a precise measurement of range (distance) of the satellite and its time derivative. A simple realization has been achieved for a ranging signal capable of very high accuracy by preserving phases and allowing for coherent demodulation. By synchronising the ranging signal to a time reference derived from a GPS receiver, a provision has been made to set up any number of passive ranging systems based on a single uplink unit at INSAT Master Control Facility (Hassan).

Preliminary results for continuous range measurement indicated a scatter of ~2-3m rms for each range measurement in a second. However, a substantial reduction in the scatter in measurements is possible by incorporating additional phase information present in the data, for which software development is in progress. Downlink units with passive receivers and signal processing systems for ranging are being established at RRI, Bangalore, and at GMRT Campus, Khodad. [Subrahmanya C. R., Somashekar R., T. Ananthprakash, Aparna R. Adapawar, Madhavi S. Bichile, Peeyush Prasad, G. C. Rashmi, A. L. Sheshadri, M. Soumya].

COMPUTERS

Augmentation of the storage space for the common home area of users was implemented. Fault tolerance in the form of mirrored disks has been incorporated. Backup of this increased storage has been made possible by implementing a multi tape auto loader. Automatic and scheduled backups are now possible with the deployment of an open source backup software 'Bacula' after necessary fine tuning.

As part of a routine maintenance and upgrade, system software and operating system were upgraded to improve overall functioning. Campus LAN was extended to include access to additional locations in the campus. Redesign and improvements to the RRI web pages as also pages on the local web server were made.

User authentication by the proxy servers has been enabled to improve local network security. Improvements were made to the printing setup and the desired security was built-in by means of user name authentication. Software to provide information on print usage and statistics has also been implemented.

LIBRARY

The library continued with its basic activities of information resources development by collecting, processing, organizing, storage and retrieval of information; maintaining liaison with other related institutes libraries for resource sharing and for exchange of information; providing need based current awareness, reference and bibliographic services; and facilitating on-line access to wide range of information resources in print and electronic versions.

LIBRARY RESOURCES DEVELOPMENT

During the period, the following information resources were procured/added.

Books	527 (60 of them on *gratis*)
Bound volumes of journals	656
Journals	168
Print + On-line	80 (14 by air mail)
On-line through consortia/ Non-cancellation offer	41
On-line only	5

The collection at the end of the period stood at: BOOKS – 22737; BOUND VOLUMES OF JOURNALS – 32242; totalling to 54979.

MODERNIZATION

The LIBSYS added with new features is being used. Additional computer access was added to facilitate remote access to library database.

CONSORTIA

On-line FORSA (Forum for Resource Sharing in Astronomy and Astrophysics) Consortium subscription of 46 Kluwer/IOP journals and Nature continued.

DIGITAL LIBRARY INITIATIVES

Conversion of audio/video cassettes available in the library into digital form for current use and archival purpose initiated. Digitization of Ph. D. theses of RRI with Vidyanidhi – Digital Library and E – Scholarship Portal – a Project of the University of Mysore was also initiated.

OTHER ACTIVITIES

- FORSA Directory: 2004- earlier edition was updated incorporating new members and distributed; Bangalore Special Libraries Group Directory: 2004 was compiled.
- Compilation work of Memoirs of RRI for 1999 – 2001 was completed.
- Web of Science database was received on trial basis during July 2003 and February 2004, and the same was thrown open for usage/exploitation to help evaluate the system.
- A library application software users meeting was hosted by the Institute on 25 June 2003. About 35 users from different organizations participated.

OTHER ACTIVITIES

Ph. D.Awarded

Name	***Topic of Study***
A. S. Govind	Theoretical studies on phase transitions in liquid crystals *Bangalore University, Bangalore.*
Niruj R. Mohan	Radio recombination line study of ionized gas in nearby starburst galaxies *Indian Institute of Science, Bangalore.*
R. Amaranatha Reddy	Synthesis and characterization of mesophases formed by compounds composed of banana-shaped molecules. *Jawaharlal Nehru University, New Delhi.*
Ujjal Kumar Sur	Studies on the effect of some solvents on the structure integrity and interfacial properties of organic thiol monolayers *Jawaharlal Nehru University, New Delhi.*
K.G. Pani Kumar	A study on some multi-line addressing techniques for driving passive matrix LCDs. *Jawaharlal Nehru University, New Delhi.*
Submitted	
Rekesh Mohan	Kinematics of diffuse interstellar clouds in the galaxy *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.*
Surajit Dhara	Physical studies on some liquid crystals *Jawaharlal Nehru University, New Delhi.*

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 (Page 47).

