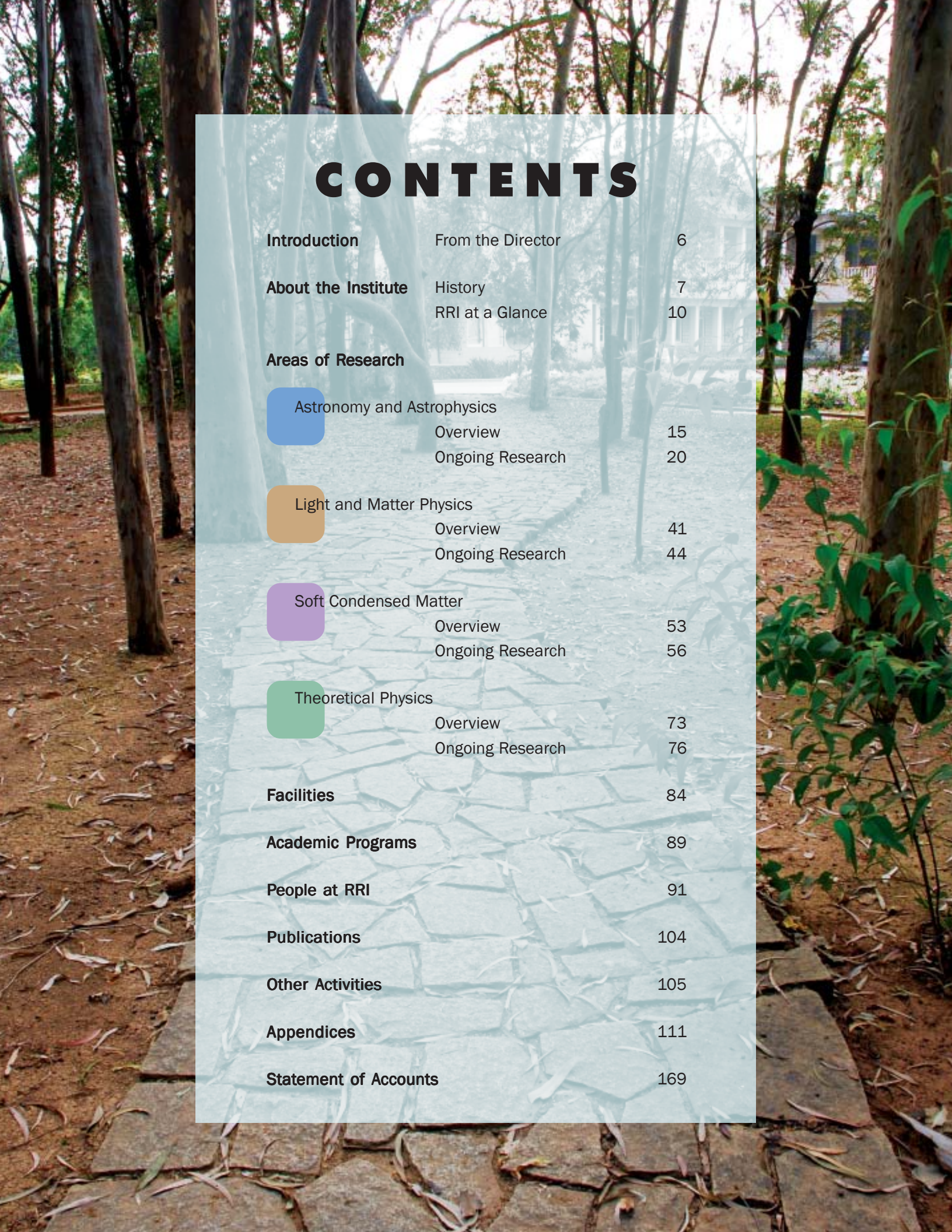
ANNUAL REPORT
2011 - 2012

Raman Research Institute
Bangalore


Sir C V Raman



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from the DIRECTOR

The annual report of the Raman Research Institute for the year 2011-12 is a summary of the research and academic activities of the institute during the year.

The annual report, as in the past, presents synopses of the ongoing knowledge creation activities in the different research groups, many of which have outcomes in the form of publications in refereed scientific journals. The institute considers the transmission of knowledge an important activity; this also includes the guidance of students for the conferment of PhD degrees as part of the PhD programme of the Institute, as well as the active Visiting Students Programme under which a number of students from all over the country visit the institute for stays ranging from a few weeks to several months and participate in the many research activities of RRI. It also continued holding schools in where students and young scientists from across the country participated.

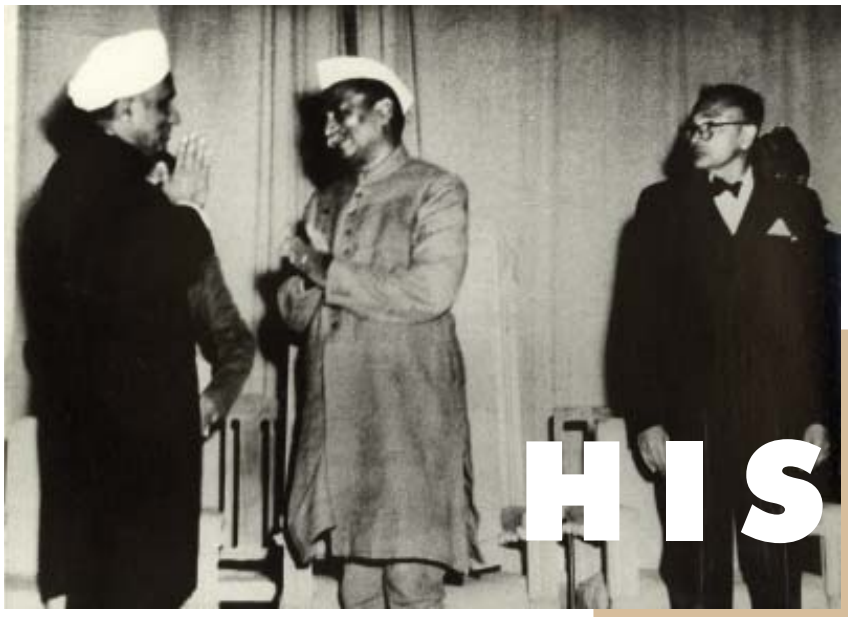
Communications of the ongoing research and also a sharing of knowledge of current research – in professional talks given by members of the Institute in conferences and in external institutions as well as journal review talks at the institute – is another aspect of our knowledge diffusion. A cultural function of a premier research institute is the upholding and promotion of academic traditions and this naturally includes the conduct of specialised seminars on technical topics targeted at specialised audiences as well as colloquia in a wider range of topics that are delivered in a style that strives to make current advances intelligible to a wider community.

Outreach activities include facilitating the involvement of students of a local school to help collect astronomical data as part of an international project, and helping a school located in hinterland to reinstall the dome at its campus to start an optical telescope, as well as writings intended for a lay and discerning audience and the delivery of motivational talks at educational institutions.

Included in this report are lists of publications in refereed journals, conference proceedings as well as in monographs, books and in popular periodicals, PhD degrees awarded during the period 01 April 2011 to 31 March 2012 as well as seminars and review meetings focused on current research, which were held at the institute. The report also lists the scientists who have visited the institute from within India and from overseas during the period.

Bangalore
August 31, 2012

Ravi Subrahmanyan
Director



a bit of

HISTORY

Before being immersed in the current exciting research activities conducted at the Raman Research Institute (RRI), take a few moments to read about its history. In between the collection of historical facts you'll discover a story about the power of basic human curiosity – the invisible foundation on which RRI was built and managed by its founder Sir CV Raman and subsequently by his successors.

In 1934, while still the director of the Indian Institute of Science (IISc), Raman started the Indian Academy of Sciences and attracted most of the best young scientists of that time, who published their work in world renowned journals of physics and chemistry. That same year, the Maharajah of Mysore gifted to the Academy 11 acres of land in the north side of Bangalore. A few years later, Raman proposed that an independent research institute be built on those premises and an agreement with the Academy was signed. The new centre was named after its founder – Raman Research Institute.

Raman embarked on a number of long journeys throughout the country to raise funds for the new institute. In 1943, the collected sum, along with his personal savings, was allotted for the construction of the first building. Its initial completion coincided with the retirement of Sir CV Raman from IISc in 1948 and in the beginning of 1949 he shifted all his activities there.

From the very first moment of its foundation Raman undertook the management of his new institute with immense vigour and enthusiasm. He not only designed the main building with the help of an architect, but also took great interest in the arrangement of the whole premises. He planted trees, decorative bushes and flowers turning the barren land around into a beautiful garden. A walk in that garden was an indispensable part of his daily life. The initial staff in the new institute consisted of four people including Raman himself. The lack of electricity during the first two years didn't affect Raman's thirst for knowledge and understanding the wonders of Nature. Great scientific work was carried out during these years using a few lenses and a manually operated heliostat. In order to support his staff and expand scientific activities at RRI, Raman, who was unwilling to take money from the government, started a couple of chemical industries along with one of his former students. He used the profit to pay his staff and

equip his laboratories. In the years to come, the institute kept expanding – soon there was a new library, a few other buildings and a museum holding Raman's personal collection of gems, crystals and minerals. Until his death in November 1970, Raman kept working tirelessly for the development and growth of the Raman Research Institute.

After his death, the Academy created a public charitable trust: the Raman Research Institute Trust. The lands, buildings, deposits, securities, bank deposits, moneys, laboratories, instruments, and all other movable and immovable properties held by the Academy for the Raman Research Institute were transferred to the RRI Trust. The foremost function of the RRI Trust was to maintain, conduct and sustain the Raman Research Institute.

In 1972, the institute started receiving funds from the Department of Science and Technology of the Government of India which, since then, has been its main funding source. The same year, Venkatraman Radhakrishnan was invited to be the Director of RRI. A renowned scientist himself, Radhakrishnan not only fulfilled CV Raman's desire to build an observatory at RRI but formed a strong group in Astronomy and Astrophysics whose research work today is regarded highly worldwide. Until the mid 90s, the two main areas of research were Liquid Crystals and Astronomy and Astrophysics. The constant growth of RRI and the expansion of the research interests of its members led to the establishment of two new groups – Theoretical Physics and Light and Matter Physics. The Liquid Crystal group was renamed Soft Condensed Matter which conveys more accurately the diverse research activities of its members.

Today, RRI research faculty, scientific staff and students conduct active research in the above mentioned four scientific fields inspired by the example of the founder – Sir CV Raman.

at a GLANCE

Mission

RRI is engaged in fundamental research in the areas of Astronomy, Astrophysics, Light and Matter Physics, Soft Condensed Matter and Theoretical Physics as a part of the global endeavour to increase human knowledge and understanding of the world.

Director

The current director of the Raman Research Institute is Ravi Subrahmanyan.

Organisation

RRI is an autonomous research institute. The supreme body of RRI is the RRI Trust. The director is the chief executive and academic officer. The Governing Council is the executive body responsible for the administration and management of the Raman Research Institute. The Finance Committee helps the Council with financial matters.

Location

RRI is located on a 20-acre plot in the north of Bangalore City, the IT capital of India. It offers a quiet refuge from the bustling megapolis as well as a natural environment that is highly conducive to creative scientific work.

Research Areas

Astronomy and Astrophysics

Light and Matter Physics

Soft Condensed Matter

Theoretical Physics

Facilities

1. LABORATORIES:

   RAL/Electronics Lab

   X-ray Astronomy Lab

   Quantum Optics Lab
   Laser Cooling and Light Propagation Lab
   Quantum Interactions Lab
   Non Linear Optics Lab
   Laser-induced Plasma Lab

   Chemistry Lab
   Physical Measurements Lab
   Liquid Crystal Display Lab
   Rheology and Light Scattering Lab
   X-Ray Diffraction Lab
   Biophysics Lab
   Electrochemistry and Surface Science Lab

   MECHANICAL ENGINEERING
   Mechanical Workshop
   Glass Blowing Facility

2. LIBRARY
3. COMPUTER FACILITIES

Education

RRI offers the following academic programmes:

- PhD Programme
- Post Doctoral Fellowship Programme
- Visiting Student Programme

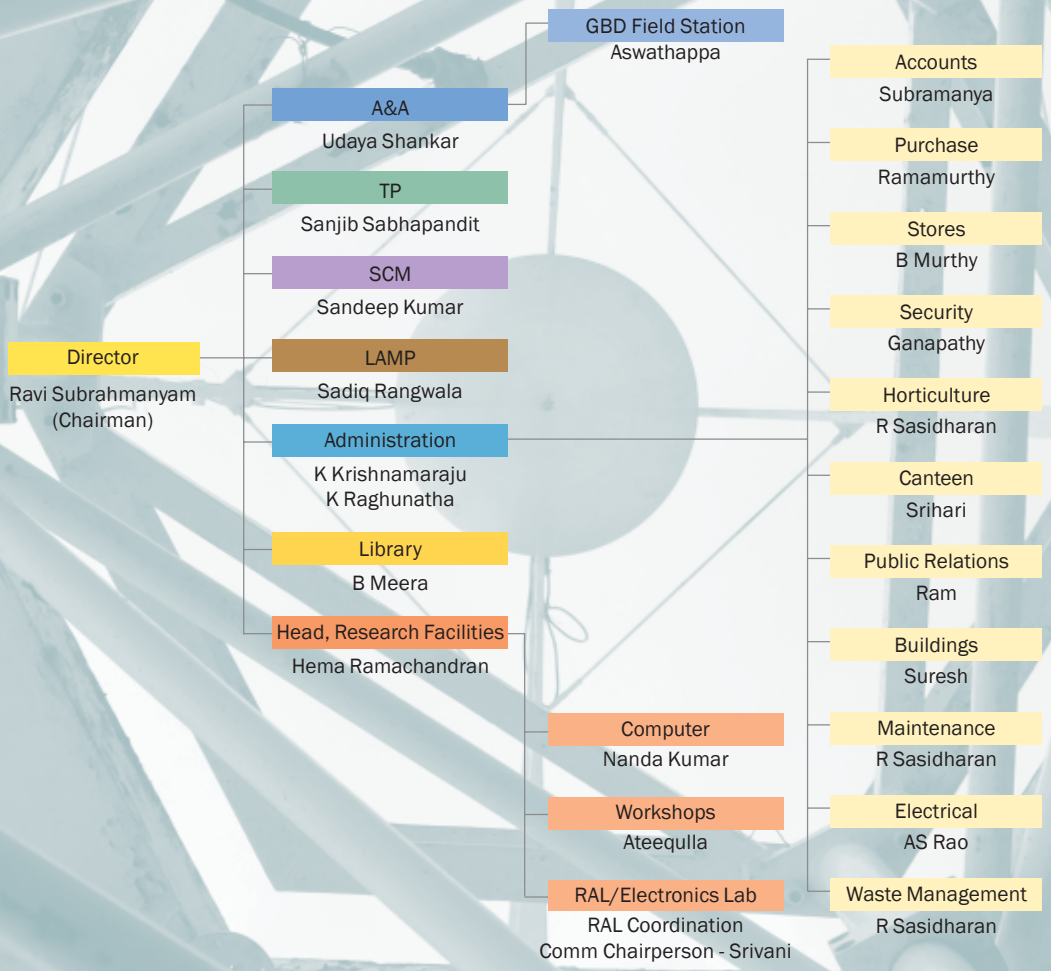
Funding

RRI is funded by the Department of Science and Technology, Government of India.

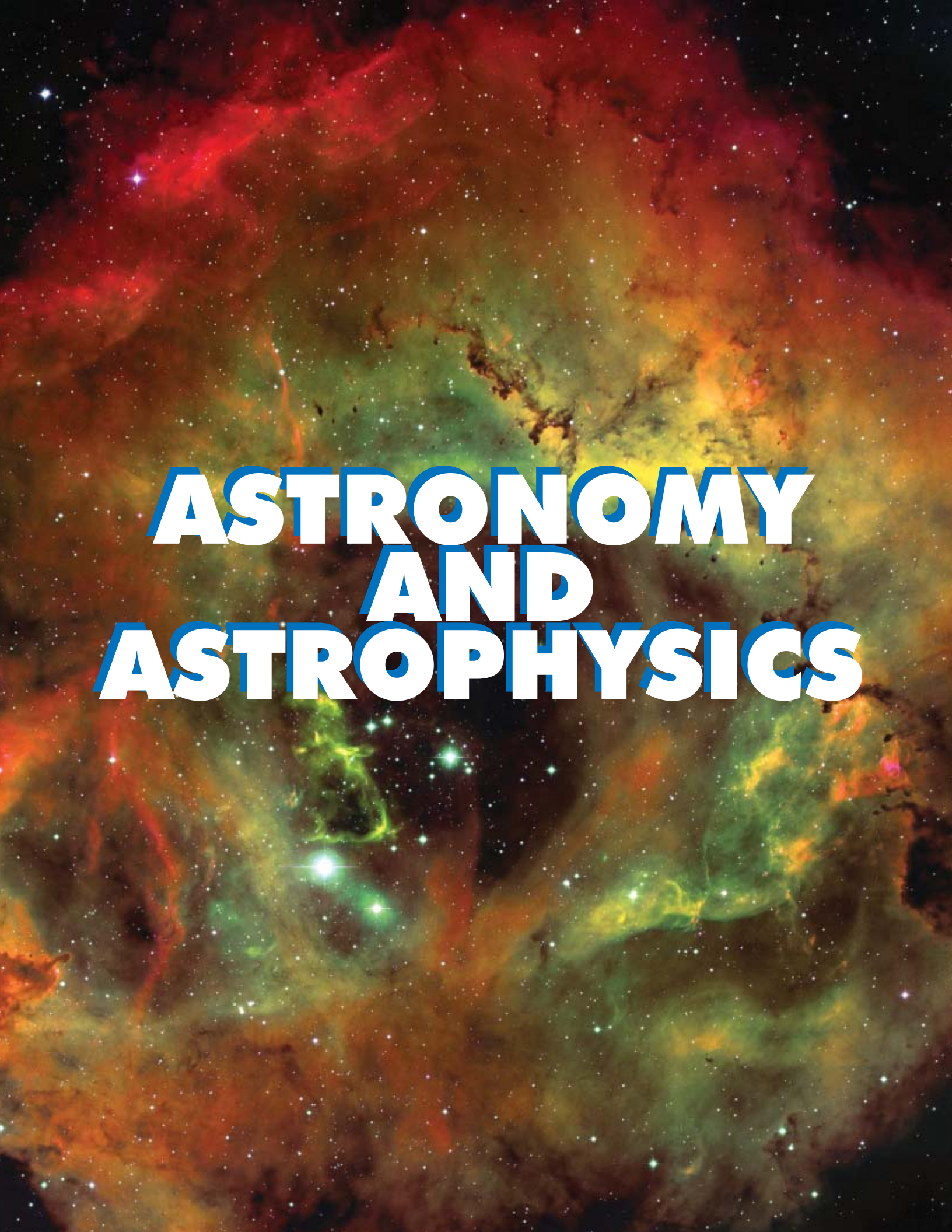
Faculty, Staff & Students

Research Faculty	46
Scientific/Technical	49
Administrative	28
PhD Students	56

Organisation



Journal Club	Supurna Sinha
Colloquia	Joseph Samuel, Pramod Pullarkat, Sadiq Rangwala
Hostel Warden	Krishnama Raju, Arun Roy
Admissions Coordinator	Arun Roy
SAAC	Madan Rao
In-House Meeting	PhD students
JAP Rep of RRI	Shiv Sethi
Complaints Committee	Srivani (Chairperson), Marisa, Vrinda, K Raghunatha, Madan Rao
Chairpersons of PhD Interview Committees	Abhishek Dhar, Biswajit Paul
Overseas Travel Committee	Sandeep Kumar (Chairman), Udaya Shankar, Madan Rao
Evaluation Committee	Joseph Samuel, Hema Ramachandran, Biman Nath, Abhishek Dhar, VA Raghunathan
Senior Management Team	Ravi Subrahmanyan, TN Ruckmongathan, Udaya Shankar, Joseph Samuel, K Krishnamaraju, K Raghunatha
Coordinator of Visiting Students Programme	Supurna Sinha
Coordinator of Summer Students Programme	Abhishek Dhar


ASTRONOMY
AND
ASTROPHYSICS

Overview

The Astronomy and Astrophysics (A&A) group at RRI comprises nearly 20 motivated researchers who study the universe from its creation to its present state. The main areas of research include theoretical astrophysics, observational astronomy, astronomical instrumentation and signal processing.

Theoretical astrophysics concentrates on the development of analytical models and computational numerical simulations that try to describe the dynamics, physical properties and underlying phenomena of celestial objects (such as stars, planets, galaxies and interstellar medium, among others) as well as answer fundamental questions about the formation and evolution of the universe.

Observational astronomers use numerous telescopes built across the globe to study the radiation from space covering the entire electromagnetic spectrum – which ranges from low frequency (long wavelength) radio waves to very high frequency (short wavelength and extremely energetic) gamma rays. These observations form part of the information that is used to test existing theoretical models and offer new directions of study. Such studies have been the basis of our collective knowledge of the universe.

Telescopes have been used since the 17th century to study the universe. Today's highly sophisticated telescopes allow scientists to study celestial bodies in different frequency bands of the electromagnetic spectrum, and answer questions about the universe and its creation. RRI's astronomical instrumentation engineers are involved in the construction and operation of such telescopes around the world.

The following pages summarise the major areas of research for the A&A group as well as each member's individual work during the last year. This section will give the reader a more detailed and technical description of the members' respective research activities.

ASTROPHYSICS

Development of Cosmological Models: Cosmology is concerned with developing and testing physical models that try to explain the formation and evolution of the universe. Researchers at RRI are working on developing such models that describe radiation from the Epoch of Reionisation (EoR). EoR refers to the period in the early history of the universe during which the emergence of the first luminous sources (such as stars and galaxies) ionised the predominantly neutral intergalactic medium. These models can provide important information about the process of structure formation in the universe and answer questions as to whether such radiation can be detected with existing telescopes.

Magnetohydrodynamic (MHD) Turbulence: Turbulence in electrically conducting fluids is a rarely observed phenomenon here on Earth. However, in galaxies, clusters of galaxies and the interstellar medium, where matter is ionised, it is a widespread phenomenon. Researchers at RRI are actively working towards the development of a comprehensive theoretical formulation of MHD turbulence.

Dynamo Theory: The astrophysics community at RRI conducts theoretical work to understand the origins of large magnetic fields around cosmic objects (stars, planets and galaxies) and the processes that sustain them. It is such magnetic fields that protect the Earth from the solar wind of particles that would otherwise destroy life on our planet.

Gravitational Dynamics: RRI researchers are also involved in the construction of models that describe the structure of the orbits of cosmic bodies around black holes. One of the ways of understanding gravitational lensing (the gravitational bending of light), which was predicted by Einstein, is by observing and studying the orbits of stars close to massive black holes.

OBSERVATIONAL ASTRONOMY

Halo and Relic Radio Sources: Clusters of galaxies are the largest structures of matter in the universe. An understanding of their formation, structure and dynamics can bring important insights about their evolution. Halos and relics are structures within a galaxy cluster that emit strong radiation in the radio portion of the electromagnetic spectrum. Various models exist that attempt to explain the origin of this radiation. Currently, researchers at RRI compare observational data from the radiations of radio galaxies with active galactic nucleus (AGN) have shown that some are slowly dying out. How many such galaxies stay invisible to us because of the limitations posed by the sensitivity of today's telescope receivers and what brings about the end of AGN are some of the questions that concern researchers at RRI.

HI Regions in the Milky Way Interstellar Medium: After the Big Bang, some 13.7 billion years ago, hydrogen was created in great quantities in the universe making it the basic building block of stars. The space between stars is filled with neutral hydrogen at extremely low densities compared to the air we breathe on Earth. The emissions from these hydrogen regions – called HI regions – carry information about the conditions before star formation. Researchers at RRI look at the formation and structure of such HI regions using observational data from various radio telescopes in India and abroad.

Pulsars: The detection of pulsars was serendipitous. Pulsars are neutron stars that originate in supernovae and spin very fast due to the conservation of angular momentum and periodically emit radio waves. Because of their periodic emission, pulsars are often called "the lighthouses of the universe". We can only observe pulsars that beam in the direction of Earth. Pulsar emissions provide insight about their structure and distance. They are also a wonderful experimental platform to test general relativity. Today, millisecond pulsars are one of

the most accurate clocks that have been found in the universe. RRI continues to conduct active research on pulsars and develop receivers that could reveal further details about their nature.

Lifecycle of Radio Galaxies: As radio telescopes become increasingly sensitive and of greater resolution, intricate features and morphologies of and within radio galaxies can be observed. A particular type of galaxy, called restarting radio galaxies, has captured the interest of researchers at RRI. It is believed that activity in the nucleus of the galaxy had stopped and then started again fresh. Such a scenario would explain the observations made and provide a useful input to our understanding of the evolution and lifecycle of radio galaxies. Why did the nucleus die, how long was it dead before it restarted its activity, what are the mechanisms that triggered its rebirth – those are some of the questions RRI astronomers are trying to answer in collaboration with Indian and international colleagues.

Radio Galaxy Morphologies: In recent years, X-shaped radio galaxies have caught the interest of the astronomy community, and members of the A&A group at RRI are active participants in this research field. In X-shaped radio galaxies, the typical two lobes are accompanied by two others to form a radio galaxy whose lobes look like the letter X. Two of the lobes are active while the other two are dead. Theories compete to explain how the two additional lobes are generated. Current observations at RRI are used to test these theories and deepen our understanding of X-shaped radio galaxies.

X-ray binaries: Compact stars (neutron stars and black holes) create some of the most extreme conditions in the universe and the extreme conditions are best investigated using the high energy emissions radiated from these compact stars in binary stellar systems. The high energy emission, mostly X-rays, are accessible to the astronomers from a fleet of space X-ray observatories. Astronomers at RRI use

observations made with a range of international space observatories to investigate the topics of orbital evolution of binary X-ray stars and orbital glitches, quasi-periodic oscillations in X-ray pulsars with many new discoveries to their credit, self absorption in X-ray pulsars and dips in the pulse profiles, cyclotron absorption lines in X-ray pulsars, study of neutron star magnetic field and optical reprocessing of thermonuclear X-ray bursts. The upcoming Indian mission Astrosat and an X-ray polarimeter that is under development at the Institute will significantly enhance our effort in study of X-ray binaries.

INSTRUMENTATION – DESIGN AND DEVELOPMENT

RRI is involved in the design and development of several telescopes across the world. Most current antenna systems are based on large reflectors with a single or a small number of feeds. The Murchison Widefield Array and Low Frequency Array prototypes have heralded a paradigm shift in the design of next generation of radio telescopes. Science projects like EoR and transients have pushed the interesting range of frequencies for many next generation radio telescopes to less than a GHz with significantly improved sensitivity with large bandwidths and large field of view. This can be realised with a phased array or Aperture Array, where the number of beams depends only on the available processing power and available communications.

RRI has accumulated expertise in this field with its involvement in the Guaribidanur Radio Telescope, Mauritius Radio Telescope, Murchison Widefield Array and development of broadband feed for the Greenbank Radio Telescope. The institute is also working on a programme to develop the Aperture Array technology in the frequency range 50 to 1000 MHz.

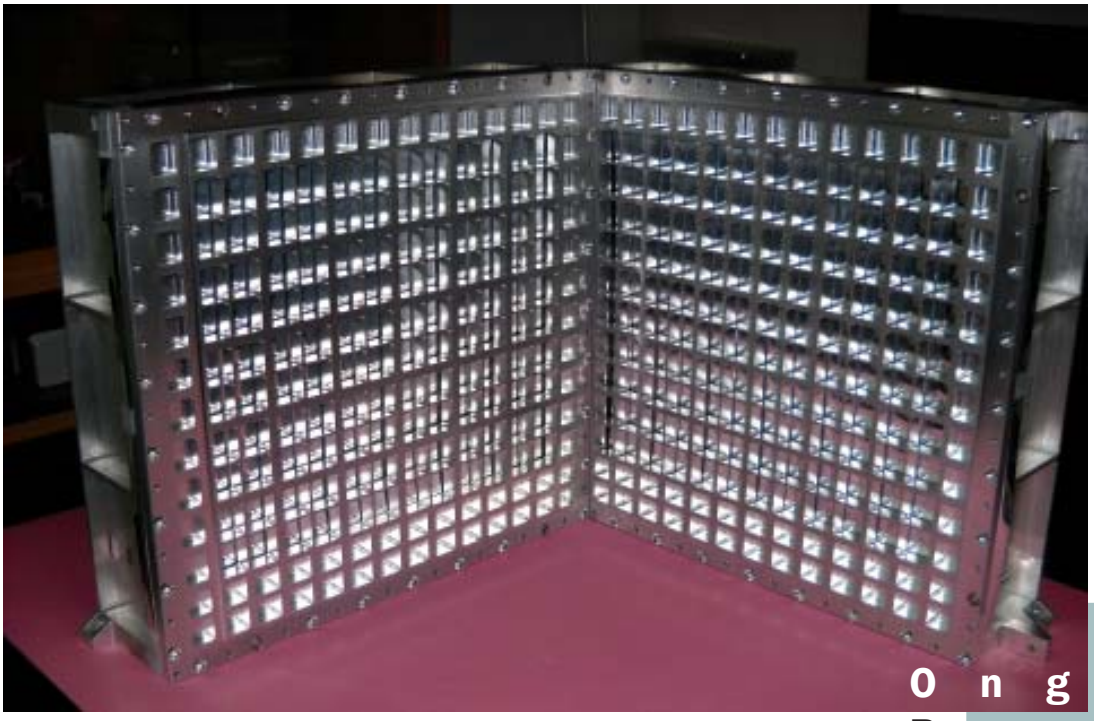
Mauritius Radio Telescope (MRT): The MRT is a Fourier synthesis array, constructed and operated collaboratively by RRI, Indian Institute of Astrophysics and the University of Mauritius. The telescope is situated at Bras d'Eau, in the north-east of Mauritius, an island in the Indian Ocean. The telescope is a T-shaped non-coplanar array, consisting of a 2,048 m long East-West (EW) arm and an 880m long South arm. In the EW arm 1,024 helices are arranged in 32 groups; in the south arm, 16 trolleys with 4 helices each that move on a rail are used for synthesis. A 512 channel, 2-bit 3-level complex correlation receiver is used to measure visibilities. At least 60 days of observations are required for obtaining the visibilities up to 880m spacing. After calibration, the visibilities are transformed to adjust for the non-coplanarity of the array and to produce an image of the area of the sky under observation. It is used to observe the sky at 151.6 MHz in the declination range of -70° to -10°. The scientific objectives of MRT are to produce radio surveys of the southern sky, observe and study pulsars, solar radio emission, extragalactic radio sources, supernova remnants and steep spectrum sources. New developments in the analysis of the data have allowed the group to complete imaging of an additional steradian of the sky covering the declination range -70° < Dec <-10° and the sidereal hour range 00hr to 06hr. In the mean time, the institute has been cataloguing extended sources seen in the MRT survey.

Gauribidanur Radio Telescope (GRT): This decametre wave radio telescope at Gauribidanur (around 100km north of Bangalore) is operated as a collaboration between RRI and Indian Institute of Astrophysics. Operating at 34.5 MHz, it is a meridian-transit instrument with some amount of tracking capability. The telescope consists of 1,000 fat dipoles arranged in the form of the letter "T". The dipole orientation is along the East-West direction, making the instrument sensitive to only the East-West component of the polarisation. The usable bandwidth is about 10 MHz centred at 32 MHz, while the maximum

available effective collecting area is about 18,000 square metres. The array beams are steered by appropriately phasing their elements. The beam of the N-S arm can be tilted within a declination range -45° to 75°. The beam of the E-W array can be tilted similarly in hour-angle within 10° around the meridian enabling tracking for a minimum of 42 minutes. This telescope is used for continuum surveys of the accessible sky, studies of supernova remnants, giant HII regions, as well as radio emissions from the undisturbed sun and solar bursts. Using the tracking facility, observations of low-frequency radio recombination lines and emission from many nearby pulsars have been made.

X-ray Polarimeter: X-ray polarimetry is an unexplored area of high energy astrophysics. Thus far, there has been only one experiment for X-ray polarisation measurement and Crab nebula is the only source for which a definite polarisation measurement exists. RRI astronomers are developing methods of detecting polarised X-rays from celestial bodies and building X-ray instruments that can detect polarised X-rays. These instruments will be launched into space and open new eyes to celestial phenomena. For this, RRI has a fully equipped lab for the fabrication and testing of X-ray detectors. The researchers are working on the development of an X-ray polarimeter sensitive in the energy range of 5-30 keV; the instrument will be launched in to space in collaboration with ISRO. A laboratory model has been made and was tested successfully. The design and fabrication of an engineering model is in progress. This involves the redesign of the lab model taking into consideration the different standards required for space qualification.

Astrosat: This is ISRO's satellite mission for multi-wavelength astronomy whose major scientific goals include: broadband spectroscopic studies of X-ray binaries, AGN, clusters of galaxies and stellar coronae and sky surveys, among others. RRI has been involved in the development of Large Area X-ray Proportional Counter (LAXPC) for X-ray timing and low-resolution spectral studies over a broad energy band, one of the payloads on Astrosat. LAXPC is designed to have a large photon collection area, which will enable detailed studies of high frequency features in X-ray light curves of bright and medium intensity point X-ray sources. However, to make use of such high sensitivity for intensity variation studies, it is necessary to measure, understand, and minimise systematic uncertainties in the timing response of LAXPC detectors and processing electronic units. Researchers at the X-ray astronomy lab in RRI are currently working on the timing and spectral calibration of the Astrosat-LAXPC instrument and development of the data reduction software.



Ongoing Research

Avinash Deshpande's current research areas of interest are neutron stars, pulsars and transients, the galaxy and interstellar medium, and instrumentation and signal processing.

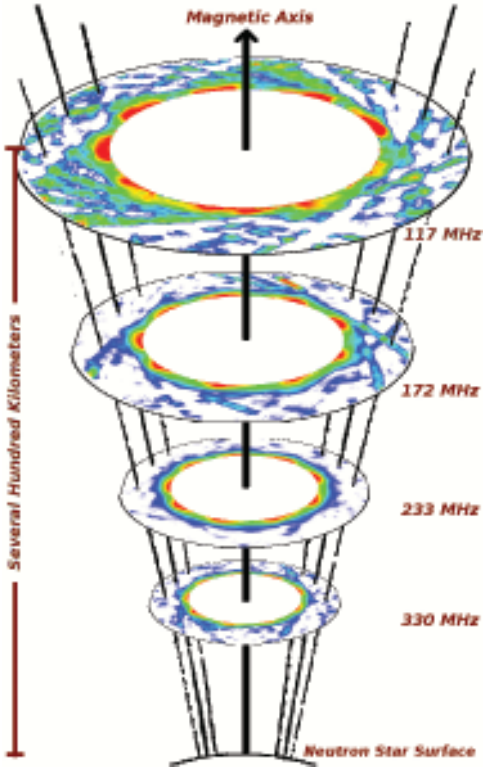
During the year gone by, Deshpande's research included studies of images of a few hundred OH maser sources in the star-forming complex W49N, obtained from VLBA observations. These showed significant anisotropy in the sources' shapes, understood to be due to anisotropic scattering in the intervening medium. The magnitude of anisotropy apparent in the scatter-broadened shapes is similar to that reported in an earlier study by Desai et al, even though the overall sizes are found to be overestimated in the latter. Further detailed analysis revealed that the orientations (position angles) of the source image ellipses deviated significantly (by 10 degrees, on average) from what would be expected (perpendicular to the Galactic plane) if the electron density irregularities responsible for the scattering were to be "stretched" due to the magnetic field strictly aligned parallel to the Galactic plane. This indicates additional significant scatter-broadening contribution from much differently aligned density anisotropy, most likely associated with the North Polar Spur. Since the data on Zeeman pairs has also revealed (for the first time) signatures of differential scattering for the two circular polarisations, it was assessed, through simulations of diffractive effects, how Faraday-rotation-induced modification of phase screens can indeed lead to different scatter broadened images in the two polarisations, when viewed at 10 or so milliarc-second resolution. These simulations support data revealing significant differential scattering on these angular resolutions. Through the various aspects seen from the W49N OH masers, the attractive, but yet unexplored, potential of the high-resolution maser observations for probing the intervening magneto-ionic medium has become evident. This work was in collaboration with WM Goss of NRAO (New Mexico, USA) and Jose E. Mendoza-

Torres of the Instituto Nacional de Astrofisica, Optica y Electronica (Mexico).

In collaboration with C Vinutha and Yogesh Maan, analysis of pulsar observations, made using the GBT-RRI multi-band receiver in 2009, was continued to obtain dedispersed pulse sequences at a range of frequencies between 110 and 1,400 MHz, starting from many tens of terra-byte size data that were recorded as raw voltage time sequences. The data on the pulsar under study showed the expected periodic drifting sub-pulse modulation, and cartographic transform is applied to the data from a set of bands to obtain respective slices of the emission cone, providing a tomography view. The fine details in this and other pulsars are being studied.

The calibrator scans in dual polarisation showed linear variation of the beam-width with wavelength, as would be desired, indicating the quasi-Gaussian illumination of the GBT dish by Deshpande to be similar across frequency and E & H planes. The measured beam-widths imply edge taper in the range of -17 to -20 dB, or about 75% aperture efficiency. However, the performance above 1 GHz (in two MBR bands) is poor, affected primarily by (a) any imbalance in phasing of the two arms of the feed and (b) the large gain slope across the wide band, combined with relatively higher spectral density of noise introduced by a fibre link.

A successful attempt was made to analyse about 6,000 single pulses of PSR B1133+16 using the 100-m Effelsberg radio telescope. The pulse-to-pulse intensity modulations were examined using longitude- and harmonic-resolved fluctuation spectral analysis of the high time resolution (60 microsecond) data, and a low-frequency feature associated with amplitude modulation was detected in the fluctuation spectrum. This feature is interpreted as corresponding to the circulation time (about 30 times the spin period) of the underlying subbeam carousel. Despite the erratic nature of this pulsar, periodic pseudo-nulls were clearly evident, with period exactly matching with that reported at a much lower radio frequency. This period would indeed be the actual carousel circulation time in the pulsar, particularly during orderly circulation. This analysis was done in association with Sneha Honnappa, W Lewandowski, J Kijak, J Gil and O Maron of the Kepler Institute of Astronomy (Poland) and A Jessner of the Max-Planck-Institut für Radioastronomie (Germany).



Deshpande worked on pending GMRT (re)observations of the Vela pulsar wind nebula made in 2011 and data analysis is in progress in collaboration with Richard Dodson and Maria Rioja of ICRAR (Perth, Australia) and Wasim Raja and Dave McConnell of ATNF (Australia). To complement this observation, full-Stokes imaging of the radio nebula using ATCA at C and X bands, in pulsar-binning mode was proposed and accepted.

In X-ray astronomy, Charge Coupled Devices (CCDs) are used for both imaging an astronomical source as well as to measure the energy spectrum of the source. These work on the simple assumption that the X-ray photon

flux reaching the CCD is very low so that no single pixel receives more than one X-ray photon during one interval of CCD read-out. This implicitly implies that all the charge detected above the threshold in any one CCD pixel is proportional to the energy of the incoming X-ray photon. But for bright sources like the X-ray binaries, this assumption might not always hold true, in which case the observed energy spectrum is artificially hardened leading to wrong modelling of intrinsic source spectrum. Motivated by this problem, Deshpande and Harsha Raichur analysed the situation of such pile-up due to finite spatio-temporal resolution in a general setting of mutually uncorrelated events that follow Poisson statistics, and have derived an elegant method for pile-up correction. This method is expected to find a wide application.

Bipolar molecular outflows have been observed and studied extensively in the past, but some recent observations of periodic variations in maser intensity pose new challenges. Even quasi-periodic maser flares have been observed and reported in the literature. Motivated by this, situations in binary systems were studied with specific attention to the two observed features: the bipolar flows and the variabilities in the maser intensity. The evolution of spherically symmetric wind from one of the bodies in the binary system, in the plane of the binary was studied. The approach included an analytical study of rotating flows with numerical computation of streamlines of fluid particles using PLUTO code. It was found that the anisotropies seen in the rotating frame have the desired character of bipolar flows and also appeared to be periodic (with binary-period) to an inertial observer for relevant sight-lines. Further, the potential maser spots in the sky-plane did not move and the minima in intensity variation cycle repeated at regular intervals of the orbital period. These characteristics are naturally produced in Deshpande's model wherein the variabilities observed in the maser intensity were due to the density modulation resulting from the flow in the binary as seen from the simulations. This study was done in collaboration with Nishant Singh.

A recent numerical simulation, by Kumar and Kumar, of the classical Langevin dynamics of a charged particle moving on a sphere placed in a uniform static magnetic field had given a non-zero orbital diamagnetic moment in the long-time limit, i.e., in the steady state. This numerical result appeared as a surprise in view of the well-known Bohr-van Leeuwen theorem on the absence of classical orbital (dia)magnetism in thermal equilibrium. It has, however, been questioned inasmuch as the Fokker-Planck (F-P) equation, associated with the Langevin equation, was pointed out to be satisfied exactly and uniquely in the steady state by the normally expected canonical probability distribution (i.e., the Maxwellian velocity distribution) that does not involve the applied magnetic field, and, therefore, gives zero magnetic moment. To investigate this further, the simulation was repeated for progressively smaller values of the chosen elementary time-step approaching zero, at which the magnetic moment was indeed found to extrapolate to zero. This not only resolves the stated disagreement, but also suggests an interesting possibility for realising a finite steady-state orbital magnetic moment in certain classical systems driven by stochastic-dissipative processes which are non-Markovian and do not obey the fluctuation-dissipation relation, instead lead to a steady state. Deshpande worked in collaboration with N Kumar of RRI and K Vijay Kumar of Yale University (USA).

Biman B Nath's professional research interests include interaction of diffuse gas with galaxies, galactic outflows, cosmic rays and intracluster medium.

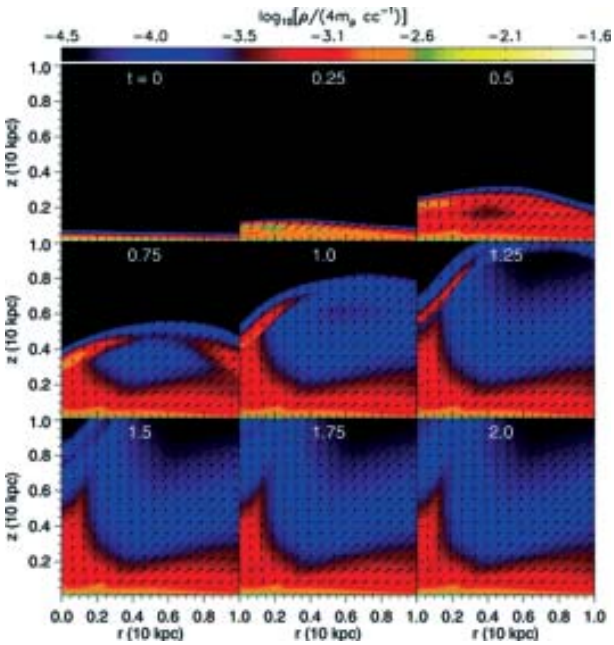
In his prior research, Nath has shown the importance of radiation pressure in driving galactic scale outflows, in addition to the standard scenario of driving the wind by thermal pressure. However, there does not exist any comparison in the literature between the roles of these two processes vis-à-vis the data. Nath, along with PhD student Mahavir Sharma, studied the relative roles of ram and radiation pressure in light of the available data, and found that radiation pressure becomes important for larger galaxies (of over 10^12 solar mass) with star formation rate in excess of 100 solar mass per year.

In collaboration with T Ensslin, C Pfrommer, M Uhlig and V Springel of MPA Garching, Nath and Sharma studied the effect of streaming cosmic rays on galactic winds. Cosmic rays exert pressure on the ambient gas and this process can contribute to driving galactic scale winds. Nath and team studied these effects with a novel numerical implementation of cosmic ray physics in a SPH simulation as well as with analytical calculation. The results showed that cosmic rays can drive powerful and sustained winds in low-mass galaxies (less than 10^11 solar mass).

He also worked on the development of a 2-D hydro-simulation code so as to study purely radiation pressure driven winds from rotating disc galaxies. The simulation, developed by I Chattopadhyay of ARIES, Sharma and Nath, showed for the first time the rotating structure of the wind gas as observed in some galaxies and also confirmed their previous theoretical results. It was found that the resulting wind has a conical structure and consists mostly of low angular momentum gas lifted from the central region of the galactic disc.

Nath, in collaboration with S Majumdar and Chaudhuri of TIFR, analysed data from 30 nearby galaxy clusters (REXCESS sample) to study the profile of enhanced entropy and to compare the observations with their previous year's analytical results. Their results showed that the profile of energy deposition in terms of gas mass is remarkably similar in all clusters and are peaked in the central regions. They also found that the total energy deposited is proportional to the cluster mass, as predicted a few years ago from work done here in the context of AGN feedback in clusters by Roychowdhury *et al*. Nath formulated the procedure for extracting energy deposition from the observed cluster data.

A recent study has put forward a new spectrum for the low energy protons in our galaxy, inferred from the observed gamma ray emission from nearby molecular clouds. This spectrum shows a break at a few GeV. Nath and N Gupta from RRI and P Biermann from MPIfR interpreted this break as arising from a spectrum with single power law in momentum, as expected from shock acceleration theory. They also showed that this spectrum was consistent with other independent measures, for example, ionisation rate and spallation in our galaxy.



In addition to his research, Nath was also invited by RAA to work on a joint review paper with Y Shchekinov on the topic of dust in the intergalactic and intracluster medium. In addition to summarising the current observational and theoretical understanding of the subject, they also provided many new estimates of different processes of deposition and survival of dust grains in the IGM.

Biswajit Paul's research interests span X-ray binaries, transients, X-ray instrumentation and data analysis. During the year, Paul's work included developmental work for an X-ray polarimeter and ASTROSAT as well as investigation into the various aspects of compact X-ray sources.

Paul and his colleagues are working on an X-ray polarimeter for a future small astronomy satellite mission. X-ray polarisation measurement is a yet unexplored area and has strong potential for understanding several important high energy astrophysics problems. During the year gone by, the following developmental work was carried out in this field. Contributors to the work included PV Rishin, MR Golapakrishna, R Duraichelvan, CM Ateequlla and many members of RAL and MES.

- Fabrication of an engineering model of the X-ray polarimeter
- Fabrication of two detector units, of which assembly and preliminary tests on one has been completed
- Further modifications on the design of the event processing electronics and detailed tests; similar developments happened on the common electronics unit
- Complete design and some preliminary development work on the housekeeping electronics of the X-ray polarimeter

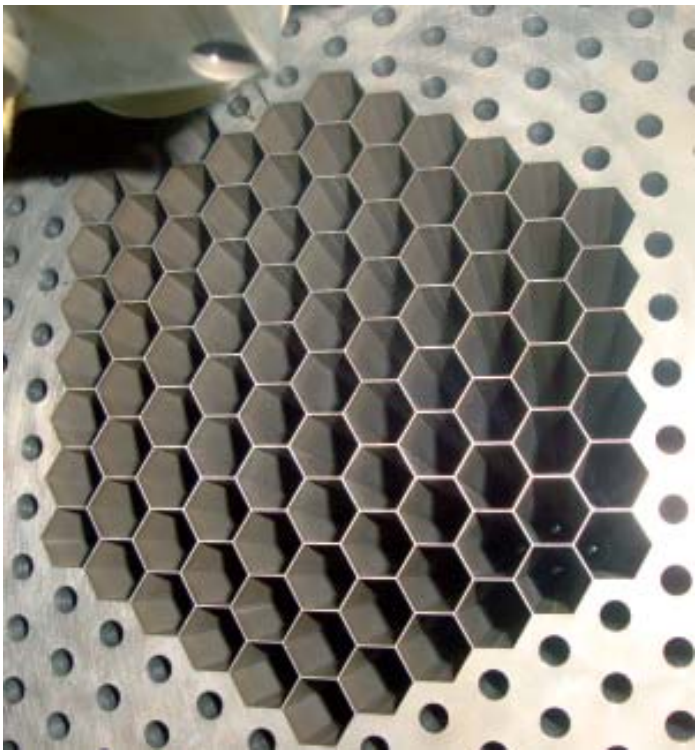
In collaboration with two teams at ISAC, Bangalore, and SAC, Ahmedabad, Paul worked on the development of the ASTROSAT-LAXPC data reduction software. He also carried out extensive analysis of the LAXPC timing data, results from which have necessitated hardware corrections on the processing electronics.

He also worked on pulse phase resolved spectroscopy in accretion powered pulsars; study of cyclotron line resonance features in accreting pulsars; and optical reprocessing of thermonuclear bursts in low mass X-ray binaries, among others.

In collaboration with Chandreyee Maitra of RRI and Sachindra Naik of PRL, Ahmedabad, Paul carried out a timing and broad-band pulse-phase-resolved spectral analysis of a transient Be X-ray binary pulsar (1A 1118-61) observed during its outburst in January 2009 using Suzaku observations. The Suzaku observations were made twice, once at the peak of the outburst, and the other during its declining phase. Pulse profiles from both observations exhibit strong energy dependence with several peaks at low energies and a single peak above 10 keV. A weak, narrow peak is detected at the main dip of the pulse profiles from both observations in the energy bands below 3 keV, indicating the presence of a phase-dependent soft excess in the source continuum. The broad-band energy spectrum of the pulsar could be fitted well with a partial covering cut-off power-law model and a narrow iron fluorescence line. They also detected a broad cyclotron feature at around 50 keV from both observations, a feature common for accretion-powered pulsars with high magnetic field strength. The pulse-phase-resolved spectral analysis showed an increase in the absorption column density of the partial covering component, as well as variation in the covering fraction at the dips of the pulse profiles, which naturally explains energy dependence of the same. The cyclotron line parameters also show significant variation with pulse phase with an approximately 10 keV variation in the cyclotron line energy and a variation in depth by a factor of 3. This can be explained either as the effect of different

viewing angles of the dipole field at different pulse phases, or due to a more complex underlying magnetic field geometry.