Summer Programme in Physics, 12 May - 20 June 2003

Exposing bright students to the Institute and its research environment is beneficial both ways. Thus, the Summer Programme has been an important annual event in the Institute over the years. This year too twenty two students drawn from different parts of the country representing universities, IITs and Colleges were selected out of the one hundred and sixty six who had applied. Nine M.Sc., three B.Tech., and five B.Sc. students, a total of seventeen finally participated. There were twenty four lectures covering several topics in current physics: Soft condensed matter physics, Matter and radiation, General relativity and gravity waves, Lensing by gravity, Dynamical astronomy, Astronomical spectral lines and masers, and Hydrogen in space. A few special lectures on unusual topics such as 'Extremal principles', 'Some structures and their beautiful properties' and 'On the nature of stars', were also included. The students worked on one of the nine projects offered by the faculty. Educational films were also screened as part of the programme. Presentation by students of their project work was held in the last week. Visits were also arranged to Labs and to the Radio Astronomy Centre, Ooty.

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 (Annexure II, page 57).

Journal Club Meetings

Twenty nine meetings were held during the year. Preprints as well as recently published papers dealing with topics of great current interest were reviewed in the meetings (Annexure III, page 63).

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. Their names are listed separately (page 42).

General

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

PLAN (Recurring & Non-Recurring)	Rs. 770.00 lakh
NON PLAN (Recurring)	Rs. 330.00 lakh
Total	Rs.1,100.00 lakh

PAPERS PUBLISHED

In Journals

1. "Stripes and superconductivity in cuprates – Is there a connection?" (**N. Kumar** and C.N.R. Rao), *Chemphyschem*, **4**, 439 (2003).

2. Response to "Carbon nanotubes provide a charge" (S. Ghosh, A.K. Sood and **N.Kumar**), *Science*, **300**, 1235 (2003).

3. "Quantum transport using the Ford-Kac-Mazur formalism" (**Abhishek Dhar** and B.S. Shastry), *Phys. Rev. B,* 67, 195405 (2003).

4. "Isospectrality in chaotic billiards" (**Abhishek Dhar**, D.M. Rao, **N.Udaya Shankar**, and **S. Sridhar**), *Phys. Rev. E,* 68, 026208 (2003).

5. "Ensemble dependence in the random transverse-field Ising chain" (**Abhishek Dhar** and A.P. Young), *Phys. Rev. B,* 68, 134441 (2003).

6. "Reexamination of experimental tests of the fluctuation theorem" (O. Narayan and **Abhishek Dhar**), *J. Phys. A*: *Math. Gen.*, 37, 63 (2004).

7. "Nucleation of solids in solids – ferrites and martensites" (**Madan Rao** and S. Sengupta), *Phys. Rev. Lett.,* **91**, 045502 (2003).

8. "Rheology of active-particle suspensions" (**Y. Hatwalne**, S. Ramaswamy, **Madan Rao** and R.A. Simha), *Phys. Rev. Lett.,* **92**, 118101 (2004).

9. "Nanoscale organization of multiple GPI-anchored proteins in living cell membranes" (P. Sharma, R. Varma, **R.C. Sarasij**, Ira, K. Gousset, G. Krishnamoorthy, **Madan Rao** and S. Mayor), *Cell*, **116**, 577 (2004).

10. "Peaks in the Hartle-Hawking wave function from sums over topologies (M. Anderson, S. Carlip, J.G. Ratcliffe, **Sumati Surya** and T. Tschantz), *Classical and Quantum Gravity*, **21**, 729 (2004).

11. "Onset of shear waves in a bacterial bath: A novel effect" (**Supurna Sinha**), *Fluctuation and Noise Letters*, **3**, L373 (2003).