Along with Maitra, Paul carried out a detailed pulse phase resolved spectral analysis of the persistent high mass X-ray binary pulsar Vela X-1 observed with Suzaku during June 2008. The pulse profiles exhibited both intensity and energy dependence with multiple peaks at low energies and double peaks at higher energies. The source shows some spectral evolution over the duration of the observation and care has been taken to average over data with minimum spectral variability for the analysis. They modelled the continuum with a phenomenological partial covering high energy cut-off model and a more physical partial covering thermal comptonisation model (CompTT) excluding the time ranges having variable hardness ratio and intensity dependence. For both the models, they detected a cyclotron resonant scattering feature (CRSF) and its harmonic at ~25 keV and ~50 keV. Both the CRSF fundamental and harmonics parameters are strongly variable over the pulse phase, with the ratio of the two line energies deviating from the classical value of 2. The continuum parameters also showed significant variation over the pulse phase and gave some idea about the changing physical conditions seen with the changing viewing angle at different pulse phases and obscuration by the accretion stream at some pulse phases.



Paul made the discovery of a large number of optical bursts in the Low Mass X-ray Binary (LMXB) EXO 0748-676 simultaneous with the thermonuclear X-ray bursts. The X-ray and the optical bursts were detected in a long observation of this source with the XMM-Newton observatory. This has increased the number of thermonuclear X-ray bursts in the LMXBs with simultaneous optical detection by several factors. The optical bursts are found to have a linear rise followed by a slow, somewhat exponential decay. Most of the optical bursts have longer rise and decay timescale compared to the corresponding X-ray bursts. The X-ray and optical excess photon counts in the bursts were determined that allowed the researchers to look at the optical to X-ray burst fluence ratio for each burst and the ratio as a function of the X-ray burst intensity and as a function of the orbital phase. The delay between the onset of the X-ray bursts and the onset of the optical bursts were also measured and found to have an average value of 3.25 seconds. No convincing evidence was found of orbital phase dependence of the following parameters: X-ray to optical delay, rise time of the optical bursts, and optical to X-ray burst intensity ratio as would be expected if the optical bursts were produced by reprocessing from the surface of the secondary star that is facing the compact star. On the other hand, if the optical bursts are produced by reprocessing of the X-rays in the accretion disk, the onset of

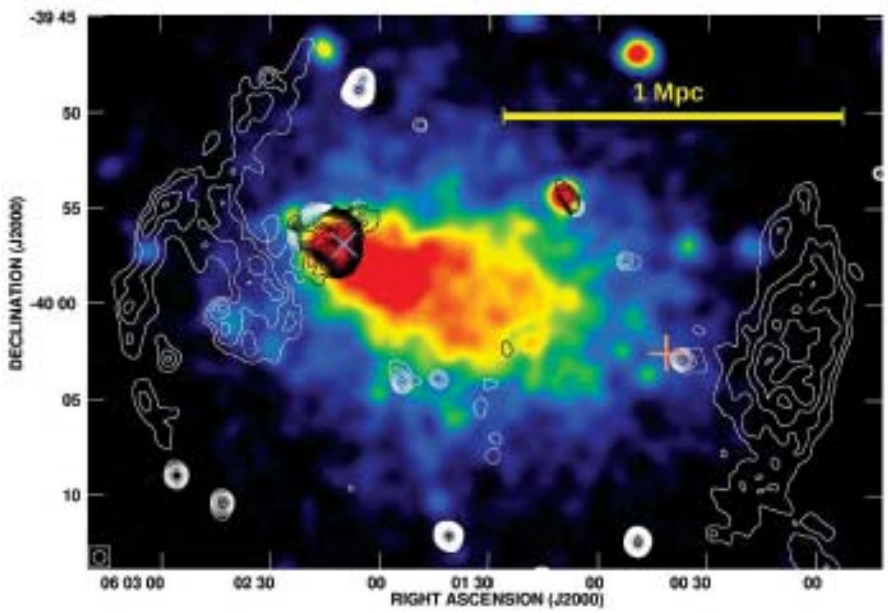
the bursts is not expected to have a sharp, linear shape as is observed in a few of the bursts in the LMXB. Simultaneous optical observations of the X-ray bursts in multiple wavelength bands will enable further detailed investigations of the reprocessing phenomena, including any non-linear effect of the X-ray irradiation. This study was done in collaboration with M Archana and Lakshmi Saripalli of RRI.

Paul, along with Maitra (RRI) and Chetana Jain of Delhi University, reported the detection of a periodic intensity modulation in the Supergiant Fast X-ray Transient (SFXT) IGR J16207-5129 in the long term 15-50 keV light curve obtained with the Swift Burst Alert Telescope (BAT) between MJD 53413 and 55888. Using the Lomb-Scargle periodogram technique, a period of 9.726 d was found. This can be the orbital period of the X-ray binary. The light curve, folded with this period shows a complex shape with a large modulation factor.

KS Dwarakanath's research interests span extragalactic astronomy, clusters of galaxies, halo and relic radio sources and the galaxy and interstellar medium.

During the year gone by, Dwarakanath's work included estimating HI mass function at a redshift. To determine the evolution of the HI contents of galaxies is a very important input into understanding the history of gas content and star formation in the universe. While the study of damped Lyman-alpha clouds in absorption gives the evolution of the aggregate HI content, the determination of HI content of a halo of a given mass remains elusive at high redshifts owing to the faintness of individual halos in the emission line of HI 21 cm-line. Recently, the first detection of HI at z1 was reported based on cross-correlating the density field of optically-selected galaxies with known red-shifts from the DEEP2 survey with the redshifted HI emission by Chang *et al.* They detected the component of HI correlated with DEEP2 galaxies and established that most of the HI at z1 is associated with star-forming galaxies observed by DEEP2. Detailed simulation by Khandai et al reproduced the results of Chang *et al*. These simulations suggest that stacking of HI 21 cm-line emission from galaxies of known redshifts can lead to a detailed reconstruction of the properties of HI in these halos at z1. The DEEP2 redshift survey has made spectroscopic measurements of over 25,000 objects in the redshift range $0.7 < z < 1.5$ in four fields. HI 21 cm-line observations of two of these DEEP2 fields were carried out using the GMRT in the 610 Mhz band. This study was done in collaboration with Shiv Sethi and the data is now being analysed.

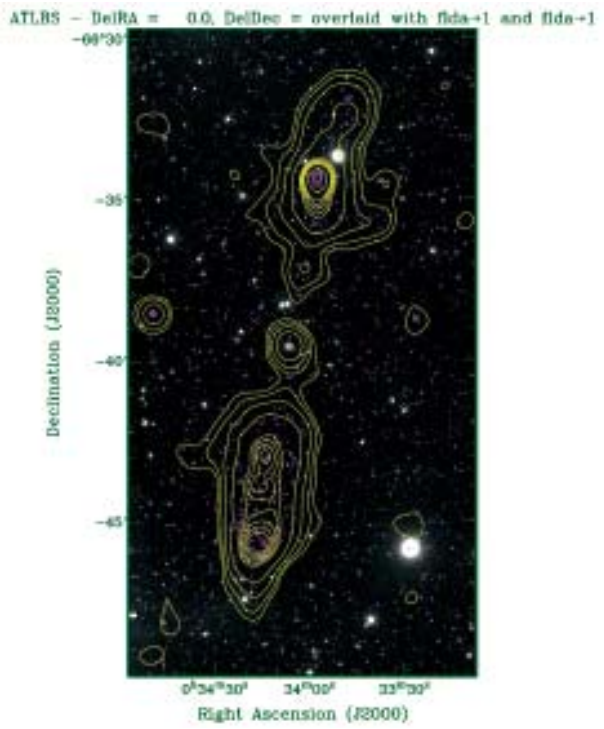
Dwarakanath, along with Chandreyee Sengupta and Tom Scott of Instituto de Astrofisica de Andaluca and DJ Saikia of NCRA, studied the spectacular displacement of HI during tidal interaction in the interacting galaxy pair Arp 181



(NGC3212 and NGC3215). They found that around 90% of the detected HI displaced well beyond the optical disks of the pair with the highest density HI located 70 kpc west of the pair. An HI bridge extending between the optical pair and the bulk of the HI, together with their HI deficiencies provide strong evidence that the interaction between the pair has removed most of their HI to its current projected position. The HI distribution to the west of the pair has two approximately equal intensity peaks. The HI intensity peak farthest to the west coincides with a small spiral companion that shows enhanced midinfrared (Spitzer), UV (GALEX) and H emission indicating intense star forming activity. The HI intensity maximum closer to the Arp 181 pair coincides with a diffuse optical cloud detected in UV (GALEX) at the end of the stellar and HI tidal tails originating at NGC3212 and, previously proposed to be a tidal dwarf galaxy in formation. Future sensitive HI surveys by telescopes such as the Australian Square Kilometre Array Pathfinder (ASKAP) and the Square Kilometre Array Interferometer should prove to be very powerful tools for identifying tidal dwarfs at moderate and large redshifts to explore in detail the evolution of galaxies in the universe.

Lakshmi Saripalli's areas of research interest span radio galaxies, including X-shaped radio galaxies, host galaxy characteristics, intergalactic medium, environments of radio galaxies, life-cycles of radio galaxies and radio galaxy types.

During the year gone by, her main piece of research related to radio galaxy lifecycles. In a survey that imaged radio galaxies to very low surface brightness levels, she and her collaborators discovered several candidate (20-30%) second-epoch radio galaxies. This, combined with the lack of a significant number of fossil radio galaxies, suggested that radio galaxies generally undergo several bursts of activity in their lifetime.



Based on the Australia Telescope Low Brightness Survey (ATLBS), Saripalli and her collaborators presented a sample of extended radio sources and derived morphological properties of faint radio sources. One hundred and nineteen radio galaxies form the ATLBS Extended Source Sample (ATLBS-ESS), consisting of all sources exceeding 30'' in extent and integrated flux densities exceeding 1 mJy. Structural details, information on galaxy identifications and source classifications were also given by the team. The ATLBS-ESS, unlike samples with higher flux-density limits, has almost equal fractions of FR-I and FR-II radio galaxies, with a large fraction of the FR-I population exhibiting 3C31-type structures. Significant asymmetry in lobe extents appears to be a common occurrence in the ATLBS-ESS FR-I sources compared with FR-II sources. The research also included a presented sample of 22 FR-Is at $z > 0.5$ with good structural information. The detection of several giant radio sources, with size exceeding 0.7 Mpc, at $z > 1$, suggests that giant radio sources are not less common at high redshifts. There was, in addition, a sample of 28 restarted radio

galaxies. The relative abundance of dying and restarting sources is indicative of a model where radio sources undergo episodic activity in which an active phase is followed by a brief dying phase that terminates with restarting of the central activity; in any massive elliptical, a few such activity cycles wherein adjacent events blend may constitute the lifetime of a radio source and such bursts of blended activity cycles may be repeated over the age of the host. The ATLBS-ESS includes a 2 Mpc giant radio galaxy with the lowest surface brightness lobes known to date. This work was carried out in collaboration with R Subrahmanyan, K Thorat, RD Ekers, RW Hunstead, HM Johnston and EM Sadler.

Other research by Saripalli during the year included high resolution imaging of the ATLBS regions, specifically, the radio source counts. The ATLBS regions were mosaic imaged at a radio frequency of 1.4 GHz with 6 arcsec angular resolution and 72 microJy/beam rms noise. The images cover 8.42 square degrees sky area and have no artefacts or imaging errors above the image thermal noise and, therefore, form a resource for attempting automated source identification and classification algorithms. Multi-resolution radio and optical r-band images were used to recognise multi-component sources and prepare a source list. Radio source counts in the flux density range 0.4-8.7 mJy were estimated, with corrections applied for noise bias, effective area correction and resolution bias. The resolution bias was mitigated to a great extent by using low resolution radio images, while effects of source confusion were removed by using high resolution images for identifying blended sources. The ATLBS counts are systematically lower than previous estimates. The work underscores the importance of using source lists –as opposed to component lists – and correcting for the noise bias in order to precisely estimate counts close to the image noise and determine the upturn at sub-mJy flux density. This study was carried out along with Thorat, Subrahmanyan, and Ekers.

N Udaya Shankar's areas of research interest include sky surveys, detection of epoch of reionisation (EoR), an array for the detection of epoch of recombination, and instrumentation and signal processing for radio astronomy.

Murchison Widefield Array (MWA) is a low frequency demonstrator operating in the frequency range 80 MHz to 300 MHz. One of the main science goals of this array is to detect signals from the EoR. Udaya Shankar, in collaboration with Harish Vedantham, Nithyanandan Thaygarajan and Ravi Subrahmanyan, is investigating imaging modes and strategy for MWA to detect EoR. As a first step, appreciating that limiting the contamination from galactic and extragalactic foregrounds is critical to the success of MWA, the frequency structure of the 3D point spread function (PSF) of MWA was studied. The 3D PSF has the peculiar property that structures in the two angular dimensions get coupled to frequency axis, which maps the Line of Sight (LOS) distance. In view of this, it is important that the PSF has acceptable frequency structure so that the residual foreground does not confuse the EoR signature. In this work, a single framework was used to understand the 3D PSF and foreground contamination. A formalism was developed to estimate the foreground contamination along frequency, or equivalently LOS dimension, and establish a relationship between foreground contamination in the image plane and visibility weights on the Fourier plane. Two dominant sources of LOS foreground contamination were identified – "PSF contamination" and "gridding contamination". It was showed that PSF contamination is localised in LOS wavenumber space, beyond which there potentially exists an "EoR window" with negligible foreground contamination where efforts will be focused to detect EoR. PSF contamination in this window may be

substantially reduced by judicious choice of a frequency window function. Gridding and imaging algorithms create additional gridding contamination and Udayashankar and his collaborators proposed a new imaging algorithm using the Chirp Z Transform that significantly reduced this contamination. They also demonstrated the analytical relationships and the merit of the new imaging algorithm for the case of imaging with MWA. They have also been working on extending their framework on minimisation of foreground contamination in the EoR window to obtain detailed statistical estimates of two-dimensional distribution in k - space of three sources of uncertainty: classical source confusion, sidelobe confusion and thermal noise. They used the 128T array configuration proposed for the MWA in their simulations.

As a part of the RRI Aperture Array (AA) project, design and development of a high-speed ADC-FPGA unit was taken up so as to digitise four analogue bands of ~1GHz bandwidth each. The design is based on two quad 10 bit ADCs and a single Virtex-6 FPGA. An FPGA is required to grab the digitised data from the quad ADCs, channelise them into narrow sub-bands, and then implement digital beam forming. Udaya Shankar participated in discussions related to the architecture of the board, carrying out interference monitoring on site to design the analogue front-end with sufficient headroom for interfering signals and generation of test vectors for testing evaluation boards.

Udaya Shankar was involved with an all sky survey at 150 MHz using the Mauritius Radio Telescope (MRT) along with Soobash Daiboo, Ramya Babu and Arvind Nayak. About a steradian of the sky (declination range -70° < Dec <-10°; sidereal hour range 00hr to 06hr) imaged during the previous year was analysed in detail. 3,837 sources in these images were detected, of which 1,500 had matching Molonglo Reference Catalogue of Radio Sources (MRC) sources. By carrying out a statistical analysis of positional errors and flux densities of sources common to MRC and MRT, corrections for positional errors were made in the images and the flux density scale was revised. This showed the median spectral index of sources between 150 and 408 MHz to be 0.87, along expected lines. From the catalogue, a list of sources with steep spectral indices (< -1.3) was made for further studies.

The MRT has a very good UV coverage with baselines going down to 2m both along EW and S directions. With this, they were able to detect all the 71 SUMSS extended sources listed in the Jones & McAdam paper as well as 16 extended sources not previously listed. The data analysis for the RA range 7-18hr met with certain difficulties and imaging of this range has been suspended.

Precise measurements of the cosmic microwave background (CMB) anisotropies have constrained the background cosmology and initial conditions for structure formation. However, understanding the non-linear growth and astrophysical evolution in the

EoR has been difficult. Evidence to date suggests a complex reionisation history. Direct observation of redshifted 21cm spin transition of neutral hydrogen has been identified to be a useful method for detecting structures in cosmological gas at high redshifts. This tomography of redshifted 21cm line promises to be a key probe of reionisation history. Udaya Shankar and his collaborators are pursuing an experiment to measure the 21cm global all sky signal with a single dipole antenna. As a first step, they have taken up precision measurements of the spectrum of the cosmic radio background. This requires frequency independent antennas of small electrical dimensions. They designed a wide-band fat-dipole antenna with a sinusoidal profile having a frequency independent performance over the octave band 87.5 to 175 MHz. The input return loss exceeds 15 dB and the radiation power pattern is frequency invariant and close to cosine square over the octave bandwidth. The structure has been optimised using electromagnetic modelling, and constructing a prototype has validated the design. This work was done in collaboration with Raghunathan, Nipanjana Patra and Ravi Subrahmanyan.

In addition, as part of a flagship research initiative, Udaya Shankar has proposed an array to detect signals from the epoch of cosmological recombination.

S Sridhar's areas of current professional research interests include dynamo action due to turbulence in shear flows, magnetohydrodynamic turbulence, stellar dynamics in galactic nuclei, exoplanetary dynamics and states of light.

During the past year, Sridhar studied mean field dynamo action in renovating flows with finite and non-zero correlation time in the presence of shear. Previous results obtained when shear was absent are generalised to the case with shear. The question of whether the mean magnetic field can grow in the presence of shear and non-helical turbulence, as seen in numerical simulations, was examined. It was shown, in a general manner that, if the motions are strictly non-helical, then such mean field dynamo action is not possible. This result is not limited to low (fluid or magnetic) Reynolds numbers nor does it use any closure approximation; it only assumes that the flow renovates itself after each time interval. Specifying to a particular form of the renovating flow with helicity, a standard dispersion relation of the dynamo in the small or large wavelength was observed. Thus, mean fields grow even in the presence of rapidly growing fluctuations, surprisingly, in a manner predicted by the standard quasilinear closure, even though such a closure is not strictly justified. This work, done in collaboration with Sanved Kolekar and Kandaswamy Subramanian of IUCAA, also suggested the possibility of obtaining mean field dynamo growth in the presence of helicity fluctuations, although having a coherent helicity will be more efficient.

Along with Jihad Touma of the American University of Beirut, Sridhar formulated the collisionless Boltzmann equation for dense star clusters that lie within the radius of influence of a massive black hole in galactic nuclei. The approach to these nearly Keplerian systems follows that of Sridhar & Touma. Delaunay canonical variables were used to describe stellar orbits and the fast Keplerian orbital phases were averaged. The stellar distribution function (DF) evolves on the longer time-scale of precessional motions, whose dynamics is governed by a Hamiltonian, given by the orbit-averaged self-gravitational potential of the cluster. Specialisation to razor-thin, planar discs was done and two counter-rotating ("±") populations of stars were considered. To describe discs of small eccentricities, the ± Hamiltonian was expanded to fourth order in the eccentricities, with coefficients that depend self-consistently on the ± DFs. The approximate

± dynamical invariants were constructed and Jeans' theorem was used to construct time-dependent ± DFs, which are completely described by their centroid coordinates and shape matrices. When the centroid eccentricities are larger than the dispersion in eccentricities, the ± centroids obey a set of four autonomous equations ordinary differential equations. It was shown that these can be cast as a two-degree-of-freedom Hamiltonian system which is non-linear, yet integrable. The linear instability of initially circular discs was studied and a criterion for the counter-rotating instability was derived. The rich non-linear dynamics of counter-rotating discs was then explored, with focus on the variety of steadily precessing eccentric configurations that are allowed. The stability and properties of these configurations are studied as functions of parameters such as the disc mass ratios and angular momentum.

Young stars in the galactic centre appear to be organised in two counter-rotating systems orbiting the central black hole. One of these is a strongly warped disc, whereas the other is thicker and highly inclined with respect to the former. Sridhar and Tarun Deep Saini of IISc present a minimal model of these gravitationally coupled stellar systems.

In collaboration with Saini and JAP student Mamta Gulati, Sridhar studied the linear m=1 counter-rotating instability in a two-component, nearly Keplerian disc. The goal was to understand these slow modes in discs orbiting massive black holes in galactic nuclei. They are of interest not only because they are of large spatial scale – and can hence dominate observations – but also because they can be growing modes that are readily excited by accretion events. Self-gravity being non-local, the eigen value problem results in a pair of coupled integral equations, which were derived for a two-component softened gravity disc. This integral eigen value problem was solved numerically for various values of mass fraction in the counter-rotating component. The eigen values are in general complex, being real only in the absence of the counter-rotating component, or imaginary when both components have identical surface density profiles. The main results were as follows:

(i) The pattern speed appeared to be non-negative, with the growth (or damping)

rate being larger for larger values of the pattern speed

(ii) For a given value of the pattern speed, the growth (or damping) rate increases as the mass in the counter-rotating component increases

(iii) The number of nodes of the eigen functions decreases with increasing pattern speed and growth rate. Observations of lopsided brightness distributions would then be dominated by modes with the least number of nodes, which also possess the largest pattern speeds and growth rates.

Again in collaboration with Touma, Sridhar also worked on developing a theory of resonant interactions in multi-planetary systems in binary stellar systems. Of great interest are questions concerning the origins of the high eccentricities and inclinations inferred for the planetary orbits (from radial velocity and transit observations). It was estimated that, in at least three systems (upsilon-Andromedae, 55 Cancri and 777 Gliese), there is a close commensurability between the binary mean motion and the secular modes of oscillations of the planets. This resonant excitation of modes will be facilitated by capture into resonance during the planetary migration phase. The status of this work is as follows:

- The basic formalism was developed which involved setting up
  - The Hamiltonian for the basic Laplace-Lagrange modes of a multi-planetary system
  - The Hamiltonian for nonlinear interactions between the LL modes (to fourth order in the eccentricities)
  - The Hamiltonian for the binary driving of the LL modes
- A numerical code was written to solve the Hamiltonian dynamics including planetary migration (which is non-Hamiltonian)
- Analytical methods were developed to analyse the results (which show, in general, chaotic motions)

The next steps will be to obtain results for specific systems as well as to write a full simulation code without restriction to small eccentricities or inclination.

Rajaram Nityananda of NCRA and Sridhar sought to describe the four-dimensional manifold L which represents the “states of light”. L is defined as the set of all plane electromagnetic waves in vacuum, of unit intensity and frequency, propagating in all directions and assuming any perfectly polarised state. For a given direction of propagation, the set of all polarisation states is the well-known Poincare sphere. This needs to be generalised to include all directions of propagation. They constructed a geometric model in which L is the set of all elements, each of which is composed of three coplanar unit vectors. Work is continuing on this.

Nayantara Gupta’s areas of professional research interest include cosmic rays, neutrinos, gamma rays and gamma ray bursts.

Her work during the past year included the study of neutrinos from decaying muons, pions, neutrons and kaons in gamma ray bursts (GRBs). GRBs are the most luminous objects in the universe, with the energy emitted by them in a few seconds being equal to the energy emitted by sun in its entire life time. It has long been speculated that these objects are also the acceleration sites of ultrahigh energy cosmic rays (UHECRs). As cosmic rays are deflected by interstellar magnetic fields, it is difficult to trace their origin. However, the secondary neutral particles (high energy photons, neutrinos) produced in the interactions of UHECRs with ambient matter and radiations inside the

astrophysical objects maintain their directionality and can be used to probe the acceleration sites. In this context, Gupta and PhD student Reetanjali Moharana from IIT Bombay calculated the high energy neutrino flux expected on earth from GRBs including in detail the different channels of neutrino and antineutrino production. In the internal shock model of gamma ray bursts, ultrahigh energy muons, pions, neutrons and kaons are likely to be produced in the interactions of shock accelerated relativistic protons with low energy photons. These particles subsequently decay to high energy neutrinos/antineutrinos and other secondaries. In the high internal magnetic fields of GRBs, the ultrahigh energy charged particles ($\mu+$, $\pi+$, K+) lose energy significantly due to synchrotron radiations before decaying into secondary high energy neutrinos and antineutrinos. The relativistic neutrons decay to high energy antineutrinos, protons and electrons.

Gupta and her colleague calculated the total neutrino flux (neutrino and antineutrino) considering the decay channels of ultrahigh energy muons, pions, neutrons and kaons. They showed that the total neutrino flux generated in neutron decay can be higher than that produced in $\mu+$ and $\pi+$ decay. The charged kaons being heavier than pions lose energy slowly and their secondary total neutrino flux is more than that from muons and pions at very high energy. Detailed calculations on secondary particle production have the total neutrino fluxes and their flavour ratios expected on earth. Depending on the values of the parameters (luminosity, Lorentz factor, variability time, spectral indices and break energy in the photon spectrum) of a GRB, the contributions to the total neutrino flux from the decay of different particles (muon, pion, neutron and kaon) may vary and be reflected on the neutrino flavour ratio.

Currently, IceCube and other large area neutrino telescopes are trying to reach very high sensitivities in detecting astrophysical neutrinos. IceCube has put limits on the flux of GRB neutrinos. However, there are many ambiguities about their method of analysis. The possibility that GRBs could be sources of UHECRs and neutrinos has not been ruled out so far.

Gupta also studied how high-energy gamma rays originate from interactions of UHECRs in the MilkyWay. Observational data from extensive air shower experiments like Hires, AGASA, Yakutsk and Auger have been widely used to understand the origin of UHECRs. The maximum energy of cosmic rays from a cosmic accelerator is determined by the size, magnetic field of the acceleration region, shock velocity and charge of the cosmic ray particle. The maximum energy of the cosmic rays originating from sources inside the Milky Way is not yet known. Most of the cosmic ray sources in the Milky Way are located near its centre, and as a result, galactocentric anisotropy is expected in the UHECR spectrum. The observed UHECR spectrum does not show such anisotropy up to 1EeV energy. Gupta calculated the PeV gamma ray background produced in the

interactions of UHECR with the ambient matter and radiations during their propagation in the Milky Way. A large number of events for PeV gamma rays are expected in Km^2 area detector in one year. If the primary UHECRs are produced from galactic point sources then those point sources also emit PeV gamma rays. Gupta suggested that the detection of galactocentric PeV gamma rays in the future would be a signature of the presence of EeV cosmic accelerators in the Milky Way.

Other research by Gupta included spectrum and ionisation rate of low energy galactic cosmic rays (GCRs), done in collaboration with Biman B Nath and Peter L Biermann. The research considered the rate of ionisation of diffuse and molecular clouds in the interstellar medium by GCRs to constrain its low energy spectrum. They extrapolated the GCR spectrum obtained from PAMELA at high energies and a recently derived GCR proton flux from observations of gamma rays from molecular clouds, and found that the observed average galactic ionisation rate could be reconciled with this GCR spectrum if there was a low energy cut-off for protons. They also identified the flattening below a few GeV as being due to (a) a decrease of the diffusion coefficient and dominance of convective loss at low energy and (b) the expected break in energy spectrum for a constant spectral index in momentum.

Research associate **Mayuri**'s work involved looking into the power density spectra (PDS) and kHz Quasi Periodic Oscillations (KQPOs) of some low-mass X-ray binaries (LMXBs) in different broad band spectral states. This work was done along with Biswajit Paul of RRI. The chosen sources were those that commonly show KQPOs and whose long-term light curves in the medium energy band (RXTE-ASM) and hard X-ray band (SWIFT-BAT) show significant spectral variations at large timescales. Mayuri is investigating the correlation between the presence of KQPOs, their frequencies, rms, quality factor, energy dependence of the QPOs, among others, with their broad band spectral behaviour. Any dependence of the power spectra on the broad band spectral state would give important clues about the origin of the temporal behaviour.

Mayuri identified sources by looking into the long-term light curves in RXTE-ASM and SWIFT-BAT and extracted the power spectra of two sources. She also looked for all observations that have the required time resolution to be able to look for KQPOs as well as have the flexibility to extract power spectra over the required energy band. As a result, power spectra have been successfully extracted for about 1,000 observations. Care was taken not to include data coming from the time interval containing a type I burst, if present in the light curve. Further research is being done to look for a correlation between the existence of the KQPOs and their spectral state. The next step for this research would be to repeat this investigation for other identified LMXBs and to try and explain the observed behaviour.

Photon arrival is widely accepted to be a Poisson random process. A Poisson process is described as one having a constant probability of occurrence per unit time. An important characteristic of a Poisson process is that it is memory-less. In the context of photon arrival, the arrival of one photon is independent of the arrival of the previous or next photon. The Leahy power of a true Poisson process is 2. Dead time of an instrument is the minimum amount of time that must separate two events for them to be distinguished and recorded. The dead time can be contributed by multiple factors, such as the response of the detector itself or the electronics that follow the detector. In general, there are two broad classifications of dead time – paralysable and non-paralysable. Due to the effects of the instrument dead time, the photons detected no longer follow a truly Poisson process and the power spectrum deviates from the expected value of 2.

For application to instrumentation on ASTROSAT, Mayuri and Paul studied how the presence of two paralysable dead times affected the power density spectrum. The two dead times were one for the detection of a photon or a true signal, by the proportional counter, and the other for the detection of a charged particle and hence a false signal. An understanding of the dead time effects would play an important role in interpreting data from the instrument. They used random number generators to simulate photon arrival as a Poisson process. Various random number generators were investigated, which would give the desired level of randomness. The test of whether the process is truly Poisson is that the power spectrum of the resulting simulated light curve would have a value of 2, or very close to 2, keeping in mind the limitations of the pseudo-random number generators. Further studies will be to look at simulating the effects of detector dead-times on the power density spectrum.

Mayuri's research for the year also included simulation and analysis software for the Large Area X-ray Proportional Counter (LAXPC) instrument of ASTROSAT. Creating power spectra from raw observation data is a time consuming process. It involves the additional process of light curve extraction and writing the same into the FITS format. On occasions, only the power spectra are of interest or only a quick view of them is needed before doing further analysis. In such cases, it would be most useful to speed up the process and obtain the power spectra directly without having to redundantly extract the light curve. Mayuri and Paul worked on a code to do just this. This code has been currently written for the GoodXenon mode of RXTE-PCA (Proportional Counter Array) data and has been tested successfully. The code can be adapted for ASTROSAT-LAXPC data when it is available.

Post doctoral fellow **Harsha Raichur**'s primary research interests lie in the field of X-ray astronomy, particularly X-ray binaries.

During the past year, Raichur conducted research into the iron-line in X-ray binaries in collaboration with Gulab Dewangan of IUCAA, Pune. Broad, asymmetric, Fe K emission lines have been observed in Active Galactic Nuclei (AGN) and Black Hole (BH) X-ray binaries using observations made by Chandra, XMM-Newton, etc. The observed emission lines are skewed and broad and hence believed to be originating in the inner accretion disk. They have been modelled by incorporating Doppler and gravitational redshift effects, and hence are argued to enable one to constrain the inner accretion disk radius and also the BH spin. But constraining model parameters of the Fe K emission line in Neutron Star (NS) binaries is not as straightforward. Firstly, the lines are weaker in comparison to the BH binaries and secondly, characterising continuum spectrum of NS binaries is difficult due to degenerate models. Suzaku NS binary observations revealed broad, asymmetric Fe K emission lines. Even though the broadband coverage of Suzaku observations mitigates the degeneracy between different continuum models to some extent, the situation is not fully resolved due to the complication by photon pile-up in the X-ray CCDs when observing bright sources. There is also a lack of theoretical models for Fe K emission lines in NS binaries. Raichur and Dewangan are investigating Suzaku observations of bright NS binaries that show the Fe K emission line with the aim of doing detailed spectral analysis of the data in light of the above stated complications.

Raichur studied the long-term spin period evolution of Cen X-3. Cen X-3 is a persistent high mass X-ray binary that shows aperiodic X-ray ux variations at time scales larger than its orbital period of 2.1 days. The binary-period averaged X-ray ux of Cen X-3 varies by a factor of more than 40. Long-term observations with

Burst and Transient Source Experiment (BATSE) of the Compton Gamma-Ray Observatory (CGRO) found that Cen X-3 has alternate spin-up and spin-down intervals which last from about 10 to 100 days. However, detailed GINGA and RXTE observations revealed that there is no correlation between the observed X-ray ux and the rate of spin-up/down of Cen X-3; hence it was suggested that the observed X-ray Flux of Cen X-3 does not represent its mass accretion rate. But it is still not clear whether the variations in the observed X-ray ux are only due to obscuration of the central X-ray source by the accretion disk or if at least a fraction of these variations are due to intrinsic change in the rate of mass accretion. Observed lightcurves from the Gamma-ray Burst Monitor (GBM) have allowed the generation of X-ray pulse patterns at different observed X-ray ux and binary orbital phase. These lightcurves also provide very precise measurements of the spin-up and spin-down rate of the pulsar. Raichur and Mark Finger of the National Space Science and Technology Center (USA) are investigating if there are correlated variations in the pulse pattern with the orbital phase, X-ray ux and spin-up/down rate of the pulsar. For these studies, the observed pulse patterns are parameterised as Fourier series with 6 harmonics, each with a different amplitude. Comparison of the amplitude of each harmonic with the amplitude of the fundamental harmonic for a series of pulse patterns shows that most of the variation is in the fundamental and the first harmonic. The two plan to study this comparison with respect to the binary orbital phase, the observed X-ray ux and the rate of spin-up/down to understand the pulsar emission mechanism and the puzzle as to why for this particular X-ray Binary Pulsar the observed X-ray ux does not correlate with the rate of spin-up/down.

Mutually uncorrelated random events are routinely monitored to estimate event spectra of various natural phenomena. Such measurements count the events occurring within finite resolution of the detector used for the observation. Within the resolution, however finite, there is always a non-zero probability of occurrence of multiple events. Such multiple unresolved events are counted as one event and the corresponding event strengths get added up. This “pile-up” of events due to finite resolution of the detector can result in significant distortion of the intrinsic event spectra. Raichur, in collaboration with Avinash Deshpande of RRI, suggested a solution to correct such observed piled-up spectrum such that the intrinsic spectrum is recovered. The method was successfully applied to piled-up X-ray photon energy spectra observed using X-ray CCD detectors used for imaging spectroscopy.

Post doctoral fellow **Harshal Bhadkamkar**’s research interests include the evolution of X-ray binaries, collective properties of X-ray binaries and binary star evolution.

During the year gone by, Bhadkamkar’s primary engagement was the study of evolutionary processes in HMXBs with a focus on tidal interactions. Observations of a very high rate of the orbital period evolution call for a new explanation of the evolutionary scenario. The work involved modelling the tidal interactions in HMXBs and calculating the future evolutionary scenario. Bhadkamkar, in collaboration with Biswajit Paul, explored if the renewed evolutionary scenario had any bearing on the formation rate of double neutron stars. He has also continued his work on the collective properties of X-ray binaries, trying to model the bivariate PDF for HMXBs as a function of luminosity and orbital period and also studying the Lx-SFR relation for HMXBs from theoretical considerations. Another topic of interest for Bhadkamkar was the modelling of stellar evolution using a recent public code MESA to be used for detailed modelling of the companion in X-ray binaries.

Post doctoral Pancharatnam fellow **Thyagarajan Nithyanandan**'s research interests cover observational cosmology, extragalactic astronomy, dynamic radio sky and statistical methods and modelling in astronomy.

During the year gone by, his research included estimation of foreground contamination in the detection of signal from the Epoch of Reionisation (EoR) using the Murchison Widefield Array (MWA) in collaboration with N Udaya Shankar and Ravi Subrahmanyan of RRI. The MWA is a next-generation radio instrument currently under construction in Western Australia. It will consist of 2,048 dual-polarisation dipole antennas optimised for the 80-300 MHz frequency range, arranged as 128 "tiles", each a 4×4 array of dipoles.

One of the three key projects related to the MWA is detection and characterisation of redshifted 21cm neutral hydrogen signals from the EoR. Power spectrum measurements of the redshifted 21cm from EoR are difficult. The EoR signal is extremely weak in comparison to the foreground emission of the galaxy and extragalactic sources and may require considerable effort to distinguish their signatures from residual errors even after careful spectral modelling and subtraction of these foregrounds. Previous research has shown that the inherent isotropy and symmetry of the EoR signal in frequency and spatial wavenumber (k) space make it distinguishable from sources of contamination which lack such symmetry. An inherent mechanism for foreground contamination via the frequency dependent structure (chromaticity) of the primary and synthesised beams has also been developed, which becomes significant owing to the relatively large bandwidths associated with EoR observations. A more recent study offers a framework to understand the localisation of this foreground contamination from residuals in spatial scales in the line-of-sight direction. It also shows that appropriate choices of bandpass window functions and imaging algorithms can significantly minimise levels of such contamination in specific regions of k-space, termed as the "EoR window".

Nithyanandan and his collaborators used this one-dimensional framework to present detailed statistical estimates of the distribution of three sources of uncertainty, namely, classical source confusion, sidelobe confusion and thermal noise, in two-dimensional k-space. The 128-tile (128T) array configuration proposed for the MWA has also been used in the estimates. They compared the relative magnitudes of these different sources of uncertainties and obtained a more complete view of the estimates of the EoR power spectrum sensitivity characteristics of the measuring instrument

The most important results of the nature of contamination are:

- The classical source confusion is restricted to a narrow region in k-space
- The sidelobe confusion is localised in a wedge-like region in the 2D k-space
- Thermal noise is distributed throughout k-space
- The shape of the bandpass causes a spillover of the contamination into the EoR window
- Choosing a Blackman-Nutall bandpass window significantly reduces the spillover of the contamination in the EoR window
- The different sources of contamination have been estimated for the snapshot mode of the MWA

Another area of study for Nithyanandan was that of radio transients and variables, in collaboration with KS Dwarakanath and Shri Kulkarni and his team from Caltech University (USA). This included follow-up studies with the Palomar Transient Factory (PTF) and Giant Meterwave Radio Telescope (GMRT).

The PTF is an experiment designed to systematically explore the optical transient and variable sky and fill the gaps in our present-day knowledge of the optical transient phase space. There exist many types of either poorly constrained events (such as luminous red novae, tidal disruption flares, etc.) or predicted but not yet discovered phenomena (such as orphan afterglows of gamma-ray bursts). As in the case of radio frequencies, dedicated wide-field instruments have the best prospect of leading to significant progress.

While a number of surveys have attempted this challenging task and provided important contributions to the understanding of time-domain science, they were designed to maximise the discovery probability for selected source populations. Thus, large areas of the phase space remain poorly explored at best and are ripe for investigation with PTF. Thyagarajan's aim is to conduct follow-up studies of the radio variables and transients related to his previous work using the PTF, whose footprint largely overlaps with those of the SDSS and the FIRST surveys. He has proposed the use of the PTF to conduct follow-up studies on the 1,623 radio variables and transients identified in the FIRST survey. Around 55% of these sources have no optical counterparts, including the SDSS. It is planned to coadd the PTF pointings on these sources with the goal of obtaining images deeper than those of SDSS. If detected, this will help significantly in knowing more about the nature of the hosts of these objects. Sources that SDSS has detected but been unable to classify could be studied for their optical light curves from the PTF to arrive at their potential classification. Besides verifying the efficiency of time-based classification schemes, assembling a combination of radio and light curves for detected and well-classified objects from SDSS using PTF data is also planned.

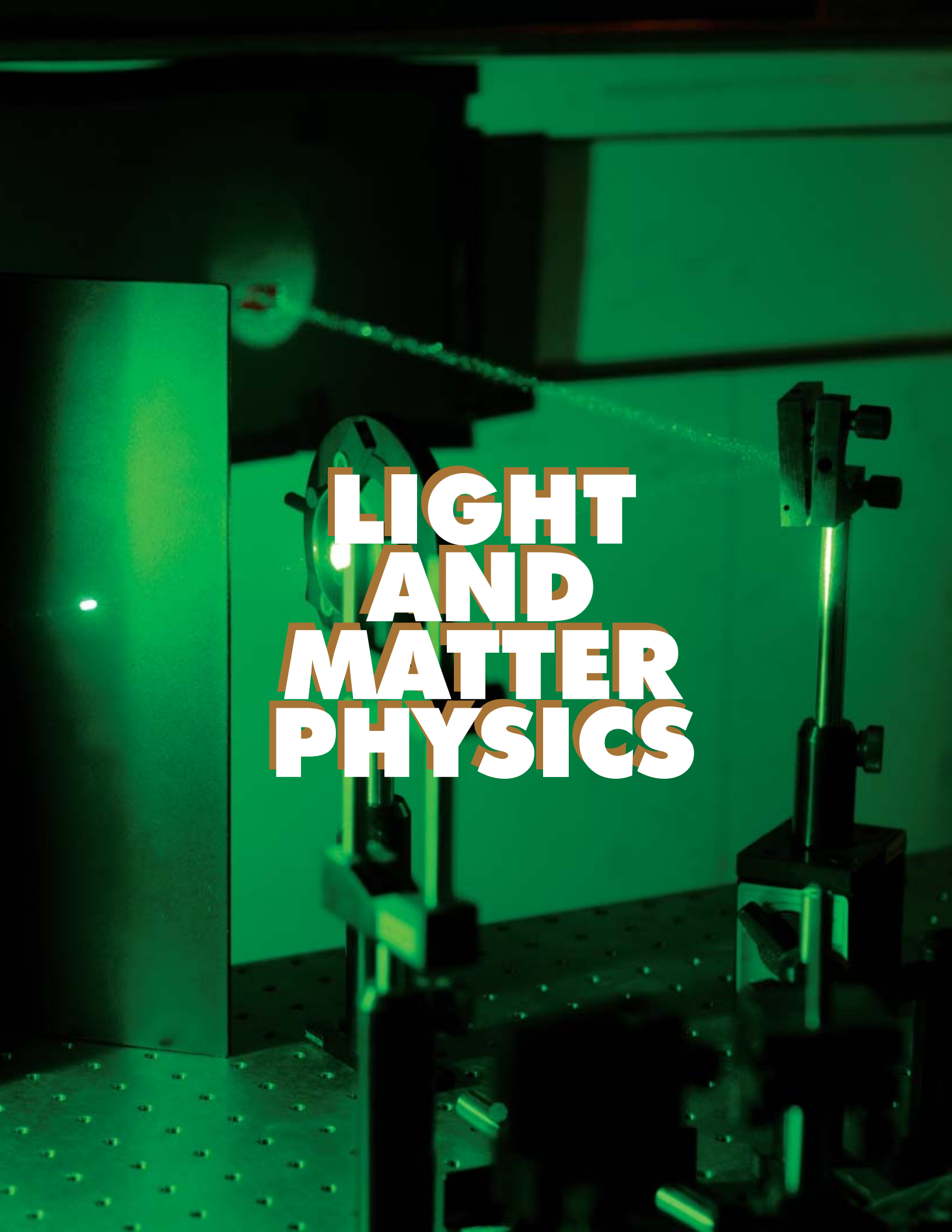
Nithyanandan also conducted a follow-up study of transients using GMRT. Based on light curves that satisfy either of the following criteria, 57 transient-like candidates were identified:

1. the source is detected only in a single epoch and the rest of the observations resulted in non-detections, or,
2. the detection with the maximum flux density is at least five times more than the observation with next highest flux density irrespective of whether the latter is a detection or not, indicating a sharp transition in the light curve.

Even though the FIRST survey does not have uniform coverage in time, it is a very sensitive survey over a large portion of the sky. Thus, it is excellent at detecting variable and transient-like behaviour in sources but poor at constraining the timescales and cadences of such behaviour. The chosen transients, which were well above the source detection threshold of the FIRST survey, were to be followed up on in a systematic fashion specifically designed to

study their behaviour with time. The flux density information of these sources was used both as a function of the observation epoch as well as the primary beam attenuation at the locations in the fields they were observed, thereby, ruling out selecting spurious candidates owing to highly attenuated primary beams and increased uncertainties. The normalised flux densities of neighbours as a function of the epoch of observations and primary beam attenuation were well behaved, once again ruling out any systematic problems such as with calibration or bad fields. The final list consisted of 20 of the 57 sources.

The 610 MHz band of the GMRT yielding will be used to find a resolution that is close to the angular resolution of the FIRST survey. In addition, the simultaneous feed capability of the GMRT will be used to observe in the 233 MHz band. This will allow the study of the source's chromatic behaviour in time (if any). The timescales of variability in these candidates are expected to be between a few days and months. The galactic centre radio transients were observed to have timescales of a few months using the VLA and the GMRT at low frequencies. The target list consists of sources at high galactic latitudes, which are thus not expected to be extragalactic. The proposed study aims to observe these candidates in two epochs separated by three months. Deep enough sensitivity is essential to identify any faint and possibly extended structures in the host galaxies, requiring two hours on each source at each epoch. This amounts to a total of 80 hours of GMRT observing time, which has been granted to Thyagarajan and his colleagues. One epoch of observations has already been completed and analysis of the data is underway.


LIGHT
AND
MATTER
PHYSICS

Overview

The Light and Matter Physics (LAMP) group comprises five motivated faculty members and their students. The members of this group are engaged in an area of light-matter interaction that is a combination of Atomic, Molecular and Optical (AMO) physics on one hand, and intense laser field studies of plasmas on the other. The group takes a holistic scientific approach, where the fields of theoretical, numerical and experimental research complement one another.

There are four labs that cater to the individual needs of the LAMP members:

- The Laser Cooling, Light Scattering Lab
- The Ultrafast and Nonlinear Optics Lab
- The Quantum Optics Lab
- The Quantum Interactions (QUAINT) Lab

In addition, a lab for quantum information and computing (QUIC) has just been initiated.

The following pages summarise the major areas of research for the LAMP group. Each member's individual work during the last year is provided in the next section, giving the reader a more detailed and technical description of their respective research activities.

QUANTUM OPTICS

Quantum optics is a field in physics that applies quantum mechanics to study phenomena involving light and its interactions with matter. Since the first indication in 1899 that light may be quantised, the field of quantum optics has witnessed significant progress in our understanding of light-matter interactions and microscopic systems. The major fields of interest in quantum optics include the manipulation of elemental particles like atoms, ions and molecules and the use of quantum optics for quantum information. Fundamental questions regarding the nature of coherence transfer between quantum light-matter interactions are actively being pursued. The experiments include low-intensity probes for atoms that are prepared in a superposition state. Quantum Non-Demolition (QND) measurements of a quantum superposition state is also being actively explored both experimentally and theoretically.

LASER COOLING AND TRAPPING

Laser cooling and trapping is an area of physics that has largely expanded over the last decade. Presently, atoms can be cooled to extremely low kinetic temperatures (as low as 1 microK) and trapped for a time period of the order of seconds. Such control over the motion of atoms allows researchers to probe their behaviour more precisely than before. There are a number of techniques to cool and trap atoms of alkali elements, with the most commonly used one being Doppler cooling. It involves three mutually perpendicular laser beams that intersect at the centre of the chamber. A pair of magnetic coils produces a magnetic field that is zero at the centre of the chamber, and increases radially outward. Using appropriate wavelength and polarisation of the laser beams, atoms can be cooled by repeated absorption and emission of light, and trapped by an inward force arising out of the combination of the polarised light beams and the spatially varying magnetic field (Magneto Optical Trap or MOT).

At the laser cooling lab, electromagnetically induced transparency and related phenomenon with cold atoms are studied. The nature and depth of correlation of an atomic CPT state created during such interactions are the central theme of current research. Another area of current study is the nature of fluctuations in a collection of cold atoms.

ELECTROMAGNETICALLY INDUCED TRANSPARENCY (EIT)

EIT is a quantum mechanical phenomenon where, under specific conditions, an absorption line of a material can be cancelled changing it from opaque to transparent at that particular frequency. To observe EIT, two highly coherent lasers are tuned to interact with three or more quantum states of the material. Considerable research activity has been devoted to this topic and RRI researchers are trying to build a strong fundamental understanding of this phenomenon using both theoretical and experimental methods.

QUANTUM WALK OF LIGHT

A random walk is a mathematical description of a trajectory where the successive steps are random. Classical random walks are used in search algorithms when the searched parameter space is random. They find application in the fields of computer science, physics, ecology, economics and psychology. Quantum walks are the equivalent of random walks in quantum computing and can form a part of a quantum algorithm. Members of this division are now investigating the quantum walk of light in the frequency space.

LIGHT PROPAGATION IN RANDOM MEDIA

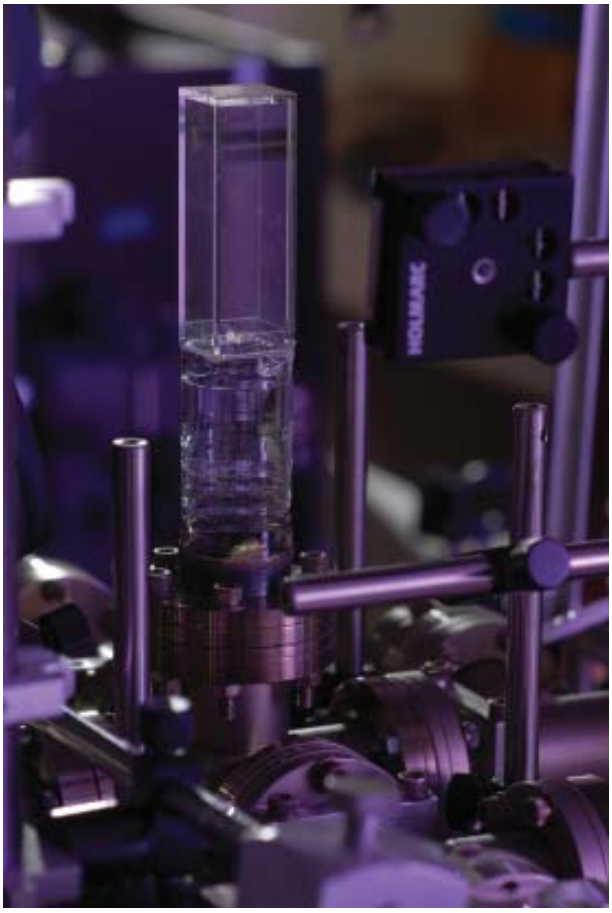
Multiple scattering of light in random media, like fog, considerably reduces visibility. The propagation of light in random media is usually diffusive rather than ballistic. This leads to a variety of interesting phenomena like mirrorless lasing, Levy statistics and weak and strong localisation, which have been subjects of the LAMP group's recent studies. The work includes experiments in colloidal suspensions of dielectric or magnetic microspheres, both active and passive. These are supported by Monte-Carlo simulations and theoretical analyses of light propagation in such media. The understanding of such phenomenon might open doors for future novel optical devices.