12. "Nonlinear light transmission through oxide-protected Au and Ag nano particles: An investigation in the nanosecond domain" (**M. Anija, Jinto Thomas, Navinder Singh**, Sreekumaran Nair, Renjis T. Tom, T. Pradeep and **Reji Philip**), *Chem. Phys. Lett.*, **380**, 223 (2003).
13. "Freely dispersible Au@TiO_2, Au@ZrO_2 , Ag@TiO_2, and Ag@ZrO_2 core-shell nano-particles: One-step synthesis, characterization, spectroscopy, and optical limiting properties" (Renjis T. Tom, A. Sreekumaran Nair, **Navinder Singh**, M. Aslam, C.L. Nagendra, **Reji Philip**, K. Vijayamohanan and T. Pradeep), *Langmuir*,**19**, 3439 (2003).

14. "Optical power limiting with photo-induced anisotropy of azobenzene films" (Pengfei Wu, Reji Philip, **Ramesh B**. Laghumavarapu, J. Devulapalli, D.V.G.L.N. Rao, B.R. Kimball, M. Nakashima and B.S. DeCristofano), *Applied Optics*, **42**, 4560 (2003).

15. "Modified pinhole spatial filter producing a clean flat-topped beam" (P. Hariharan and **Andal Narayanan**), *Optics & Laser Tech.*, **36**, 151 (2004).

16. "A computational model for quantum measurement" (**R. Srikanth**), *Quantum Information Processing*, **2**, 153 (2003).

17. "Relationship between horizontal flow velocity and cell lifetime for supergranulation from SOHO Dopplergrams" (U. Paniveni, V. Krishnan, J. Singh and **R. Srikanth**), *Mon. Not R. Astron. Soc.*, **347**, 1279 (2004).

18. "Free-standing films of twist grain boundary TGB_A and $UTGB_{C*}$ liquid crystals studied by fluorescence confocal polarizing microscopy" (I.I. Smalyukh, **R. Pratibha**, O.D. Lavrentovich and **N.V. Madhusudana**), *Liquid Cryst.*, **30**, 877 (2003).

19. "High pressure studies on a nematogen with highly polar molecules: Evidence for a nematic-nematic transition" (**V. Manjuladevi** and **N.V. Madhusudana**), *Curr. Sci.*, **85**, 1056 (2003).

20. "Influence of fluorine substituent on the mesomorphic properties of five-ring ester banana-shaped molecules" (**R. Amaranatha Reddy** and **B.K. Sadashiva**), *Liquid Cryst*., **30**, 1031 (2003).

21. "Banana-shaped mesogens: A new homologous series of compounds exhibiting the B_7 mesophase" (**H.N. Shreenivasa Murthy** and **B.K. Sadashiva**), *Liquid Cryst*., **30**, 1051 (2003)

22. "Twist grain boundary smectic A phase in compounds derived from cholesterol" (**S. Shubashree** and **B.K. Sadashiva**), *Current Science*, **85**, 1061, (2003).

23. "Observation of a transition from non-switchable B_7 mesophase to an antiferroelectric sub-phase in strongly polar bent-core compounds" (**H.N. Shreenivasa Murthy** and **B.K. Sadashiva**), *J. Mater. Chem.,* **13,** 2863 (2003).

24. "Direct transition from a nematic phase to a polar biaxial smectic A phase in a homologous series of unsymmetrically substituted bent-core compounds" (**R. Amaranatha Reddy** and **B.K. Sadashiva**), *J. Mater. Chem.,* **14**, 310 (2004).
25. "Synthesis and mesomorphic properties of compounds exhibiting the undulated twist grain boundary smectic C* phase" (**S. Shubashree** and **B.K. Sadashiva**), *Liquid Cryst.,* **31,** 81 (2004).

26. "Observation of filamentary growth patterns at the isotropic-$SmCP_A$ phase transition in new unsymmetrical compounds composed of bent-core molecules" (**H.N. Shreenivasa Murthy** and **B.K. Sadashiva**), *Liquid Cryst.,* **31,** 361 (2004).

27. "Polar head group interactions in mixed Langmuir monolayers" (**P. Viswanath** and **K.A. Suresh**), *Phys. Rev. E.*, **67**, 061604 (2003).