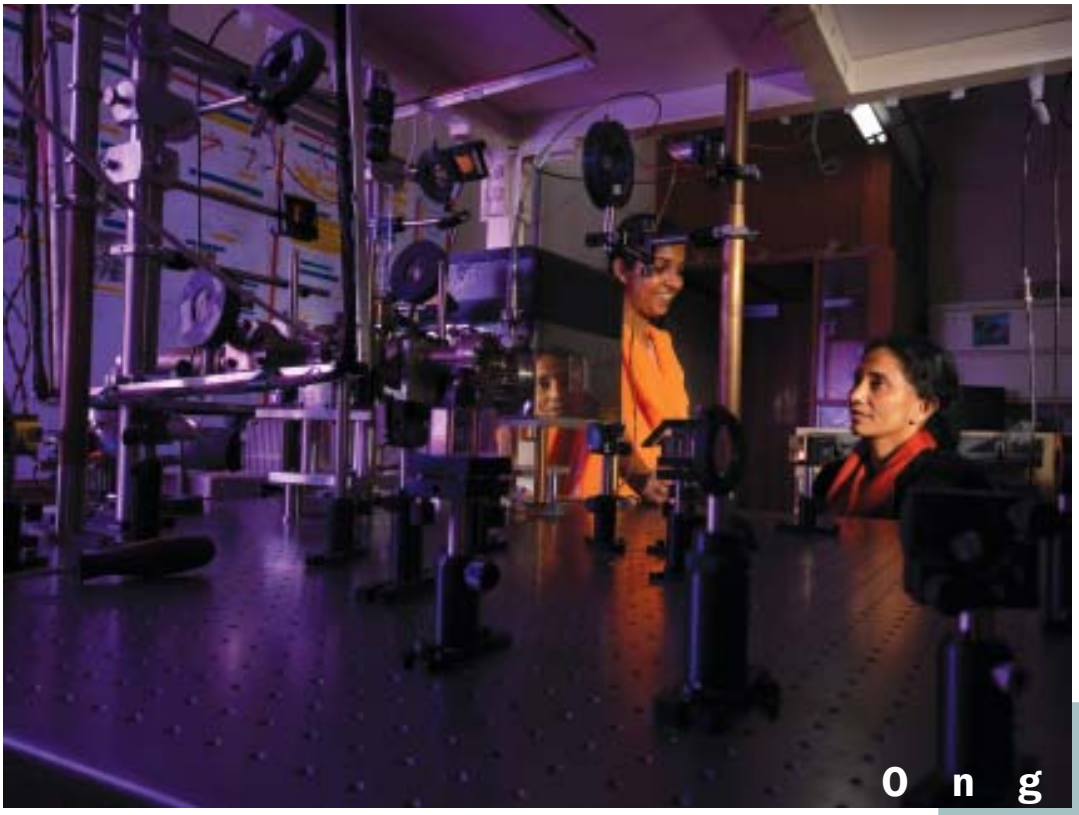
NONLINEAR OPTICS

The nonlinear optical transmission of material systems finds applications in optical switches, saturable absorbers and optical limiters. Over the years, RRI researchers have investigated the nonlinear optical properties of various types of materials, with an emphasis on nanoparticles and nanocomposites. These materials may be synthesised in the chemical room of the LAMP group. They are relatively new and show properties that are quite different from their bulk counterparts. Evolution of the nonlinear response in these media in the ultrashort (femtoseconds) timescales have been investigated using ultrafast laser systems. Some of the interesting materials studied recently were ferrofluids and cobalt-in-carbon nanotubes. The experimental techniques used are pulsed laser z-scan, degenerate four wave mixing (DFWM) and femtosecond pump-probe spectroscopy. Experiments in white light z-scan, low-power z-scan and hyper-Rayleigh scattering are underway.

LASER INDUCED PLASMAS

It is possible to generate a plasma – the fourth state of matter – in the lab using powerful pulsed lasers. Such plasmas are nothing but short-lived stars, and their study is aptly named "laboratory astrophysics". The LAMP researchers have studied the spectrum of laser-induced plasma emission from planar liquid jets (250 microns thickness) at atmospheric pressure. Presently they are generating ultrafast laser plasmas from metal targets in vacuum. The emission spectrum is found to contain high energy photons in the soft and hard X-ray regimes, as well as electrons and ions. In future, such table-top systems are expected to replace larger particle accelerators in certain applications including medical diagnosis.





Ongoing Research

Andal Narayanan's areas of current professional research interests are quantum optics and cold atoms. During the year, Narayanan's research included microwave-optical non-linear coupling through Coherent Population Trapping (CPT) resonances. An experimental signature of transfer of coherence from the microwave frequency domain (around 3 GHz) to the optical domain (around 1000 TeraHertz) had been demonstrated during the previous year (2010-2011). As a follow up of this work, the existing microwave cavity was redesigned during 2011-12. This work was done in collaboration with Asha K and Meena MS of RRI.

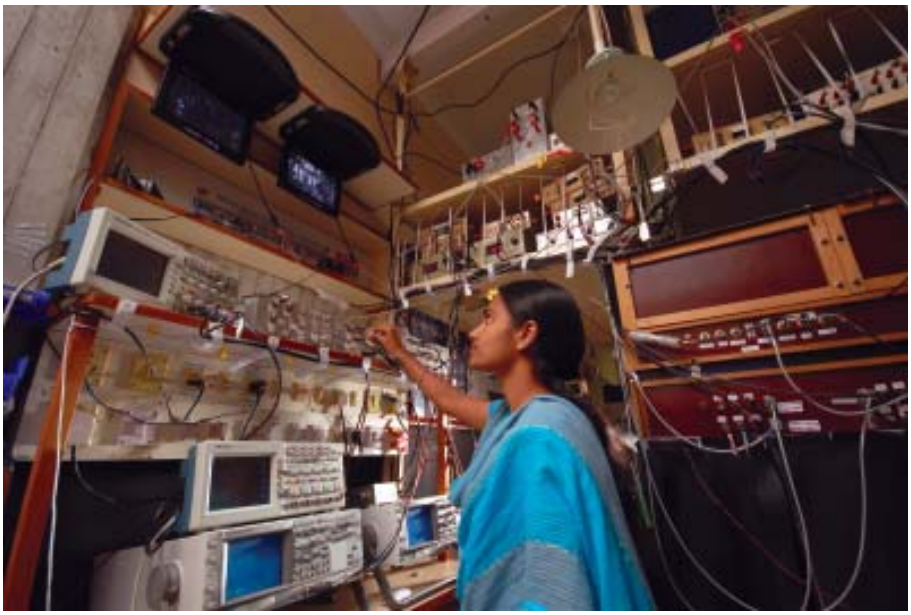
She also worked on a project, in collaboration with Pantita P and Alex Lvovsky of the University of Calgary (Canada), that aimed to introduce an ultra-narrow optical fibre (of diameter less than the wavelength of light used) into a Magneto-Optical (MOT) setup of ultra-cold atoms. The study was done with a fibre pulling setup to generate the thin optical fibre. The existing MOT setup was interfaced with a high speed DAC card for this purpose. In addition, a new vacuum module was set up with an octagonal chamber. An ultra-low pressures of 10^(-8) mbar was achieved with a turbo pump after bakeout in this setup.

Hema Ramachandran's areas of current professional research interests cover quantum computing/quantum logic, light propagation in random media and novel optical applications of nanomaterials.

During the year, Ramachandran pursued her work in quantum logic on two fronts – using light and using atoms. Quantum logic with photons and atoms requires the ability to manipulate single atoms and to detect single photons. In addition, the protocol intended on being used requires the ability to control very precisely and rapidly the phase of light. Ramachandran's efforts in the laboratory have been focused on achieving these capabilities. In this effort:

- It was demonstrated that electronically controllable precise phase shifts (as small as 0.010) on timescales as short as ~100ns may be imparted to light using the acousto-optic interaction. This has provided a new way of introducing phase noise to light, and of controlling the extent of dephasing. This is of particular importance in causing uniform spread of a quantum walker, desirable in a variety of applications like search algorithms, solar energy harvesting, photosynthesis, and communications. This work was done in collaboration with research scholars Nandan Satapathy and Deepak Pandey and Project Assistant MS Meena.
- With Pandey, Satapathy and Suryabrahmam, using appropriately tailored radio-frequency input, Ramachandran created light sources exhibiting different photon statistics. Further, the equivalence of detection of statistics in classical photodetectors and single photon detectors was demonstrated.
- She also worked on the building of a coincidence detector at the single photon level. This uses a pair of avalanche photodiodes, the outputs of which are fed to an NI data-acquisition card. Using LabVIEW, the system was programmed to count coincidences in detection and save them onto the computer for further processing if required. The system has a timing resolution of microsecond, limited by the data-acquisition card and the Windows environment. This system has been used to examine the second-order correlation function of a laser source and a pseudo-thermal source created using acousto-optically imprinted random phase noise. This was done along with Pandey and Suryabrahmam.

The setup to trap a single atom is in the final stages of completion. A few-atom MOT (100 atoms) has been created and a dipole trap has been superposed. A confocal imaging system has been built to observe the few atoms



collected in the dipole trap. The dipole trap now needs to be "tightened" to obtain single atom-trapping due to dipole-blockade. Ramachandran worked with Pandey and VSPs Soumya, Shahid, Mohammed Shafi and Akhil Raaj on this project.

The 3-D MOT for rubidium, which routinely traps about 109 atoms, has been functioning very reliably and robustly. Absorption imaging of the cold atoms has been setup. From simple rate-dynamics analysis, a more efficient trapping under certain detuning parameters of the laser beam is expected. This is currently being verified by experiments. This research was done in collaboration with Satapathy, Meena, project assistant D Dhanalakshmi and visiting scientist Vandna Gokhroo.

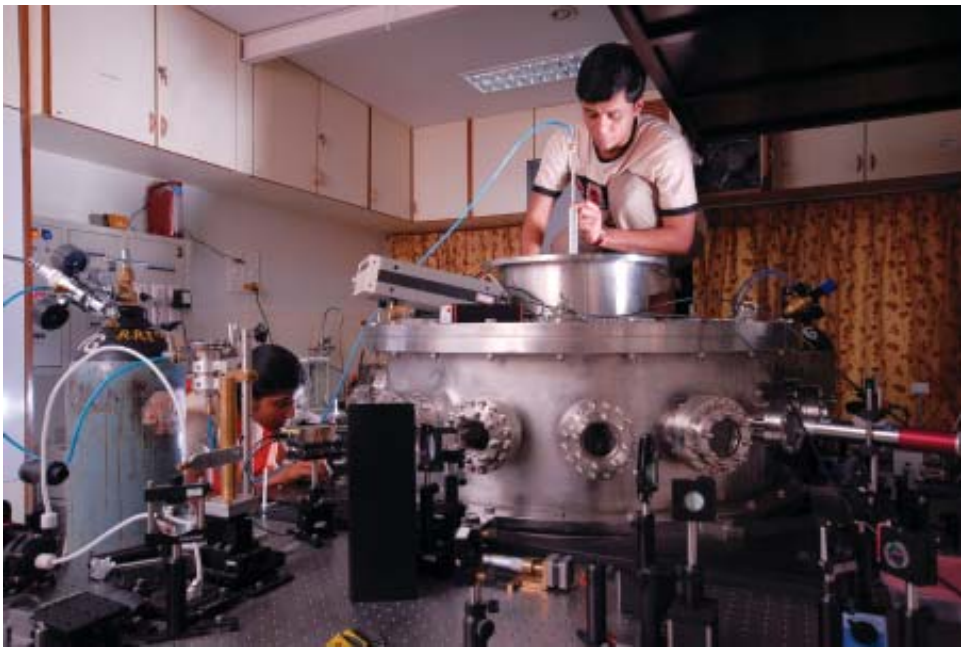
A recent theoretical work showed the existence of a non-local geometric phase in the intensity-intensity correlations in a polarised Hanbury-Brown Twiss interferometer. This could be considered the classical analogue of the non-local, two-particle Aharonov-Bohm effect. Using their technique of acousto-optic phase imprint, Ramachandran and her collaborators generated pseudo-classical light and demonstrated that this non-local phase indeed exists, as evidenced by the modulation in the second-order cross-correlation and the absence of this modulation in the self-correlation. The experiment was carried out with the help of Satapathy and Pandey, while the theory was worked out with J Samuel, Supurna Sinha and Poonam Mehta.

Ramachandran also studied light propagation in random media. The introduction of scattering polystyrene microspheres into a dye solution is known to lead to enhancement of light emission (random lasing) due to the increased dwell time of light within the medium caused by the multiple scattering. The introduction of nanospheres is, however, not expected to lead to such an enhancement, because of the sub-wavelength size of the particle. Nevertheless, preliminary experiments done at RRI have shown enhancement of light emission from a dye solution upon the addition of magnetite nanospheres. This is believed to be due to Dicke super-radiance and experiments are being conducted to verify this conjecture. This study was done in collaboration with visiting scientist Divya Sharma.

Reji Philip's research interests are in nonlinear optical materials and laser induced plasmas. Nonlinear optical transmission finds applications in optical switches, saturable absorbers and optical limiters. Philip's work includes the investigation of the nature and ultrafast temporal evolution of nonlinearity in various materials, particularly nano-particles and nano-composites. On the plasma front, his research also covers ultrafast laser-induced plasmas from liquid and solid targets kept under high vacuum as well as ambient pressure. The plasma spectrum contains high energy photons in the soft and hard X-ray regimes, as well as electrons and ions.

During the past year, he studied in detail the effects of disorder on the nonlinear optical properties of CVD grown polycrystalline graphene. Nanosecond Z-scan measurements done at two different wavelengths on single-layer, bi-layer and few-layer graphene films revealed that the crystallite size significantly changes the saturation intensity due to the influence of defect-induced states. He also studied the optical limiting properties of few-layer graphene (synthesised via reduction method), functionalised graphene, and metal-graphene composites. The strong nonlinear absorption in graphene is attributed to the large number of structural defects on its surface. It was shown that the optical limiting performance in graphene can be improved through acid functionalisation and metal decoration, where defect-induced states and inter band transitions contribute to the nonlinear absorption.

In another study, through a systematic measurement of nonlinear absorption coefficient in the nanosecond regime, Philip and his team confirmed the presence of mid-gap states which result in green luminescence in ZnO nanotetrapods. By annealing the sample in different atmospheres (O2, Ar and Zn), it was found that the mid-gap state density is strongly influenced by the Zn interstitials.



It is possible to generate radiation ranging from TeraHertz frequencies (wavelength H" 10 μm) to γ-rays (wavelength << 0.1nm) from laser-produced plasmas. X-rays generated from laser-produced plasmas have been of interest owing to a variety of applications, including time-resolved X-ray diffraction, X-ray lithography and microscopy. Philip has been able to investigate plasma produced from pure targets such as Zn, Ni, C, Al and Cu, using high-energy laser pulses of 7ns, 300ps and 100fs durations, respectively. In order to calculate the plasma parameters, techniques employed included laser induced breakdown spectroscopy (LIBS), time-resolved spectroscopy and ICCD imaging.

LIBS is an atomic emission spectroscopy technique which helps determine the elemental composition of the target under study. The goal of the LIBS experiments was to generate plasma emission spectrum of pure elemental metals and semiconductors under different ambient pressures. Plasma parameters such as plasma electron temperature and number density are then calculated. The LIBS studies were carried out in a pressure range of 760 Torr to 10-6 Torr.

Time resolved spectroscopic measurements involve the monitoring of time-dependent evolution of emission intensity of one or more plasma spectral lines. Time resolved studies were conducted in C, Zn, Ni and Cu targets using a monochromator-PMT combination. ICCD (intensified charge coupled device) imaging was used for taking photographs of the plasma plume at different time delays and gate delays, to record the evolution of the plasma plume over its lifetime.

Sadiq Rangwala's areas of current professional interest include ultra-cold molecules and quantum interactions. During the past year, Rangwala continued experimental work on the atom ion molecule, which is now producing results.

An apparatus and technique which simultaneously traps ions and cold atoms with spatial overlap was designed, motivated by the study of ion-atom processes at temperatures ranging from hot to ultra-cold. This is a largely unexplored domain of physics with cold trapped atoms, and the use of the set up for several problems in physics and chemistry were looked

into. For this, Rangwala worked in collaboration with K Ravi, Seunghyun Lee and Arijit Sharma of RRI and G Werth of the Institut für Physik, Johannes Gutenberg-Universität Mainz (Germany).

A mixed system of cooled and trapped, ions and atoms paves the way for ion assisted cold chemistry and novel many-body studies. Due to the different individual trapping mechanisms, trapped atoms are significantly colder than trapped ions, therefore in the combined system, the strong binary ion-atom interaction results in heat flow from ions to atoms. Conversely, trapped ions can also get collisionally heated by the cold atoms, making the resulting equilibrium between ions and atoms intriguing. The sympathetic and swap cooling of trapped ions by cold atoms in a magneto-optically trapp was demonstrated experimentally by Rangwala and his colleagues. Rubidium ions (Rb+) cool in contact with MOT Rb atoms, contrary to the general expectation of ion heating for equal ion and atom masses. The cooling mechanism is explained theoretically and substantiated with numerical simulations. The resonant charge exchange (RCx) collisions, which allows swap cooling of ions with atoms, wherein a single glancing collision event brings a fast ion to rest, was studied.

The atom loss rate from an MOT due to ion atom interaction is characterised on the basis of experiments, where trapped ions and MOT atoms are spatially overlapped. Using a set of rate equations, the dynamics of the MOT during the photo-ionisation of the 85Rb in the 5p3/2 state to ionisation continuum was studied. Subsequently, the dynamics of a combined trap were also studied. These experiments allow the measurement of atom loss rate as a function of intensity of the light source used for the photoionisation.

Rangwala also studied the photo-association of molecules from cold atoms in the presence of trapped ions. Cold molecules are created out of cold atoms either by a photo-associative process or by resonant free-bound scattering. The photo-associative path was explored, but with a crucial difference. The association was attempted in the presence of trapped ions. This is the first such experimental study anywhere in the world. The experimental results showed a significant decrease in the rate at which molecules are associated from the free atoms, over a limited but continuous range of association energies. Two significant possibilities that could yield such signatures are (1) the presence of ions inhibits molecular photo-association or (2) the ions open dissociation channels, and the dissociated molecules are recaptured in the MOT. Theoretical analysis and

critical detailed analysis of the experimental data should allow the determination of the dominant pathway.

Rangwala's research during the year included the study of atom-cavity interaction. The cold molecules project mentioned above needs extremely low light level detection. The most sensitive detection that is possible is resonant detection via cavities. Before attempting cold molecule detection, the technique for cold atoms must be proved. This involved an experiment each with negative logic switching and positive logic switching.

The transmission properties of a cavity containing atoms on resonance with laser light on resonance with the cavity, and the atoms in the cavity mode, was studied. Several interesting features in the laser atom-cavity system were explored. Most dramatically, the cavity mode can be completely switched OFF and ON by addressing the atoms in the cavity mode from the side. While the experiments are procedurally quite similar, the theoretical description is quite different and so are some of the effects observed.

A follow-up experiment for switching was constructed with potassium (K). The KD2 spectrum is very different from the Rb D2 spectrum and therefore significant differences are expected in the switching behaviour effected by the K vapour. The experiment was constructed and the atom cavity properties for this system were studied with great care. However no switching behaviour was observed despite best efforts. One possibility is that the K vapour pressure is too low for this experiment and this will be checked in the coming months. This is an interesting development and will be explored in the future mainly by project students.

An experiment for Molecule-Ion-Cavity-Atom (MICA) trap was tested and proven in the span of this year. In this case, Rangwala and his collaborators developed the possibility of trapping multiple species of atoms, ions and molecules simultaneously, within a high finesse cavity which is a trap for photons. All of these traps converge around a volume of approximately 107 cubic micro meters and allow for the interactions between these particles and fields to be probed at some of the coldest temperatures possible. Notable successes on this experiment during the year include:

- The creation of stable and controlled cold atoms in the cavity mode: This was by no means easy because the cooled atoms are expected to couple light into the cavity mode, which would disrupt the laser cooling of the atoms. The extent of the disruption in the cooling process is not easily calculable and so it is best to do the experiment. The creation of the MOT in the cavity mode was quite successful and one important objective was realised.
- Coupling of light from the cold atoms into the cavity: The light coupled from the atoms into the cavity was very significant in intensity and was coupled into a variety of modes. While this was expected, the density of modes populated was too large to work productively with. Systematic characterisation of the experimental operating conditions allowed the suppression of most of the unwanted modes and focusing attention on a few stable modes.
- Weak and strong coupling of atoms to the cavity: When the cavity, which is an optical resonator, is tuned so that it is resonant with the atomic medium contained within, there are two broad ranges of operation, (1) the weak coupling regime and (2) the strong coupling regime. This cavity has been designed to be in the weak coupling regime for a single atom within the cavity mode. However, when the number of atoms in the mode increases to about a

1,000, the atom cavity system goes well into the strong coupling regime. This is a major milestone for the experiment as it opens the window to cavity QED on these experiments, as well as allowing experiments with small numbers of photons and atoms, where the system properties can be measured using frequency measurements instead of intensity measurements. Extension of this class of measurement has never been done for any molecular system anywhere and is now an important experimental goal for the future.

Many experiments in the QuaInt lab concern particles and transition from isolated particles to cooperative behaviour and response. These are regimes where single particle physics, which forms the basis of our overall understanding of related physics, falls seriously short of providing adequate explanation for the experiments.

Thus, a parallel programme of simulation of the experimental systems is conducted so that a detailed understanding of the physics emerges. During the past year, several numerical simulations were implemented to enable a better understanding of the physics problems thrown up by the experiments.

The simulations include:

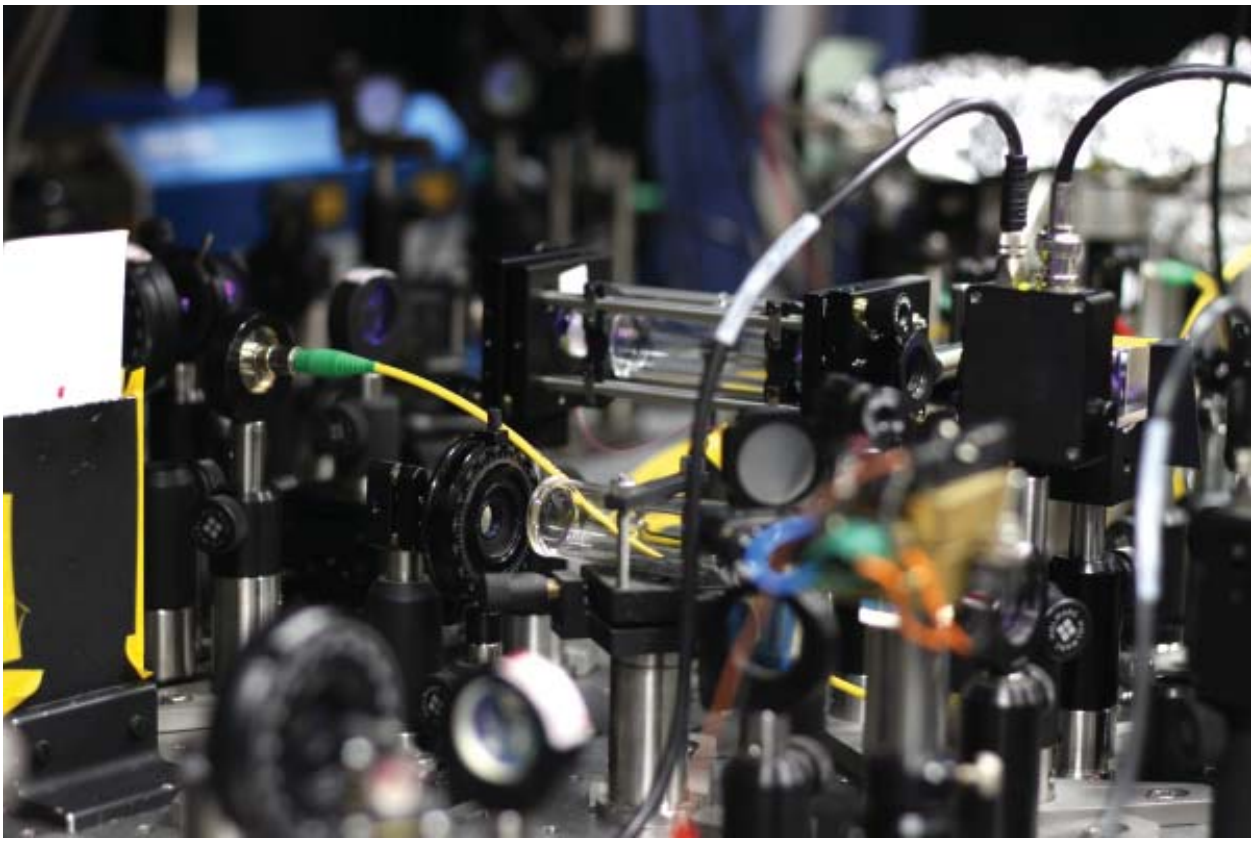
- Molecular dynamics simulations which evolve thousands of interacting ions simultaneously in the ion trap: This allows researchers to follow the evolution of "n" interacting ions at a given temperature with time. It helps them relate to the situation in the experiment at an ion level.
- Multiple scattering of trapped ions with trapped atoms: This allows the study of the evolution of "n" non-interacting ions, one at a time, within an atomic gas. The ion-atom scattering is calculated in detail and the evolution of the trapped ion within the atomic cloud and its change in energy is tracked with time. The elastic and the inelastic (charge exchange) channels are both calculated within this simulation, which helps make connections with the experimental situation.
- Atom light and atom cavity interactions: An attempt was made to understand the dynamics of the state population in the presence of the multiple light fields with various intensities and detuning. The specifics for these simulations are evolving to address the physics coming out of the MICA experiment.
- Molecular potentials and molecule formation simulation: This is a very critical simulation for future molecular formation experiments. Here it is required to determine the asymptotic molecular potentials so that the atom-molecule transition rates and populations can be accurately determined. What makes these simulations exceedingly challenging is that the potentials are required to very high accuracy to help with the experiment interpretation and to have the required predictive value to plan new experiments.

Postdoctoral fellow **T Priya Rose**'s research interests are ultrafast laser induced plasma in liquid droplets.

Laser produced plasmas are known to emit intense electromagnetic radiation. It is possible to generate radiation from Tera Hertz frequencies to gamma rays. Apart from the fundamental interest in diagnosing the dynamics of laser plasmas, X-rays generated from laser-produced plasmas have been of interest owing to the variety of applications like time-resolved X-ray diffraction, X-ray lithography and microscopy. The advantage of using a droplet as the target is that it can act like a lens and focus the light incident on it. Thus the electric field inside the droplet can act like a lens and focus low-intensity light incident on the droplet can far exceed the incident laser field.

As an initial step, Rose set the experiment to run in atmospheric pressure. Micro droplets of ethanol were generated using a piezo-capillary. It was driven by applying a signal of amplitude 5V with 1MHz. The laser used for producing the plasma is a Ti:sapphire chirped pulse amplification system at 800 nm. The laser is focused to the droplets using a convex lens. Rose is currently working towards synchronising the laser pulses with the droplet jet. The plasma will later be characterised by various techniques like spectral analysis, time-resolved studies, etc.

J Solomon Ivan's area of current professional research interest is the quantum information theory. During the year gone by, Ivan continued his research into unsolved problems such as the entanglement of formation for two-mode Gaussian states. He also spent substantial time in attempting to understand the theory of positive maps. He has had frequent discussions with Deepak Pandey, Nandan Sathpathy and Buti Suryabrahmam of RRI with regard to the ongoing experiment on tailoring a classical resource. The attempt of the experiment is to convert a coherent light source from a laser to a light source with a desired classical feature. The simplest example is the conversion of coherent light to thermal light. Such a convertability can lead to various practical applications. Ivan's assistance to the above mentioned three experimentalists has essentially been on the theoretical side, especially on suggesting to them a scheme which directly implements the Sudarshan diagonal representation (at a classical level) in achieving the desired end. Data acquisition is ongoing, with the acquired data thus far being in line with the theory.




SOFT
CONDENSED
MATTER

Overview

The Soft Condensed Matter (SCM) group concentrates its research activities in the area of liquid crystal synthesis, characterisation and other analysis of their physical properties. The group has also expanded its activities to investigate other soft condensed matter like polymers, colloids, amphiphilic systems and nanocomposites.

Theoretical and experimental research today includes the well-established area of liquid crystal synthesis and characterisation as well as electrochemistry and surface science, liquid crystal displays, rheological studies of soft condensed matter and biophysics. The research environment of the SCM group is highly interactive with constant knowledge sharing and exchange of ideas among chemists, electrochemists, condensed matter physicists, theoretical physicists and members with statistical physics expertise.

The following pages summarise the major areas of research for the SCM group. Each member's individual work during the last year is provided in the next section, giving the reader more detailed and technical description of their respective research activities.

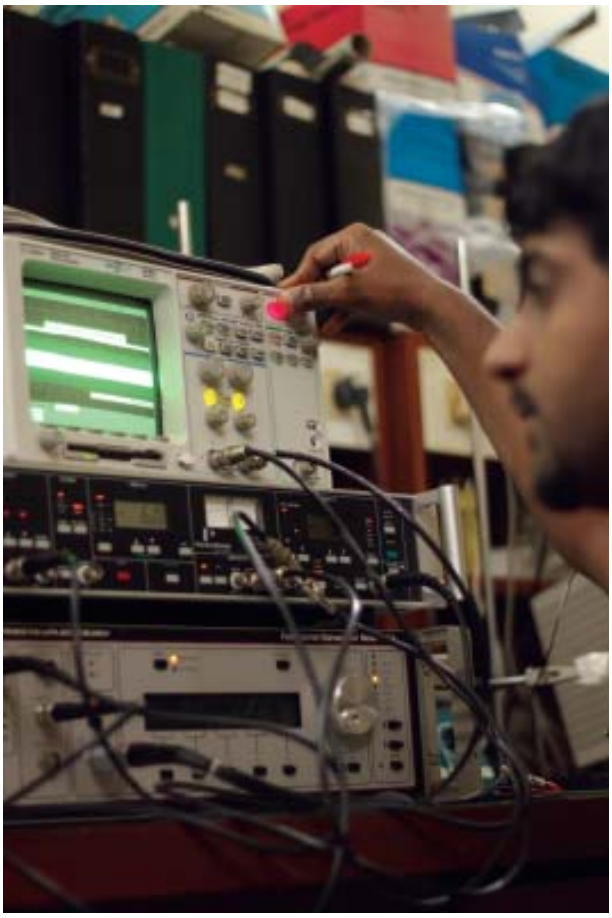
LIQUID CRYSTALS

The chemistry wing of the SCM group is involved in the synthesis and characterisation of a number of molecules, including bent-core mesogens, discotic mesogens and nanocomposites. Over 700 bent-core mesogens – mesomorphic banana-shaped or bent-core molecules – have been synthesised and characterised. In addition to many novel mesophases, these compounds show interesting features such as spontaneous electric polarisation and chiral structures made up of achiral molecules. Several new liquid crystalline phases and phase sequences have also been achieved.

The lab has also designed, synthesised and characterised novel discotic liquid crystals that exhibit remarkable electronic and optoelectronic properties, including various monomeric, oligomeric, polymeric and ionic liquid crystalline materials containing disc-like mesomorphic units. The synthesis of liquid crystalline materials using microwave heating has also been carried out with a view to find quick and environment-friendly synthetic routes.

The incorporation of nanomaterials like gold-nanoparticles and carbon nanotubes in the supramolecular order of liquid crystals is likely to lead to novel materials for many applications. Such nanocomposites have been prepared and are being characterised.

The SCM group also studies phase transitions, the structure and physical properties of thermotropic liquid crystals and their mixtures as well as various types of topological defects and patterns in liquid crystals. Recent years have seen the discovery of several new liquid crystalline phases, such as the undulating twist grain boundary phase and the biaxial Smectic-A phase. Another area of interest is instabilities and pattern formation in thermotropic liquid crystals under shear flow and/or external electric fields. Surface-induced effects in liquid crystals are also being explored.



Research is also being done to help reduce power dissipation and hardware complexity of drive electronics in passive matrix Liquid Crystal Displays.

COLLOIDS

Investigations are being carried out into the ageing dynamics of colloidal systems, such as aqueous suspensions of synthetic clay. Rheological techniques are used to study the effects of strain history and sample age on their relaxation spectra. The results demonstrate that stress relaxation measurements can be effectively used to estimate the relaxation times of these samples. Dynamic light scattering (DLS) and diffusing wave spectroscopy (DWS) experiments are also being set up to study the dynamics of these complex fluids.

The SCM group has set up a Hele-Shaw cell to study the fingering instability at the quasi two-dimensional interface between an ageing clay suspension and a Newtonian fluid. The effects of differences in the densities and viscosities of the two fluids on the fingering instabilities are being studied.

AMPHIPHILIC SYSTEMS

Rheology of micellar soft-solids: Pluronic triblock copolymers self-assemble to form micelles in aqueous solutions as a result of their amphiphilic nature. The temperature-concentration phase diagram of this system, which exhibits the intriguing phenomenon of inverse crystallisation, has been determined from rheological data. These studies clearly demonstrate the soft solid-like nature of these materials.

Magnetic susceptibility studies: Studies of the magnetic susceptibility of micellar solutions and lyotropic nematic liquid crystals provide insights into the role of bound water and molecular organisation in these systems. Similar studies on inverse micellar systems are currently underway.

Phase behaviour of ionic surfactants: The influence of strongly bound counterions on the phase behaviour of ionic surfactants is being investigated using X-ray diffraction and polarising light microscopy. The aim of these studies is to look at novel surfactant aggregate morphologies and novel phases induced by these counterions.

Structure of DNA-surfactant complexes: The influence of different types of counterions on the structure of DNA-cationic surfactant complexes has been investigated using X-ray diffraction techniques. Novel structures of these complexes are found to occur in the presence of strongly bound counterions.

Organisation of sterols in membranes: The phase behaviour of lipid membranes containing different sterol molecules is being studied using X-ray diffraction and fluorescent microscopy techniques, with a view to understand the organisation of these biologically important molecules in the membrane.

POLYMER PHYSICS

Investigations are being made into the morphologies of polyethylene single crystals. The crystallisation of high molecular weight polyethylene from melt or solution leads to the formation of tent-like structures. The stability of these structures has been probed using a free-energy expression based on membrane elasticity. Tent-like structures have been found to arise due to the tilt of the polymer chains with respect to the layer normal.

BIOLOGICAL PHYSICS

The group's study of cellular dynamics is driven by the primary interest to understand force generation, locomotion and transport processes in cells, including neurons. For this, they have designed novel experiments to perform quantitative measurements on a variety of simplified cell systems. They are also designing experiments to investigate stem cell differentiation and patterning. This is an interdisciplinary approach, which involves active collaborations with biologists and theoretical physicists, at both local and international levels.

PHYSICAL CHEMISTRY OF SURFACES

The principal research subjects in this area include the study of supercapacitors as energy storage devices, the effect of applied magnetic field on electrodeposition, studies on molecular self-assembly of organic thiol molecules on noble metal surfaces, and carbon nanotubes for electron transfer studies as well as a chemical sensor.

Ongoing Research

Arun Roy's current research interests include phase transitions and electro-optic properties of liquid crystals, mean field phenomenological modelling, and the physics of nano-materials and nano-composites.

During the year gone by, Roy continued his investigation from the previous year of the phase behaviour and the physical properties of a new homologous series of compounds consisting of the hockey-stick shaped molecules that were synthesised in RRI's chemistry laboratory. This study was in collaboration with BK Sadashiva, R Pratibha, Meenal Gupta and S Radhika of RRI. Polarising optical microscopy (POM), differential scanning calorimetry (DSC), X-ray diffraction (XRD) and dielectric studies were carried out to characterise the different phases. The team reported experimental evidences for two new fluid lamellar phases exhibited by a homologous series of bent-core hockey-stick shaped molecules having triclinic point symmetry of the layers. The packing of these bent-core hockey-stick shaped molecules in the layers leads to an apolar intercalated strongly biaxial layer structure in these tilted smectic phases. These smectic phases are the lowest symmetry achiral liquid crystalline phases reported so far in the literature.

Along with the same team, Roy reported on the two types of vitrified states formed from the dark conglomerate (DC) liquid crystal phase by two members of a homologous series made of bent-core molecules under different cooling procedures. These states were characterised using POM, DSC, XRD, electro-optics, dielectric spectroscopy and atomic force microscopy. The results showed that though the vitrified state formed on gradual cooling of the sample from the DC phase has some glassy feature, it is fragile and unstable against crystallisation over time. On the other hand, direct quenching of the DC phase to room temperature results in

stronger glass formation. It was proposed that the vitrified state obtained on progressive cooling of the DC phase may have some analogy to strain glass and that the DC phase itself may be rather like unfrozen starin glass.

Another of Roy's research themes for the year was the design and synthesis of six new series of anthraquinone-based monomers and dimers as well as studies on their structure, specifically the property relationship with respect to their liquid crystalline properties. This research was in collaboration with Veena Prasad and students NG Nagaveni and K Gayathri of the Centre for Soft Matter Research, Bangalore. The chemical structures of these newly synthesised compounds were characterised by IR, NMR and mass spectroscopy. The liquid crystalline properties were investigated using POM, DSC and XRD studies. Most of the compounds synthesised here were found to be liquid crystalline. In many cases, the mesophases stabilised up to room temperature. A variety of mesophases was exhibited – colr, colh, DL and an unidentified mesophase, Roy and his collaborators attempted to propose a molecular model in the discotic lamellar phase of one of the dimer compounds based on the X-ray data obtained.

Roy, with Prasad and Nagaveni, also designed, synthesised and reported mesomorphic properties of six new homologous series of azo – substituted bent-core compounds. They investigated the effect of different types of linkage groups and their direction of linking on the mesomorphic properties. The study was focused on the photochromic bent-core materials, and all the compounds synthesised consisted of an azo linkage in their molecular architecture, in addition to other linkage groups. The molecular structures of these newly synthesised compounds were characterised by spectroscopic methods. The liquid crystalline properties were studied using POM, DSC, XRD and electro-optical studies. Mesophases observed in these compounds were N, B1, B2, SmA, SmAdPA. It was found that the type and direction of linkage group do affect the thermal range or sometimes even the nature of the mesophases. Photo-induced effects on B2 mesophase of some of the selected compounds were also carried out.

D Vijayaraghavan's areas of professional research interests span nanoparticle-liquid crystal composites, magnetic properties and physical studies.

During the year, part of his research was based on his interest in studying the mass diamagnetic susceptibility of micellar systems in general and lyotropic liquid crystal systems in particular to look for any structure-(magnetic) property correlations. He carried out magnetic susceptibility studies on a ternary lyotropic liquid crystal system [sodium decylsulfate(SdS)/ decanol/water] for two different concentrations of the constituents. This system exhibited nematic, isotropic and hexagonal phases on heating. The isotropic phase in this system exhibited admixtured and pure phases. Correspondingly, findings included a temperature dependent susceptibility at low temperature and a temperature independent susceptibility at high temperature isotropic phases. Diamagnetic anisotropies in the nematic phases of these samples were calculated by extending the pure isotropic phase susceptibility in the nematic region. For the sample containing a high concentration of surfactant and low concentration of alcohol, the diamagnetic anisotropy value is small and found to be temperature independent. In the case of the sample containing a low concentration of surfactant and high concentration of alcohol, the diamagnetic anisotropy is about six times higher and also temperature dependent. This marked difference in diamagnetic anisotropy between the two samples is attributed to the difference in shape of the micelles present in these samples.

Vijayaraghavan also carried out differential scanning calorimetry (DSC), magnetic susceptibility and electrical conductivity studies as a function of temperature on these ternary lyotropic liquid crystal systems. On heating, the DSC thermogram exhibited peaks corresponding to nematic and hexagonal phases. However, on cooling, the peaks were absent, indicating that the liquid crystalline phase is absent on cooling the system. Temperature dependent hysteresis was found in the electrical conductivity and magnetic susceptibility studies as well. The hysteresis in the diamagnetic susceptibility was attributed to the difference in temperature dependence of micellar sizes on heating and cooling. The inference from these studies is that changes in the micellar sizes may lead to changes in the viscosity of these systems and leads to the observed hysteresis in the electrical conductivity of the systems.

He also carried out mass diamagnetic susceptibility, AC and DC electrical conductivity studies on two nonionic micellar systems namely, Triton X-100 (TX-100)/water and Brij-35/water systems. It is known that the TX-100/water system exhibits hexagonal (H) and isotropic phases (I) for 40 to 60 wt% of TX-100 in water. The TX-100 system also exhibits clouding behaviour on heating resulting in a two-phase region consisting of micellar rich and micellar poor regions in water. Discontinuous changes at the HI phase transition temperatures as well as at the cloud point temperatures in the TX-100 system were found. Comparing the reported temperature dependence of the micellar sizes studied through NMR with that of magnetic susceptibility, it was inferred that the diamagnetic susceptibility is directly related to the sizes of the micelles. It was found that the electrical conductivity follows Arrhenius relation and exhibits slope changes at the cloud point temperatures in the conductivity-temperature plots. Vijayaraghavan calculated the activation energies for conductivity in these systems and found them to depend on the concentration of the surfactant. This led to the inference that the AC electrical conductivity depends on the degree of hydration of the micelles in both the systems. Temperature dependence of DC conductivity in these systems is similar to that of the reported degree of hydration of the micelles studied through light scattering studies in both the systems.

Other research by Vijayaraghavan, in collaboration with Ashok Kumar, included magnetic susceptibility studies on phospholipid vesicles and bicelles. Phospholipids in water form multilamellar vesicles and a mixture of long-chain and short-chain

phospholipids in water form disc-like micelles or bicelles on appropriate conditions. Mass diamagnetic susceptibility studies were undertaken on the pure DPPC/water and DMPC/water systems with the addition of various concentrations of cholesterol. In the absence of cholesterol, the temperature dependence of susceptibility for both the systems exhibits a sharp peak at the gel-to-liquid crystalline phase transition temperature. These peaks broaden and disappear on increasing the cholesterol concentration. It was found that the susceptibility of the ternary system markedly depends on the cholesterol concentration. Temperature dependence of mass diamagnetic susceptibility studies on the DMPC/DHPC/water systems were also conducted for various concentrations of the constituents. Marked discontinuous changes at the reported phase transition temperatures for these systems were found. Vijayaraghavan and Kumar related the temperature dependent susceptibility variations to that of the shape anisotropy of the bicelles.

Pramod Pullarkat's research interests lie in the areas of biophysics in cell dynamics, locomotion, cell cytoskeleton, transport and dynamics in axons.

During the past year, Pullarkat continued his work probing the mechanical properties of axons and other soft materials under extension. This research was in collaboration with PhD student Seshagiri Rao, Chirag Kalelkar from MIT (USA) and Ashish Lele of National Chemical Laboratories in Pune. An optical fibre based force measurement device was used to probe the viscoelastic properties of polymer melts and reconstituted silk. The setup was completed with the addition of a feedback loop to independently control force and extension and a quadrant photodiode for high sensitivity (nano-meter) high speed (tens of kilo-hertz) measurements.

New applications for the force setup were found and experiments to probe polymer melts under extensional flow were performed. Such measurements are critical in understanding material properties during fibre extrusion. The novelty of the setup is in the filament diameters it can probe – thin filaments with only a few tens of microns in diameter can be studied using microscopic amounts of sample. Using this technique, Pullarkat and his collaborators made systematic measurements in PDMS of a test material. Preliminary tests were also performed on reconstituted silk. The data is being analysed.

Pullarkat and his collaborators made progress in probing active suspensions by monitoring the fibre fluctuations in bacterial suspensions. Swimming E-coli bacteria produce forces of about a pico Newton, large enough to be sensed by the optical fibre setup. Statistical analysis of the fluctuations revealed significant deviations from pure brownian dynamics, and the nature of these deviations depends on the type of motion the particular strand of bacteria exhibit (tumbling vs. running). They compared the fluctuation data with brownian dynamics of a free tracer particle in bacterial suspension. These experiments reveal super-diffusive regimes which are of interest. The next steps for the research include tests on axonal mechanics.

Along with Anagha Datar and Roli Srivastava of RRI and Aurnab Ghose of IISER, Pune, Pullarkat continued with experiments to quantify the beading process (also known as pearling instability) in axons of tissue-cultured neuronal cells. They have now acquired the ability to fluorescently label specific cytoskeletal components. They first developed immunofluorescence techniques (using primary and secondary antibodies) to label the different cytoskeletal filaments and to follow changes in their distribution during beading. Subsequently they started genetically modifying live primary neurons to make them express fluorescent proteins of interest to enable live cell imaging.

They carried out a number of quantitative experiments, some using new techniques, and are currently analysing the data. They have also initiated a collaboration with colleagues at Institute Curie to develop theoretical models for the beading or pearling instability based on the experimental findings.

During the year, Pullarkat also studied pattern formation in differentiating stem cells. Stem cell differentiation into specialised cell types can be moderated by controlling the stiffness of the substrate they grow on. The mechanism responsible for this stiffness sensitivity is not understood. One line of thought relates changes in the geometry of cell nucleus to its gene expression profile. Pullarkat performed a series of experiments (with quantitative results) aimed at understanding the relation between cell spreading and nuclear geometry in stem cells. He was able to show that the stress on the nucleus is related to the extent of spreading and is independent of the mode by which cell spreading is regulated. This points to a simple mechanical relationship that is being studied in greater depth. Characterisation of the substrates with gradient stiffness, prepared with a home-developed setup, is underway. This research was in tandem with Renu Vishavkarma of RRI and Jyotsna Dhawan of INSTEM, Bangalore.

R Pratibha's research interests lie in the field of liquid crystals, specifically their nano composites.

During the past year, she studied strain glass analogue in a bent-core liquid crystal exhibiting the dark conglomerate phase. Vitrified states formed from the dark conglomerate (DC) liquid crystalline phase, exhibited by two members of a homologous series derived from 2,7-dihydroxynapthalene made of bent-core molecules, were characterised using a variety of experimental techniques like optical microscopy, differential scanning calorimetry (DSC), x-ray diffraction (XRD), electro-optic studies, dielectric spectroscopy and atomic force microscopy. The results show that two different types of vitrified states are formed depending on the cooling procedure.

One of them, obtained on gradual cooling from the DC phase, exhibits glassy features that have structural similarity with the DC phase as evidenced by XRD and optical studies and a non-Debye behaviour with one of the dielectric relaxation modes satisfying the Vogel-Fulcher-Tamman (VFT) relation. However, this vitrified state is of fragile nature and unstable against crystallisation over time. On the other hand, the vitrified state obtained by direct quenching of the DC phase to room temperature results in stronger glass formation.

The difference between these two types of vitrified states has been explained invoking the basic structure of the DC phase. It is now well established that the DC phase is characterised by focal conic domains (FCDs) with negative Gaussian curvature along with saddle splay layer deformation and absence of long range ordering. Pratibha proposed that a random distribution of the FCDs can create random local strains, resulting in disorder on a longer length scale, making the DC phase somewhat similar to unfrozen strain glass. In such a case, a gradual lowering of the temperature can cause the FCDs, and hence the local strains, to become locally ordered resulting in a transition into the X phase, which is a form of vitrified state similar to strain glass. However when the sample is suddenly quenched from the DC phase to room temperature, the time required for rearrangement of the FCDs, and therefore the local strains, is not sufficient and the disorder present on the longer length scale gets frozen, resulting in a more stable vitrified state.

Pratibha put forth experimental evidence for lowest symmetry achiral smectic liquid crystalline phases in compounds made of bent-core hockey stick shaped molecules. The generalised smectic phase (SmCG) proposed by

de Gennes corresponds to a tilted lamellar phase of fluid biaxial layers. In such a phase, macroscopic tensorial quantities like the dielectric and diamagnetic susceptibility are neither orthogonal nor parallel to the layer planes. Such systems possess only inversion symmetry and belong to the triclinic Ci symmetry class. However, if the molecules constituting the smectic phase have a bent shape, spontaneous polar order becomes possible, the inversion symmetry is removed

and the system becomes chiral and belongs to the symmetry class C1 of the lowest symmetry fluids. Experimental studies have been carried out on a compound composed of bent-core hockey stick shaped molecules and have found the occurrence of two new types of smectic phases. Optical, X-ray, dielectric and electro-optic studies show that these smectic phases have triclinic Ci point symmetry of the layers. This has been attributed to a special type of intercalated packing that is possible because of the shape of the molecules forming the compound. These smectic phases are the first examples of lowest symmetry achiral liquid crystalline phases.

Composites materials composed of liquid crystals and nanomaterials are being investigated intensely because of the prospect of obtaining interesting and improved material properties for practical applications. Pratibha continued her work in this field with investigations of the combination of zinc oxide (ZnO) nanoparticles and a discotic liquid crystal. ZnO nanoparticles possess special properties like luminescence, high electron mobility and optical transparency. They are of interest because of their possible use in light emitting diodes, field effect transistors and solar cells. On the other hand, discotic liquid crystals which form columnar structures are known to have applications as one-dimensional conductors and in light emitting diodes and photovoltaic solar cells. The insertion of ZnO nanoparticles into the columnar matrix can therefore lead to novel functional materials. Pratibha has been carrying out experimental investigations on composites of a discotic liquid crystal and ZnO nanoparticles and has evidence for increased stability of the columnar matrix and an improved stacking of the discs within the columns. Such a stacking can aid in providing an efficient path of electrons and holes along the column axis resulting in high conductivity.