28. "Reentrant phase transitions of DNA-surfactant complexes" (**Rema Krishnaswamy**, **V.A. Raghunathan** and **A.K. Sood**), *Phys. Rev. E*, **69**, 31905 (2004).

29. "A cholesterol-induced modulated phase in phospholipid membranes" (**Sanat Karmakar** and **V.A. Raghunathan**), *Phys. Rev. Lett.*, **91**, 098102 (2003).

30. "Relationship between the unbinding and main transition temperatures of phospholipid bilayers under pressure" (T.A. Harroun, M.-P. Nieh, M.J. Watson, **V.A. Raghunathan**, P. Pabst, M.R. Morrow and J.Katsaras), *Phys. Rev. E*, **69**, 031906 (2004).

31. "Highly aligned lamellar lipid domains induced by macroscopic confinement" (M.P.-Nieh, **V.A. Raghunathan**, H. Wang and J. Katsaras), *Langmuir***, 19**, 6936 (2003).

32. "Discontinuous unbinding of lipid multibilayers" (B. Pozo-Navas, **V.A. Raghunathan**, J. Katsaras, M. Rappolt, K. Lohner and G. Pabst), *Phys. Rev. Lett.*, **91**, 028101 (2003).

33. "Concentration-independent spontaneously forming biomimetric vesicles" (M.-P. Nieh, T.A. Harroun, **V.A. Raghunathan**, C.J. Glinka and J. Katsaras), *Phys. Rev. Lett.*, **91**, 158105 (2003).

34. "Structure of the ripple phase of phospholipid multibilayers" (**Kheya Sengupta, V.A. Raghunathan** and J. Katsaras), *Phys. Rev.*, **68**, 031710 (2003).

35. “Cyclic voltammetric and electrochemical impedance studies on the structure, adsorption kinetics, and barrier properties of some organic dithiols self-assembled monolayers on gold” (**Ujjal Kumar Sur, R. Subramanian** and **V. Lakshminarayanan**), *J. Colloid & Interface Sc.*,**266**, 175 (2003).

36. “A study of the hydrophobic properties of alkanethiol self-assembled monolayers prepared in different solvents” (**Ujjal Kumar Sur** and **V. Lakshminarayanan**), *Electroanalyt. Chem.*, **565**, 343 (2004).

37. “Tuning the structure of surfactant complexes with DNA and other polyelectrolytes” (**R. Krishnaswamy,** P. Mitra, **V.A. Raghunathan** and **A.K. Sood**), *Europhys. Lett.*, **62**, 357 (2003).

38. “Single particle tracking of correlated bacterial dynamics” (**Y.V. Hatwalne** and **G.V. Shivashankar**), *Biophys. J.*, **84**, 2634 (2003).

39. “Effect of surface roughness on interfacial reaction-diffusion admittance” (Rama Kant and **S.K. Rangarajan**), *J. Electroanalytical Chem.*, **552**, 141 (2003).

40. “A flattening in the optical light curve of SN2002ap” (S.B. Pandey, G.C. Anupama, R. Sagar, **D. Bhattacharya**, D.K. Sahu and J.C. Pandey), *Mon. Not. R. Astron. Soc.*, **340**, 375 (2003).

41. “Changes in the measured image separation of the gravitational lens system PKS 1830-211” (C. Jin, M.A. Garrett, **S. Nair**, R.W. Porcas, A.R. Patnaik and R. Nan), *Mon. Not. R. Astron. Soc.*, **340**, 1309 (2003).

42. “Optical observations of the bright long duration peculiar GRB 021004 afterglow” (S.B. Pandey, D.K. Sahu, L. Resmi, R. Sagar, G.C. Anupama, **D. Bhattacharya**, V.Mohan, T.P. Prabhu, B.C. Bhatt, J.C. Pandey, Padmaker Parihar and A.J. Castro-Tirado), *Mon. Not. R. Astron. Soc.*, **31**, 1309 (2003).

43. “The optical afterglow of the not so dark GRB 021211” (S.B. Pandey, G.C. Anupama, R. Sagar, **D. Bhattacharya**, A.J. Castro-Tirado, D.K. Sahu, P. Parihar and T.P. Prabhu), *Astron. Astrophys*., **408**, L21 (2003).