During the past year, Pratibha undertook studies on switchable columnar phases to investigate in detail switching mechanisms and the related structural changes. The spontaneous polarisation present in columnar phases exhibited by bent-core molecules can

either be perpendicular or parallel to the column axis. Liquid crystalline phases pertaining to the former and latter types are designated as the B1 phase with a non-centred unit cell and the B1rev phase with a centred unit cell, respectively. Further, in the B1rev phases the molecules can be either non-tilted or tilted. Unlike in the B1 phase, spontaneous polarisation in the B1rev phases can be reoriented by an external field. The mechanism of switching in polar columnar phases made of bent-core molecules can be quite complex as it involves a collective rotation around the molecular long axes in the non-tilted version and a competition between collective rotation around the molecular long axes and rotation around the tilt cone in the tilted versions.

Ranjini Bandyopadhyay's areas of professional research interest include structure, dynamics and rheology of non-Newtonian fluids; ageing and soft glassy rheology; flow-structure correlations in complex fluids; targeted drug delivery; interfacial instabilities; sedimentation of colloidal suspensions and the physics of granular media.

During the year gone by, Bandyopadhyay studied the rise of an intruder in a quasi 2D granular bed. A single large intruder embedded at the bottom of a vertically and sinusoidally vibrated quasi two-dimensional rectangular cell packed with mustard seeds rises to the top. For a range of relative density ratios, intruder sizes and bed heights, the intruder rise time, measured at several angular frequencies and peak-to-peak amplitudes, varies as a function of these parameters as well as the critical vibration velocity (vc) for the onset of convective motion of the mustard seeds. The velocity of convection of the mustard seeds at the walls is independently estimated using high speed digital video tracking and is found to be in very good agreement with the values of vc obtained earlier. These experiments prove unambiguously that boundary-driven granular convection is responsible for the rise of the intruder in quasi two dimensions and that the peak-to-peak velocity of shaking, rather than the peak-to-peak acceleration, is the relevant parameter for describing the results. This study was done in collaboration with Prakhyat Hejmady, Sanjib Sabhapandit and Abhishek Dhar.

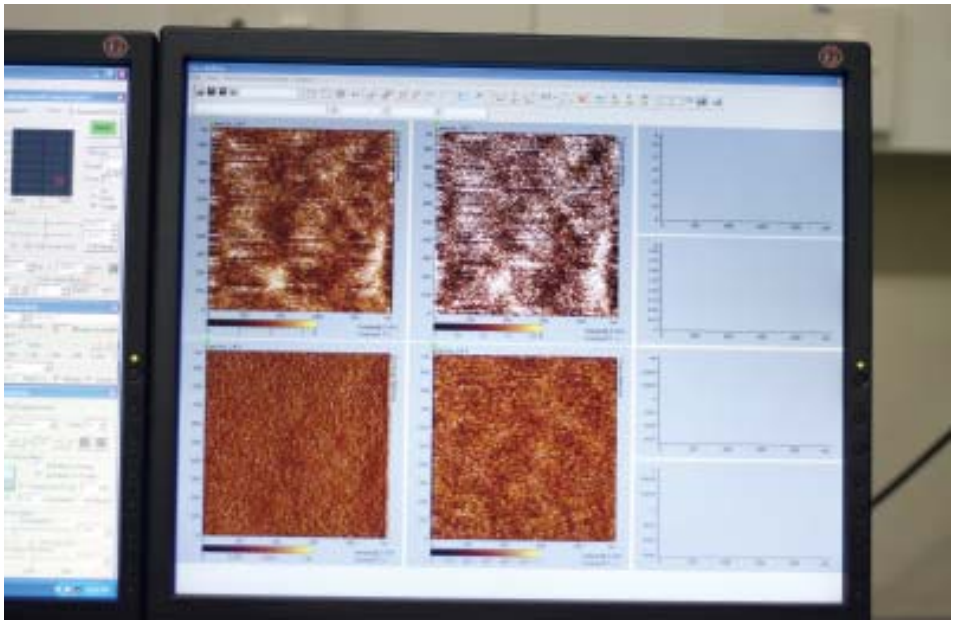
Research was continued on the caging dynamics in colloidal glasses of laponite in collaboration with Debasish Saha of RRI and Rama Govindarajan of JNCASR. The glassy state is an out-of-equilibrium, disordered state of matter that originates due to the jamming or freezing of the constituents comprising the system. Colloidal glasses are soft glasses (their shear modulus is much lower than that of hard glasses) and exhibit all the properties typically expected in hard glassy materials – jamming, disorder and non-equilibrium ageing behaviour. "Ageing" is a phenomenon in the glassy state wherein the motion of the constituents appears to be arrested and the dynamics of the system continues to slow down with time. In this study, Bandyopadhyay and her collaborators addressed the various issues regarding glass formation in the context of ageing colloidal suspensions prepared by dissolving a glass former (laponite – a synthetic hectorite clay) in highly deionised water. In colloidal glasses, the constituent particles or clusters are trapped in cages formed by their neighbours, which restricts their motion and slows down their dynamics. Such caging dynamics, whose time scales are typically expected to be 1-100 μs, were studied by Dynamic Light Scattering (DLS) experiments. The intensity autocorrelation function (ACF) exhibited by a glassy laponite suspension has a stretched exponential form due to the presence of competing relaxation rates in the system. The origin of this non-exponential decay in ageing colloidal glasses was investigated in systematic experiments. Further study will include detailed investigation of the length scale-dependence of the fragility of the colloidal glasses as well as the possibility

of a gel-like microstructure of laponite suspensions in salt-free conditions.

Block copolymers such as F127 find important uses in diverse industrial and technical applications and as novel agents in drug and gene delivery applications. Bandyopadhyay and Rajib Basak studied the changes in F127 micellar morphology on the inclusion of the painkiller drug ibuprofen (IBF) in the hydrophobic core. They used Dynamic Light Scattering (DLS) to estimate the changes in the sizes and critical micellisation temperatures (CMTs) of F127 micelles when IBF is encapsulated in the hydrophobic micellar core. Thus far, they have succeeded in encapsulating up to 1g/cc IBF in a 0.5 wt.% F127 micellar solution and DLS experiments have been completed on several F127 samples with encapsulated ibuprofen. Analysis of the data shows that the F127 micelles become increasingly compact on the inclusion of IBF. This is attributed to the increase in the hydrophobicity of the micellar aggregate upon incorporation of IBF. It was also found that the sample CMT decreases on the inclusion of IBF, confirming previous results that micellisation of F127 copolymers is accelerated in the presence of IBF.

Investigations continued into the physics behind pattern formation at the quasi 2D interface between a Newtonian fluid (such as water) and an ageing non-Newtonian fluid (such as an aqueous suspension of laponite). The injection of a low viscosity fluid into a more viscous fluid results in the Saffmann Taylor fingering instability. These finger patterns are ubiquitous in technological applications, such as in the percolation of oil in porous rocks, and understanding them is important. Laponite is first injected through the central hole of a radial Hele-Shaw cell and allowed to age for a pre-determined time. Next, the dyed Newtonian fluids (water and CCl4 are both used to check the role of fluid miscibility on the fingering instability patterns) are injected in separate experiments, and the patterns that form due to interfacial instabilities are recorded by a digital camera. It is found that the fractal dimensions of the patterns change significantly as the age of the Laponite suspension changes. Saha, Hejmady and Govindarajan have also contributed to this research.

Basak and Bandyopadhyay worked on estimating the variations in the yield stresses and the critical shear rates for thickening and banding phenomena observed in cornstarch suspensions with changes in its concentration. The light scattering patterns are being analysed using Matlab to extract I(q) vs. q (where I(q) is the intensity at a wavevector q), the anisotropy of the patterns and their orientation angles. The dependence of rheological data (such as the flow curve) and creep



curves on the thickness of the sample cell and therefore the extent of shear banding is being investigated.

The terminal velocities that a ball attained during its fall through laponite suspensions of various ages were estimated during the year, and the effective viscosity of the laponite medium surrounding the falling ball (i.e. its "microviscosity") was calculated from a Stokes Einstein equation, after incorporating corrections for high Reynolds number flows (Re~ 25 for low laponite ages) and wall effects. These microviscosity results were compared with rheometric estimates of the zero-shear bulk viscosities of laponite suspensions of the same ages. It was observed that when the ball fell through laponite suspensions of ages less than 4 hours, the calculated microviscosity values were much lower than bulk viscosity estimates, implying that the ball rejuvenates the boundary layer surrounding it as it falls through these laponite samples. For "older" laponite suspensions (suspension where age is greater than 4 hours), the microviscosity estimates are higher than the bulk viscosity values. Presumably, this occurs as the repulsive electrostatic interactions in the older laponite suspensions are long-ranged enough that the effective volume of the laponite clusters reaches the random close packing limit. The falling ball therefore struggles to find a path between the laponite particles, which is manifested as an increase in the microviscosity of the surrounding medium. Bandyopadhyay, along with Debasish Saha and Skanda Vivek of RRI and Rama Govindarajan of JNCASR, proposed a simple toy model (a Poisson Boltzmann equation for a 1-D array of discs) to understand their results in terms of the swelling of laponite clusters due to the percolation of water between the layers of laponite particles.

The sedimentation of colloidal gels and glasses of the natural clay bentonite was studied in collaboration with Samim Ali. The sedimenting front was tracked using a CCD camera and the sedimentation velocity of the front was calculated. Three distinct regimes were unearthed from the sedimentation data: an initial quiescent regime where there was no sedimentation, followed by a regime of transient collapse and finally, a logarithmically slow compaction regime. Additionally, it was found that in the transient collapse regime, for large enough salt concentrations, the sedimentation velocity increased linearly and then decreased exponentially. The extents of the three regimes were found to be sensitive to the method of sample preparation. The following three methods were used: salt was added to water before bentonite, salt was added soon after the addition of bentonite to water and salt was added to bentonite suspensions of age seven days or more to allow the bentonite platelets to first delaminate completely. Attempts are being made to model the data acquired using a poroelastic model.

Sandeep Kumar's research interests cover the design, synthesis and applications of various liquid crystalline materials and understanding the structure-property relationship in self-assembling supra-molecular architectures.

In the field of liquid crystal nanoscience, his research during the year involved investigating the thermo physical properties of liquid crystal nanocomposites, specifically cadmium selenide quantum dots (QDs) dispersed in a discotic liquid crystal columnar matrix. The studies included UV-Vis spectroscopy, photo luminescence spectroscopy, differential scanning calorimetry, polarising optical microscopy, DC conductivity and small angle X-ray diffraction. This was in collaboration with Sagar Laxmi Kishore.

Along with C Kavitha, BS Avinash and V Lakshminarayanan, Kumar studied the photoconductivity of undoped as well as nanostructures of gold chloride doped hexa-alkoxytriphenylene series (HAT4, HAT5 and

HAT6). It was observed that after doping with gold chloride, the photoconductivity increased by more than ten times for HAT4 and HAT5 but not for HAT6. The high photoconductivity can be explained in terms of the transition temperatures, the core-core distances and their length of side chains. Photoconductivity of the gold chloride doped hexa-alkoxytriphenylene derivatives was five orders of magnitude higher than that of undoped compounds. The high NIR absorbance combined with the photoconductivity makes this nanocomposite a potential candidate for organic solar cell applications.

An experimental characterisation of dispersions of ZnO nanoparticles in the columnar matrix of a discotic liquid crystal was carried out during the year. Thermophysical properties were investigated through UV-Vis spectroscopy, differential scanning calorimetry, polarising optical microscopy, dielectric measurements, ac and dc conductivity and X-ray diffraction. The experimental results showed that the inclusion of ZnO nanoparticles into the columnar matrix enhanced the order of the matrix and did not affect the two dimensional hexagonal lattice. The real and imaginary parts of the permittivity increase by a small amount in the dispersions and a new loss process appears in the isotropic phase. This study was in collaboration with R Pratibha, Supreet and KK Raina.

As part of designing and synthesising new liquid crystalline materials, Kumar and Satyam Kumar Gupta constructed a novel discotic core by fusing an imidazole unit with a well-known triphenylene discotic core. Two new imidazole fused unsymmetrically substituted triphenylene derivatives were prepared and characterised. While the molecular structures of the new compounds were verified by 1H NMR, UV, MS and elemental analysis, their liquid crystalline properties were determined by polarising optical microscopy, differential scanning calorimetry and X-ray diffraction studies. These triphenylenoimidazole derivatives were found to exhibit hexagonal columnar mesomorphism over a wide temperature range.

In collaboration with AK Prajapati of University of Baroda, Kumar studied H-shaped liquid crystalline compounds. Two mesogenic

homologous series of H-shaped symmetrical dimers were synthesised and their thermotropic properties studied by differential scanning calorimetry and on a hot-stage of a polarising microscope. These compounds consisted of two mesogenic units of azoester interconnected through tetramethylene flexible spacers by ether linkage resulting in the structure of "H-shaped" dimeric compounds. The difference between the two series was in the structure of terminal substituents ($-CH_3$ for series I and $-OCH_3$ for series II) attached on the azoester mesogens at one terminus. All these compounds were found to be smectogenic. The mesomorphic properties of the series were compared with each other and with other structurally related mesogenic H-shaped dimers. The trans-azobenzene groups of the H-shaped dimeric compounds displayed a high-intensity ð–ð* transition at about 365 nm and a low intensity ð–ð* transition at around 470 nm. Thus photochromism can be achieved by the introduction of the azo linkage to the H-shaped dimeric compounds.

Kumar conducted physical studies on liquid crystalline materials along with ADL Chandania, Atsuo Fukudaa and Jagdish K Vij. Several compounds have been prepared at RRI for various physical studies. In a binary mixture system of ferroelectric and antiferroelectric liquid crystals whose major component showed an unusual reversed phase sequence of $SmC^*_A(1/2)$ – SmC*, a new phase with ferrielectric order of five layers was discovered by the electric field-induced birefringence (EFIB) measurements. The EFIB was measured using a photo-elastic modulator (PEM) set-up and by applying an in-plane electric field to a homeotropic aligned cell filled with the binary mixtures of compounds with ferroelectric and antiferroelectric compounds. The contours of constant birefringence in the electric field–temperature (*E*–*T*) phase diagrams clearly indicate a distinct region corresponding to a new phase bordering the four-layer SmC*(1/2) on the low temperature side and SmC*á on the high temperature side. This new phase is unambiguously assigned to SmC*(3/5) whose structure was calculated by Osipov and Gorkunov.

TN Ruckmongathan's areas of current professional research interests lie in the field of soft condensed matter in general and displays in particular.

During the year gone by, his research was on low power projection displays. Digital Micro-mirror Devices (DMD) are optical semiconductors that are used in digital light processor (DLP) based projectors. DMD has a two-dimensional array of tiny mirrors that reflect light from light source(s) on to the screen or away from it to project images on the screen. DMD is an efficient light modulator and about 60% of the light incident on DMD is utilised. Each mirror is of size 12 x 12 µm and operates in bi-stable mode. Micro-mirrors can switch within two microseconds and have a long operational life of 10^{12} operations without any visible sign of ageing. DMD-based projectors use pulse width modulation to display 8-10 bits of gray shades. The number of time intervals to display is 255 and 1,023 to display 256 and 1,024 gray shades, respectively. Ruckmongathan proposed a micro-pulse width modulation method to displaying gray scales and achieving a drastic reduction in the number of time intervals. Gray scale bits are split to form a few groups of bits, each consisting of a few (2-4) bits and using intensity modulation to display large number of gray scales. For example, eight bits of gray scale can be split into 2 four bits to reduce the number of time intervals to 30 as compared to 255 of pulse width modulation. Intensity of the light source is reduced by a factor 16 for the least significant four bits as compared intensity of light source for the most significant four bits to achieve about 88% reduction in the number of time intervals to display 256 gray scales with micro pulse width modulation. About 20%-50% reduction in power consumption of light sources

(that illuminate the DMD) is achieved by selectively switching OFF the light sources that illuminate large clusters of OFF pixels in frames that are projected sequentially based on micro pulse width modulation.

V Lakshminarayanan's research interests include electrochemical studies of surfaces and interfaces formed by self-assembled monolayers and other organic thin films; electron transfer processes in bio-molecules on electrode surfaces; electrochemistry in lyotropic liquid crystalline systems; electrical conductivity of doped discotic liquid crystalline systems and conducting polymer nanostructures.

During the past year, Lakshminarayanan conducted experiments that demonstrated that bovine milk can act as a stable electrolytic medium with surprisingly reproducible characteristics by a study of electrochemical behaviour. Various minerals in bovine milk such as calcium, potassium, magnesium, etc., in free form provide sufficient ionic conductivity for this purpose. The electron transfer properties of three different redox systems in bovine homogenised whole milk, skimmed milk and reconstituted milk powder have been studied by cyclic voltammetry and impedance spectroscopy using a three-electrode system with a gold disc working electrode, a platinum sheet counter electrode and a standard calomel reference electrode. It has been shown that the milk sustains the redox reactions in the absence of a supporting electrolyte and the electrochemical responses are comparable to those obtained when the same reactions were carried out in standard solvent preparations containing supporting electrolytes. The study demonstrates the potential of developing new innovative techniques based on the intricate concepts of electrochemistry to study various aspects of milk that may help in the development of analytical sensors for the diary industry. This study was done in collaboration with VSP student K Shrikrishnan.

Electrochemical reactions of ferrocene are a quintessential reversible redox system studied in non-aqueous systems. This is also a system in which the redox species is present in the neutral state in reduced form and in positively charged state in the oxidised form. This makes the system a fascinating example of transition from neutral to charged form and simultaneously from hydrophobic to hydrophilic states. This prompted Lakshminarayanan and PhD student Anu Renjith to undertake extensive studies on the redox behaviour of the systems. Electrochemical studies carried out with different ferrocene derivatives dissolved in different solvents showed that the half peak potentials depend on the dielectric constant of

the medium which has been rationalised in terms of the stability of the species in the medium. Studies were also carried out on the effect of electron withdrawing/donating substitution on the half peak potentials. The variations in the half peak potentials have been interpreted in terms of the rate of charge transfer phenomenon at the interface.

The electron mediating properties of the surface films are important in the development of biosensors and studies of biological electron transfer processes. In this connection, the ferrocene thiol self-assembled monolayer lends itself as a possible candidate for interesting studies as electron mediator due to the fact that it has the properties of widely varying in nature in the oxidised and reduced states on the surface. In this regard, the electron mediating properties of ferrocene hexane thiol self-assembled monolayer on gold electrode were studied. The behaviour during the electron transfer process was correlated with the nature of the redox properties.

The immobilisation of enzymes and proteins on surfaces are important in the study of the electron transfer processes in biological systems and also in the development of biosensors. In this regard, Lakshminarayanan and Renjith prepared the Langmuir Blodgett films of Heme proteins such as Cytochrome-C and Myoglobin using self-assembled monolayers of aromatic thiols as substrate materials. They studied their potential application as a hydrogen peroxide sensor which is an important reaction product in biological electron transfer reactions. Similar work is being continued for the study of other proteins.

VA Raghunathan's areas of research interest lie in amphiphilic systems, membranes, self-assembly and phase behaviour of surfactant polyelectrolyte complexes.

Raghunathan, along with PhD student Md Arif Kamal, studied the effect of two secosteroids, namely cholecalciferol (vitamin D3) and ergo-calciferol (vitamin D2), on the structure and phase behaviour of dipalmitoyl phosphatidylcholine (DPPC) membranes, using X-ray diffraction. Temperature-composition phase diagrams of both the systems were determined from diffraction data from aligned multilayers at 98% relative humidity. The two-phase diagrams were found to be almost identical, with the appearance of four distinct modulated phases as a function of secosteroid concentration below the main-transition of the lipid. Three of these phases are characterised by periodic height modulation of the bilayers, whereas the one that occurs at high secosteroid concentrations has a periodic thickness modulation. These results demonstrate the ability of these important components of biomembranes to modulate membrane curvature and thickness, which are factors implicated in the lateral organisation of proteins in the membrane.

Raghunathan worked on defect-mediated lamellar-isotropic transition of amphiphile bilayers along with Antara Pal of RRI and Georg Pabst of the Institute of Biophysics and Banosystems Research, Austrian Academy of Sciences, Graz (Austria). A novel isotropic phase of amphiphile bilayers, characterised by small average inter-bilayer spacing and short-range positional correlations, has been observed in an amphiphile-water system. These bilayers form a weakly-swollen lamellar (L) phase over a wide range of water content, which transforms into an isotropic (Li) phase on heating. This transition is not observed in samples without excess water, where the L phase is stable at higher temperatures. Small-angle X-ray scattering and ionic conductivity studies

indicate that the L-Li transition is driven by the unbinding of edge dislocation loops, which have been shown to destroy the quasi-long-range positional order of the lamellar phase. Observation of similar behaviour in other bilayer forming systems dominated by attractive inter-bilayer interactions suggests that this isotropic phase is generic to such systems.

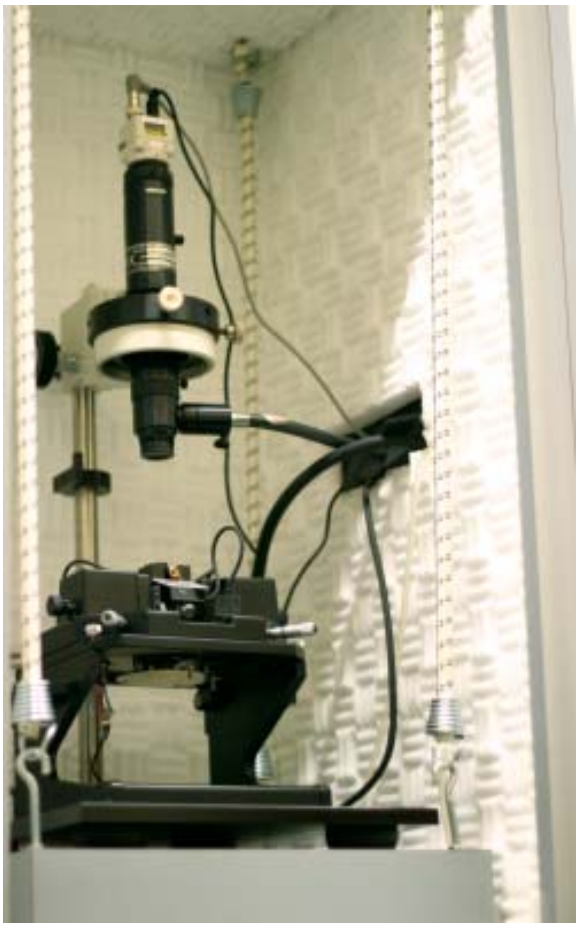
With Kamal, Raghunathan studied the influence of some major phytosterols on the structure and phase behaviour of 1,2-dipalmitoyl-sn-glycero-3-phosphocholine (DPPC) and 1-palmitoyl-2-oleoyl-sn-glycero-3-phosphoethanolamine

(POPE) membranes. Phase diagrams of the binary systems were determined from X-ray diffraction data. All DPPC-phytosterol membranes studied exhibit a sterol-induced modulated phase (P_) below the main transition, first reported in DPPC-cholesterol membranes. Structural features of this phase were deduced from electron density maps calculated from the diffraction data. In addition, a re-entrant ripple phase was observed in DPPC-stigmasterol membranes as a function of temperature. The increase in the bilayer thickness in the fluid phase, due to the ordering of the lipid chains by the sterol molecules, was also determined from the electron density profiles of the bilayers. All the phytosterols studied were found to increase the bilayer thickness, but to a lower extent compared to cholesterol. Some of the phytosterols phase separate from POPE even at very low concentrations, whereas the others have a similar effect on the phase behaviour of POPE, with the temperature range over which the fluid lamellar phase occurs first decreasing and then increasing with increasing phytosterol concentration.

The influence of tocopherols on the structure and phase behaviour of DPPC bilayers was determined from X-ray diffraction studies on oriented multilayers. In all the three cases the main-transition temperature (Tm) of DPPC was found to decrease with increasing tocopherol concentration up to around 25 mol%. Beyond this the main transition was suppressed in the case of tocopherol, whereas the Tm became insensitive to composition in the other two cases. The pre-transition was found to be suppressed over a narrow tocopherol concentration range between 7.5 and 10 mol% in DPPC-tocopherol and DPPC-tocopherol bilayers, and the ripple phase occurred down to the lowest temperature studied. In all three cases, a modulated phase was observed above a tocopherol concentration of about 10 mol%, which is similar to the P_ phase reported in DPPC-cholesterol bilayers. This phase is found to occur even in excess water conditions at lower tocopherol conentrations and consists of bilayers with

periodic height modulation. These results indicate the ability of tocopherols to induce local curvature in membranes, which could be important for some of their biological functions.