44. “Early optical and millimeter observations of GRB 030226 afterglow” (S.B. Pandey, R.Sagar, G.C. Anupama, **D. Bhattacharya**, D.K. Sahu, A.J. Castro-Tirado and M. Bremer), *Astron. Astrophys.*, **417**, 919 (2004).

45. “The topology and polarization of sub-beams associated with the ‘drifting’ subpulse emission of pulsar B0943+10-III. Analysis of Pushchino 103/40-MHz observations” (J.M. Rankin, S.A. Suleymanova and **A.A. Deshpande**), *Mon. Not. R. Astron. Soc.*, **340**, 1076 (2003).

46. “The radio luminosity distribution of pulsars in 47 Tucanae” (D. McConnell, **A.A. Deshpande**, T. Connors and J.G. Ables), *Mon. Not. R. Astron. Soc.*, **348** 1409 (2003).

47. “Renewed activity in the radio galaxy PKS B1545-321: Twin edge-brightened beams within diffuse radio lobes” (Lakshmi Saripalli, Ravi Subrahmanyan and **N. Udaya Shankar**), *Astrophys. J.*, **590**, 181 (2003).

48. “A VLBA search for a stimulated recombination line from the accretion region in NGC 1275” (R.C. Walker and **K.R. Anantharamaiah**), *Astron. J.*, **125**, 1756 (2003).

49. “Nanolensing of gamma-ray bursts” (**Mark A. Walker** and Geraint F. Lewis), *Astrophys. J.*, **589**, 844 (2003).

50. “Implications of the universal temperature profile for galaxy clusters” (**S. Roychowdhury and B.B**. **Nath**), *Mon. Not. R. Astron. Soc.*, **346**, 199 (2003).

51. “GMRT detection of HI 21 cm associated absorption towards the z=1.2 red quasar 3C 190” (C.H. Ishwara-Chandra, **K.S. Dwarakanath** and **K.R. Anantharamaiah**), *J. Astrophys. Astron.*, **24**, 37 (2003).

52. "High resolution, high sensitivity imaging of the galactic center at 330 MHz" (M.E. Nord, C.L. Brogan, S.D. Hyman, T.J.W. Lazio, N.E. Kassim,T.N. LaRosa, **K. Anantha-ramaiah** and N. Duric), *Astron. Nachr./AN,* **324**, 9 (2003).

53. "Spatially resolved very large array 74 MHz observations toward the galactic center" (C.L. Brogan, M. Nord, N. Kassim, J. Lazio and **K.R. Anantharamaiah**), *Astron. Nachr./AN*, **324**, 17 (2003).

54. "Large scale magnetic fields: Density power spectrum in redshift space" (**Rajesh Gopal** and **Shiv K. Sethi**), *J. Astrophys. Astr.*, **24**, 51 (2003).

55. "Large-scale magnetic fields: Galaxy two-point correlation function" (**Shiv K. Sethi**), *Mon. Not. R. Astron. Soc.*, **342**, 962 (2003).

56. "Recovery of transverse velocities of steadily rotating patterns in flat galaxies" (**S. Sridhar** and N. Sambhus), *Mon. Not. R. Astron. Soc.*, **345**, 539 (2003).

57. "The radio nebula surrounding the Vela pulsar" (R. Dodson, D. Lewis, D. McConnell and **A.A. Deshpande**), *Mon. Not. R. Astron. Soc.*, **343**, 116 (2003).

58. "Suppression of thermal conduction in non-cooling flow clusters" (**Biman B. Nath**), *Mon. Not. R. Astron. Soc.*, **340**, L1 (2003).

<u>In Conference Proceedings</u>

1. "Fluorescence studies of a double-driven four-level system in an optical molasses: Experiment" **(Uday Kumar Khan, J. Sebastian, N. Kamaraju, Andal Narayanan, R. Srinivasan** and **Hema Ramachandran**), *Proceedings of the Golden Jubilee DAE-BRNS National Laser Symposium, IIT, Kharagpur*, December 2*003*, Eds. A.K. Nath and K.S. Bartwal (Allied Publishers, 2003), p. 505.

2. "Enhancement of the cooling by frequency upconversion through multiple scattering" (**Divya Sharma** and **Hema Ramachandran**), *Proceedings of the Golden Jubilee DAE-BRNS National Laser Symposium, IIT, Kharagpur*, December 2*003*, Eds. A.K. Nath and K.S. Bartwal (Allied Publishers, 2003), p. 601.

3. "Fluorescence from doubly-driven four level atoms – a density matrix approach" (**Andal Narayanan**, **R. Srinivasan**, **Ashok Vudayagiri**, **Uday Kumar Khan** and **Hema Ramachandran**), *Proceedings of the Golden Jubilee DAE-BRNS National Laser Symposium, IIT, Kharagpur*, December 2*003*, Eds. A.K. Nath and K.S. Bartwal (Allied Publishers, 2003), p. 503.

4. "Nonlinear light transmission through oxide-protected Au and Ag nanoparticles in the nanosecond domain" (**M. Anija**, **Jinto Thomas**, **Navinder Singh**, Sreekumaran Nair, Renjis T. Tom, T. Pradeep and **Reji Philip**), *Proceedings of the Golden Jubilee DAE-BRNS National Laser Symposium, IIT, Kharagpur*, December 2003, Eds. A.K. Nath and K.S. Bartwal (Allied Publishers, 2003), p. 475.

5. "Relaxation of femtosecond photoexcited electrons in a metallic sample" (**Navinder Singh**), *Proceedings of the Golden Jubilee DAE-BRNS National Laser Symposium, IIT, Kharagpur*, December 2003, Eds. A.K. Nath and K.S. Bartwal (Allied Publishers, 2003), p. 431.

6. "On non-local singularity" (**R. Srikanth**), *Proceedings of the Golden Jubilee DAE-BRNS National Laser Symposium, IIT, Kharagpur, December 2003*, Eds. A.K. Nath and K.S. Bartwal (Allied Publishers, 2003), p. 473.

7. "On some liquid crystalline phases exhibited by compounds made of bent-core molecules and their mixtures with rod-like molecules" (**R. Pratibha, N.V. Madhusudana** and **B.K. Sadashiva**)*, Proceedings of the Conference on Liquid Crystals and Other Soft Materials, Bangalore, December 2002 – Pramana*, **61**, 405 (2003).

8. "The cone phase of liquid crystals: Triangular lattice of double-tilt cylinders" (**Yashodhan Hatwalne** and **N.V. Madhusudana**), *Proceedings of the Conference on Liquid Crystals and Other Soft Materials, Bangalore, December 2002*, Pramana, **61**, 277 (2003).

9. "Columnar phases exhibited by some polycatenar ligands and a few related metal complexes" (**B.K. Sadashiva** and **V.A. Raghunathan**), Proceedings *of the Conference on Liquid Crystals and Other Soft Materials*, Bangalore, December 2002, *Pramana*, **61**, 219 (2003).

10. "Viscoelastic modes in chiral liquid crystals" (**K.A. Suresh**), *Proceedings of the Conference on Liquid Crystals and Other Soft Materials, Bangalore*, December 2002, *Pramana*, **61**, 297 (2003).

11. "Structures of some surfactant-polyelectrolyte complexes" (**Rema Krishnaswamy, V.A. Raghunathan** and **A.K. Sood**), *Proceedings of the Conference on Liquid Crystals and Other Soft Materials,* Bangalore, December 2002, *Pramana*, **61**, 447 (2003).

12. "Displaying gray shades in liquid crystal displays" (**T.N. Ruckmongathan**), *Proceedings of the Conference on Liquid Crystals and Other Soft Materials,* Bangalore, December 2002, *Pramana*, **61**, 313 (2003).

13. "Hydrophobicity-induced drying transition in alkanethiol self-assembled monolayer water interface" (**V. Lakshminarayanan** and **Ujjal Kumar Sur**), *Proceedings of the Conference on Liquid Crystals and Other Soft Materials,* Bangalore, December 2002, *Pramana*, **61**, 361 (2003).
14. "Molecular engineering of discotic nematic liquid crystals" (**Sandeep Kumar**), Proceedings of the Conference on Liquid Crystals and Other Soft Materials, Bangalore, December 2002, Pramana, **61**, 199 (2003)

15. "Nonachromaticity and reversals of topological phase as a function of wavelength" (**R. Bhandari**), in *Coherence and Quantum Optics VIII*, eds. N.P. Bigelow, J.H.Eberly, C.R. Stroud Jr. and I.A. Walmsley (Kluwer, 2003), p. 405.

16. "The realm of the supermassive black holes" (**G. Srinivasan**), Proceedings of the 22nd meeting of the Astronomical Society of India, *Bull. Astr. Soc. India*, **31**, 121 (2003).

17. "SN2002ap, the hypernova of class Ic" (S.B. Pandey, D.K. Sahu, G.C. Anupama, **D. Bhattacharya** and R. Sagar), Proceedings of the 22nd meeting of the Astronomical Society of India, *Bull. Astr. Soc. India*, **31**, 351 (2003).

18. "Energy and radiation spectrum of electrons in ultrarelativistic shocks of GRB afterglows" (L.Resmi and **D. Bhattacharya**), Proceedings of the 22nd meeting of the Astronomical Society of India, *Bull. Astr. Soc. India*, **31**, 353 (2003).

19. "A dynamic sky simulation for the scanning sky monitor on ASTROSAT" (S. Mishra and **D. Bhattacharya**), Proceedings of the 22nd meeting of the Astronomical Society of India, *Bull. Astr. Soc. India*, **31**, 487 (2003).

20. "Image reconstruction for a continuously rotating coded mask camera" (B.T. Ravi Shankar and **D. Bhattacharya**), Proceedings of the 22nd meeting of the Astronomical Society of India, *Bull. Astr. Soc. India*, **31**, 491 (2003).

21. "Division XI: Space and high energy astrophysics" (**G. Srinivasan**), in *Transactions of the International Astronomical Union*, **25A**, 363 (2003).

22. "Sub-millimeterwave efforts in India" (**B. Ramesh**), Proceedings of the 22nd meeting of the Astronomical Society of India, *Bull. Astron. Soc. India*, **31**, 231 (2003).

23. "GMRT neutral hydrogen observations of the Sombrero galaxy" (**Chandreyee Sengupta**, **Ramesh Balasubramanyam** and Kenji Bekki), Proceedings of the 22nd meeting of the Astronomical Society of India, *Bull. Astr. Soc. India*, **31**, 419 (2003).

Books

1. "Invitation to Contemporary Physics", Second Edition (Quang Ho-Kim, **N. Kumar** and C.S. Lam), (World Scientific, 2004).

2. "Quantum Transport in Mesoscopic Systems: Complexity and Statistical Fluctuations" (Pier A. Mello and **Narendra Kumar**), (Oxford University Press, 2004).

Invited Review Articles

1. "Liquid crystal displays" (**T.N. Ruckmongathan** and **N.V. Madhusudana**), in *Handbook of Luminescence, Display Materials and Devices*, Vol. 3, Eds. H.S. Nalwa and L.S. Rohwer (American Scientific Publishers, 2003), pp.211-259.

2. "Liquid crystals of compounds composed of banana-shaped molecules: Influence of a fluorine substituent" (**R. Amaranatha Reddy** and **B.K. Sadashiva**), Invited article in Materials Research: Current Scenario and Future Projections, Eds. R. Chidambaram & S. Banerjee, P 157, Allied publishers, New Delhi, 2003.

Popular articles

1. "New results in microwave background anisotropy from WMAP" (**Biman B. Nath**), *Resonance*, April 2003.

2. "Dirac's large numbers hypothesis" (**Biman B. Nath**), *Resonance*, August 2003.

3. "Biopolymer elasticity" (**Supurna Sinha**), *Science*, December 2003.

4. "Ramaseshan and the Raman legacy" (**G. Srinivasan**), *Curr. Sci*., **86**, 224 (2004).

5. "Nobel Prize for Physics – 2003: Matter close to absolute zero" (**R. Srinivasan** and **Andal Narayanan**), Resonance, February 2004.

6. "S. Ramaseshan, the teacher" (R. Nityananda, T.G. Ramesh and **G.S. Ranganath**), *Curr. Sci.*, **85**, 1082 (2003).