Raghunathan and Kamal also studied the influence of ring-substituted oxysterols on the phase behaviour of DPPC membranes Oxysterols are oxygenated derivatives of cholesterol that form a class of potent regulatory molecules with diverse biological activity. Given the implications of oxysterols in several physiological/pathophysiological pathways of human diseases, it is important to identify how their presence influences the biophysical properties of cell membranes. They first described the structure, formation and biological functions of oxysterols, along with previous work on the influence of these molecules on the structure and phase behaviour of lipid membranes. They presented the results of X-ray diffraction experiments on aligned multilayers of DPPC membranes containing some ring-substituted oxysterols. The influence of these molecules on the phase behaviour of DPPC membranes is was to be very similar to that of cholesterol. All the oxysterols studied induced a modulated phase in DPPC membranes, similar to the one reported in DPPC-cholesterol membranes. However, some differences were observed in the ability of these molecules to suppress the main transition of the lipid and to induce chain ordering, which might be related to differences in their orientation in the bilayer.



Yashodhan Hatwalne's current areas of professional interest are phenomenological theory of liquid crystals, membranes and polymer crystallisation.

During the past year, he conducted experimental studies on statics and dynamics of some novel instabilities in lyotropic systems in collaboration with Tripta Bhatia and NV Madhusudana. New instabilities were observed which led to the formation of lamellar tubules with a solvent core during dissolution of amphiphilic molecules in water. The tubules underwent a further instability, leading to the formation of beads on these tubules. Using fluorescence confocal microscopy, the structure of the metastable tubules and beads were modelled. The stability of the tubular structure was studied.

Hatwalne studied the detailed structure of the TGBA phase within linear elasticity theory with Venkatramanan PR. They clarified the role and connection between the geometry, topology and energetics of this lattice of screw dislocations, which is the analogue of Abrikosov flux lattice in superconductors. A new modulated phase of liquid crystals was predicted based upon the co-variant elasticity of smectic-C liquid crystals. This phase is a manifestation of covariance in the unusual context of achiral smectics. This

research was in collaboration with Venkatramanan and Madhusudana.

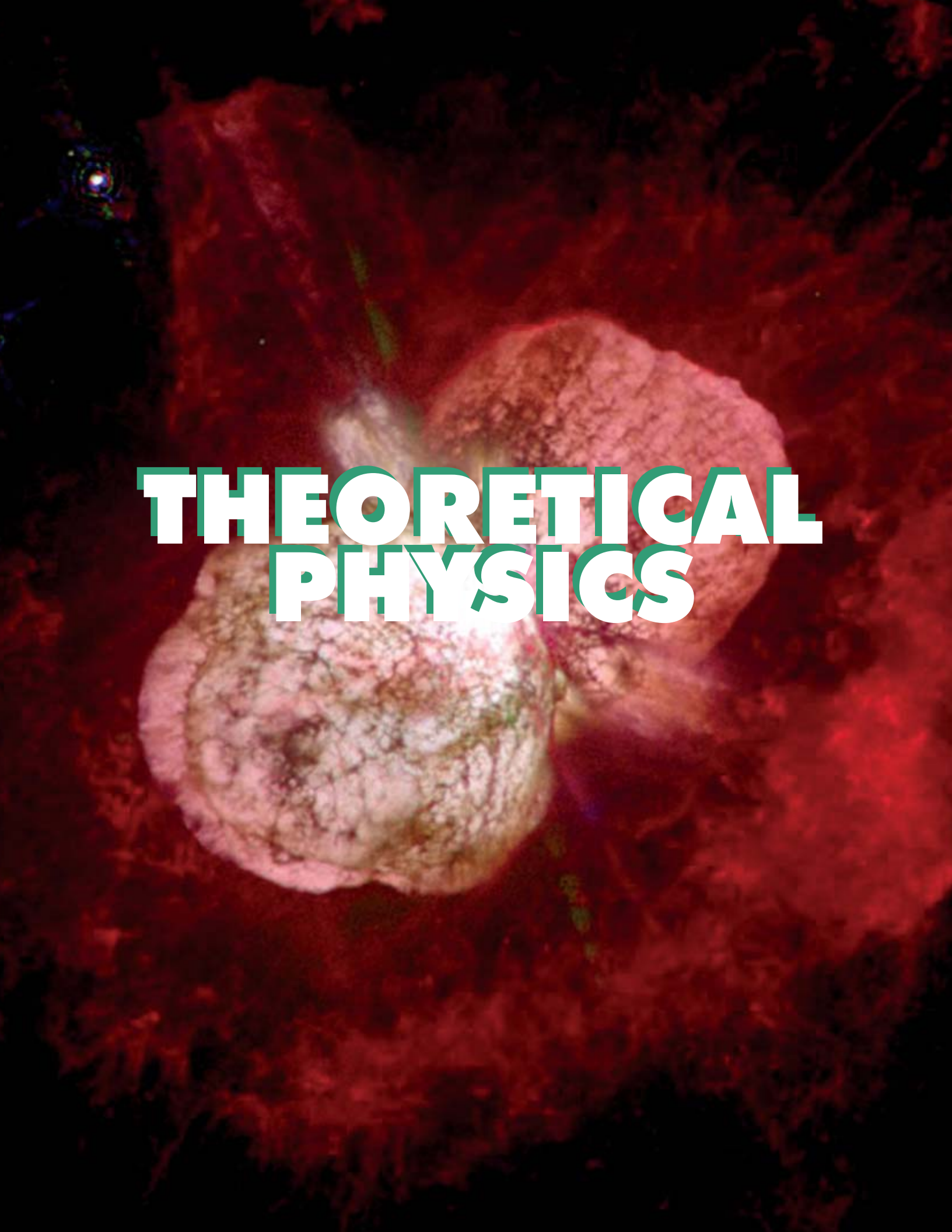
Earlier work on chiral symmetry was extended, in collaboration with Jaya Kumar A and M Muthukumar, to take into account the effect of line tension in the mechanism for chiral symmetry breaking in ribbon-like structures forming spherulites of achiral molecules (such as polyethylene). Other ongoing work includes the formulation of elasticity theory of crystalline membranes and thin plates with topological defects.

Mahesh Kumar Varia's research during the year gone by included synthesis of blue phase forming materials. He synthesised two new series having blue phase, but work is going on to complete their homologues. Stabilising these blue phases is being attempted with carbon nano-tube and other materials. During these experiments, an N* phase was discovered on another new molecule, which is being studied for its physical properties.

Synthesis of the *peri*-dodecasubstituted hexabenzenecoronene and *peri*-hexasubstituted hexabenzenecoronene compounds are well known and very interesting DLCs but their isotropisation temperature is very high. To lower this temperature, Varia and his collaborators synthesised one final *peri*-dodecasubstituted hexabenzenecoronene molecule, which is still under chemical characterisation.

Truxene is much more interesting from the researcher's point of view because of the discotic nematic phases and curvature on the shape of the molecule. As such, hexamethoxy truxene was synthesised and work is going on regarding the branched and oxy-methylene peripheral hexa-substituted truxene via ether and/or ester linkages.

The rod-disk type rufigallol molecule was synthesised successively and presented at the International Workshop on Soft Matter Chemistry in November 2011. It was found to have nematic as well smectic mesophases; work on rod-disk type triphenylene molecule is underway.


THEORETICAL
PHYSICS

Overview

Established in 1995, the Theoretical Physics (TP) group comprises research faculty, post doctoral fellows and students who work at the interface between mathematics and physics. There are four main areas of research – statistical physics, soft matter physics (including physics in biology), gravitation and the foundations of quantum mechanics. Areas of interest within statistical mechanics are mesoscopic physics, non-equilibrium physics, soft condensed matter physics and biophysics. Research in general relativity includes gravitational waves and quantum gravity.

Members often engage in collaborations among each other and/or groups of the institute that conduct experimental physics activities. The group has also created a forum for theorists to conduct simple table-top experiments that can express conceptual points.

The following pages summarise the major areas of research for the TP group. Each member's individual work during the last year is provided in the next section, giving the reader a more detailed and technical description of their respective research activities.

STATISTICAL MECHANICS

When a macroscopic device or a sample of bulk material is scaled down to mesoscopic size (from a few microns to the size of a single atom), they begin to reveal quantum mechanical effects. As a result, its properties might be very different from its parent material.

Research in this area is focused on developing theories for transport of heat and electricity using the Langevin equation and scattering approaches. The role of disorder (including localisation), nonlinearity and dissipation on transport properties are being investigated. Other areas of interest include the study of large deviations and nonequilibrium fluctuation theorems as well as the statistics of extreme events. Issues related to the jamming of granular matter and onset of shear waves in a bacterial bath have been addressed in the realm of nonequilibrium statistical mechanics of soft matter. There is also interest in understanding the equilibrium and dynamical properties of polymers.

Theoretical and experimental research in heat and electron transport in mesoscopic scale systems is important for the advancement of the fundamental understanding of the transport properties of materials, which in turn would lay the foundation needed to improve the performance of nanodevice applications and technologies.

The development of fast algorithms to estimate the probability of rare events is part of the ongoing research in the field of non-equilibrium statistical mechanics. Developed in the context of physics, such algorithms are also important in other areas of life like finance and cellular processes in biology.

BIOLOGICAL PHYSICS

Various topics in the field of biophysics have attracted the interest of the TP as well as the SCM groups. This field is an example of the value of having a relatively small institute with a wide range of professional research interests and scientists who are open-minded and eager to move into new areas and apply their experience to related fields. Recent work in biological physics includes investigations on vesicle formation and transport, mitochondrial distribution dynamics, and the physics in experiments of DNA stretching and twisting. Research in biophysics involves active collaboration with experimental groups on campus and at the National Centre for Biological Sciences.

GENERAL RELATIVITY

Research has been undertaken in the precise calculation of gravitational waveforms expected from inspiralling binaries. This problem is of contemporary significance because laser interferometer gravitational wave detectors like LIGO and VIRGO have come online and achieved their design sensitivity. However, the signals are weak and buried in noise, and one needs accurate templates with which the data may be cross-correlated in order to detect gravitational wave signals from astrophysical sources. Research by the TP group at RRI includes examining signal detection with future space based gravity-wave detectors like LISA and shows that improvements are possible in detection limits with more complete treatments of the waveforms. The full waveform leads to improved angular resolution for super massive black hole binaries, and hence data from LISA can be used to constrain the dark energy equation of state to within a few percent, comparable to the level expected from other dark energy missions.

Research is also being carried out into physical applications of the Ricci flow in general

relativity. The Ricci flow is a heat equation for metrics, which tends to smooth out geometries and wipe out memory of the initial conditions. The analogy between the Ricci flow and the approach of a physical system to thermal equilibrium is being studied to understand black hole entropy.

QUANTUM GRAVITY

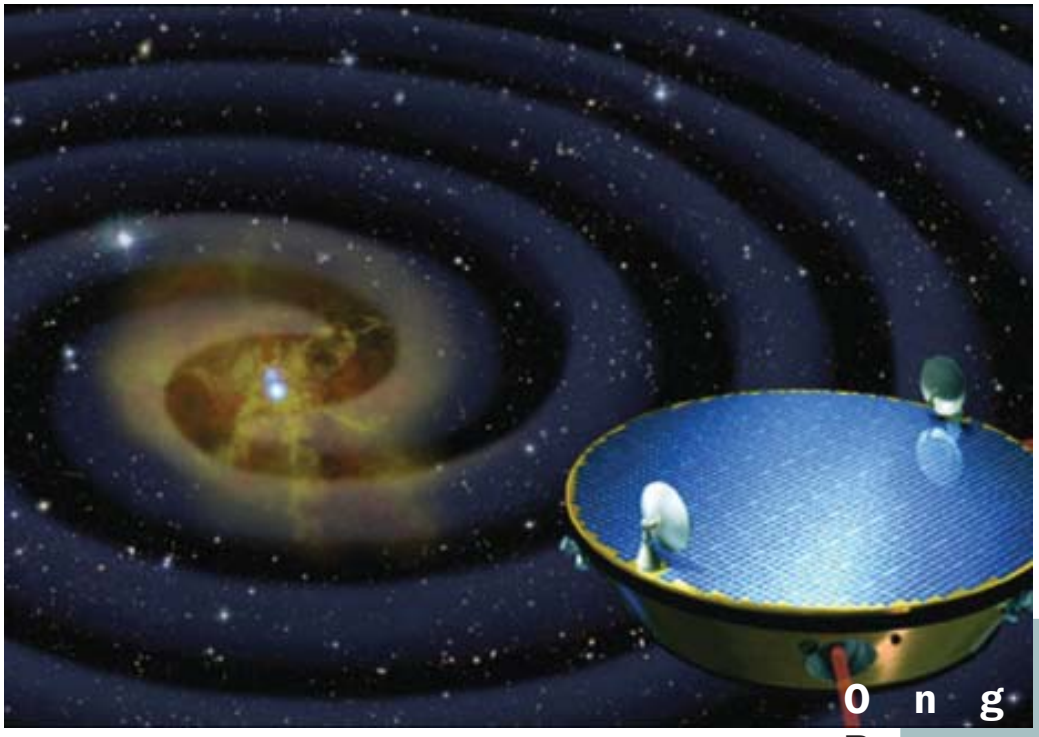
At RRI, research is carried out within two distinct approaches to quantum gravity. One is Loop Quantum Gravity (LQG), which is an application of standard Hamiltonian methods of quantisation to the classical gravitational field without recourse to perturbation theory. In particular, this requires an understanding of how to quantise a field theory in the absence of a fixed background spacetime. New tools and ideas have been developed in LQG to deal with the absence of a background spatial geometry, while issues related to the absence of background time and recovery of continuum space-time geometry in the classical limit continue to be a frontier area of research. Other areas of interest are the application of LQG ideas to a truncated space of homogeneous and isotropic (cosmological) gravitational fields as well as technically simpler generally covariant toy models.

The other approach is Causal Set Theory, in which the space-time continuum is replaced by a discrete substructure that is a locally finite partially ordered set, the causal set. The fundamental idea is that finite continuum space-time volumes in fact contain only a finite number of basic space-time elements, related to each other by a causal relation. Work on causal set theory includes investigations into classical stochastic growth models, causal set topology, toy models for quantum causal set dynamics and on the construction of a consistent quantum theory of causal sets. Alongside, investigations have also been carried out into observer-independent alternative formulations of quantum theory.

One of the puzzles of cosmology is the smallness of the cosmological constant, the dark energy that drives the expansion of the universe. It has been suggested that the observed cosmological constant may be due to quantum gravity fluctuations. Pursuing this idea, an analogy has been made between the cosmological constant and surface tension of fluid membranes. The analogy relates esoteric quantum gravity effects that are too high in energy to probe directly to standard physics that can be tested in a laboratory. This suggests an analogue quantum gravity experiment, which probes the fluctuating surface tension of micron sized fluid membranes. This is an example of the connections that emerge from the interactions at the institute between different fields of research.

THEORISTS LABORATORY

This is a forum for theorists to conduct simple table-top experiments. There have been experiments with vibrated grains, the Marangoni effect and studies of Brownian motion in milk globules. There have been several demonstrations developed using simple materials such as a rotating cube, an archimedian screw pump, a low Reynold's number effect, and demonstrations involving soap films and soap bubbles to express conceptual points. These serve as an aid to education as well as understanding.



Ongoing Research

Abhishek Dhar's areas of professional research interests include non-equilibrium statistical mechanics and soft matter physics.

During the year gone by, he, along with Prakhyat Hejmady, Ranjini Bandyopadhyay and Sanjib Sabhapandit, studied new scaling behaviour in boundary-driven granular convection. When a quasi-two-dimensional bed of mustard seeds is vertically vibrated, the formation of convection rolls in the cell is observed. Convection is obtained only when the side walls of the cell are roughened, which means that convection is boundary-driven. To quantify the observed convection, the time it takes for a test particle, driven by the flow, to rise from the bottom of the cell to the top was measured. A wide range of driving parameters – including amplitude of vibration (a), frequency of vibration (f) and cell size – was also measured. It was found that the data collapsed when plotted as a function of the driving velocity (af) as against the accepted belief that the parameter controlling convection is the driving acceleration (af^2).

He also studied the density matrix description of quantum systems in non-equilibrium steady states. For systems in equilibrium, the probability of various allowed states of a quantum system kept in contact with a heat bath is given by the Gibbs-Boltzmann distribution. The density matrix is the canonical distribution; if the system is also in contact with a particle reservoir, then the grand-canonical distribution is used. However, there is no such general prescription for specifying the density matrix of systems that are out of equilibrium. This research, in collaboration with Keiji Saito of Tokyo University (Japan) and Peter Hanggi of the University of Augsburg (Germany), looked at models where a quantum system is connected to two reservoirs of energy and particles, so as to product current-carrying non-equilibrium states. A procedure for explicitly finding the non-equilibrium density matrix in these models was demonstrated.

In collaboration with Venkateshan Kannan and Joel L. Lebowitz of Rutgers University (USA), Dhar researched the non-equilibrium steady state of a harmonic crystal with alternating masses. They analysed the non-equilibrium steady state of a one-dimensional harmonic chain of N atoms with alternating masses connected to heat reservoirs at unequal temperatures. It was found that the temperature profile defined through the local kinetic energy oscillated with period two in the bulk of the system. The heavier or the lighter particles in the bulk are hotter depending on boundary conditions. The explicit integral expressions for the bulk temperature profile and steady state current in the limit of large N were obtained.

In trying to understand transport properties of systems with applied thermal gradients or electrical fields, the area of interest is not just the average current flow but also the fluctuations of the current. The current generating function is a quantity that contains information on all moments of the current. Its computation is a difficult problem. In 2004, Bodineau and Derrida made a remarkable conjecture, namely, the additivity principle, which enables one to compute the full generating function from just the temperature dependent thermal conductivity of a system. So far the conjecture has been proved only for one-dimensional diffusive systems. Saito and Dhar studied heat transport in two- and three-dimensional disordered harmonic crystals and numerically demonstrated the validity of the conjecture even in these systems.

Along with Anjan Roy and Sanjib Sabhapandit of RRI and Onuttom Narayan of UC Santa Cruz (USA), Dhar investigated the motion of one single marked particle in a gas of interacting particles kept inside a box, by looking at the mean square deviation (MSD) of its position. For a gas of equal mass hard particles, it is known that there is a diffusive regime and the MSD saturates because of the finite size of the box. This study is addressing the questions of whether the diffusive behaviour occurs universally and of the nature of the approach to the saturation value. This work is computation-intensive and has extensively used the RRI cluster.

Bala Iyer's professional research interests lie in the areas of general relativity and gravitational waves. During the year gone by, he was involved in the computation of the quadrupole mode of the gravitational waveform of inspiralling compact binaries at the third and half post-Newtonian (3.5PN) approximation of general relativity. This research was done in collaboration with Guillaume Faye, Sylvain Marsat and Luc Blanchet of the Institut d'Astrophysique de Paris (France).

The computation was performed using the multi-polar post-Newtonian formalism, and restricted to binaries without spins moving on quasi-circular orbits. The new inputs mainly include the 3.5PN terms in the mass quadrupole moment of the source and the control of required subdominant corrections to the contributions of hereditary integrals (tails and non-linear memory effect). The result was given in the form of the quadrupolar mode in a spin-weighted spherical harmonic decomposition of the waveform, and will allow a more accurate comparison with the outcome of numerical relativity simulations.

Joseph Samuel's areas of professional interests are in the use of geometry and topology in physics, especially geometric phase in quantum mechanics and optics, general relativity and DNA elasticity. His recent work relates to analogies between quantum gravitation and the physics of lipid membranes which leads to a relation between surface tension and the cosmological constant.

During the past year, Samuel continued his research into DNA elasticity, in collaboration

with Supurna Sinha, to arrive at a clear understanding of DNA elasticity using the standard techniques of statistical mechanics. While experiments do exist, their interpretation requires special attention because of the geometric and topological subtleties of the Writhe. This work examines the effect of thermal fluctuations on the statistical mechanics of DNA by using the Gelfand-Yaglom method for computing fluctuation determinants.

With Sinha, Samuel studied whether atom interferometry can be used to accurately test the Red Shift effect. The study involves critically examining the idea of a clock in general relativity. The study leads to a proposal of a new class of experiments in general relativity which study the interference of quantum clocks.

Samuel – in collaboration with A Martin, O Alibart, JC Flesch and S. Tanzilli from the Laboratoire de Physique de la Matièr Condense, Université Nice (France), and Supurna Sinha and A Kastberg from RRI – experimentally demonstrated the geometric phase effect on coincidence counts of photons. The effect was predicted in an earlier theoretical paper and confirmed by this experiment. The experiment suggests ways of tuning entanglement in quantum optics.

Along with a team from RRI comprising Nandan Satapathy, Deepak Pandey, Poonam Mehta, Supurna Sinha and Hema Ramachandran, Samuel demonstrated the existence of a non-local geometric phase in the intensity-intensity correlations of classical incoherent light, not seen in the lower order correlation. This two-photon Pancharatnam phase was observed and modulated in a Mach-Zehnder interferometer. Using acousto-optic interaction, independent phase noise was introduced to light in the two arms of the interferometer to create two independent incoherent classical sources from laser light. The experiment is the classical optical analogue of the multi-particle Aharanov-Bohm effect.

Samuel presented an analytical closed form expression that gives a good approximate propagator for diffusion on the sphere. The formula is the spherical counterpart of the Gaussian propagator for diffusion on the plane. While the analytical formula is derived using saddle point methods for short times, it works well even for intermediate times. This formula goes beyond conventional “short time heat kernel expansions” in that it is nonperturbative in the spatial coordinate, a feature that is ideal for studying large deviations. This work, done in conjunction with Abhijit Ghosh of the Sogang University, Seoul (South Korea), and Sinha, suggested a new and efficient algorithm for numerical integration of the diffusion equation on a sphere.

Madhavan Varadarajan’s areas of professional research interest are classical and quantum gravity.

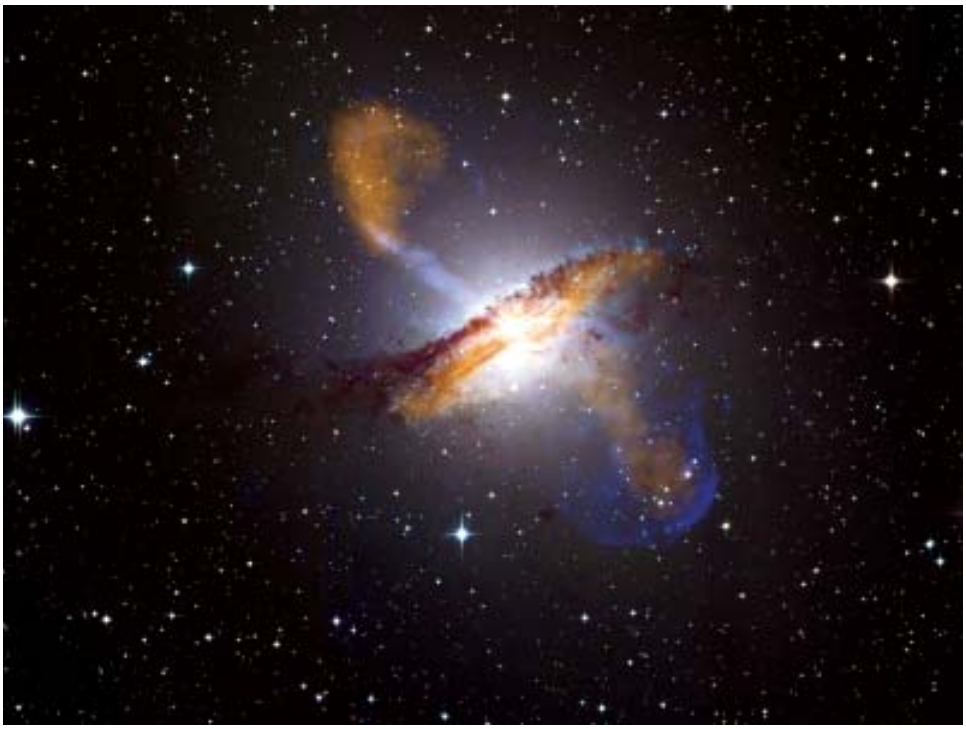
During the past year, he worked an anomaly-free quantum dynamics for a weak coupling limit of Euclidean gravity, in collaboration with C Tomlin of Penn State University (USA). The weak coupling limit of Euclidean gravity introduced by Smolin is described by a generally covariant abelian gauge theory. The Poisson bracket algebra of its Hamiltonian and diffeomorphism constraints is isomorphic to that of gravity. Motivated by recent results in Parameterised Field Theory and by the search for an anomaly-free quantum dynamics for Loop Quantum Gravity (LQG), the quantum Hamiltonian constraint of density weight 4/3 for this abelian theory is constructed so as to produce a non-trivial LQG-type representation of its Poisson brackets through the following steps. First, the constraint at finite triangulation, as well as the commutator between a pair of such constraints, is constructed as operators on the “charge” network basis. Next, the continuum limit of the commutator is evaluated with respect to an operator topology defined by a certain space of “vertex smooth” distributions. Finally, the

operator corresponding to the Poisson bracket between a pair of Hamiltonian constraints is constructed at finite triangulation in such a way as to generate a “generalised” diffeomorphism and its continuum limit is shown to agree with that of the commutator between a pair of finite triangulation Hamiltonian constraints. Varadarajan’s results, in conjunction with the recent work of Henderson, Laddha and Tomlin in a 2+1-dimensional context, constitute the necessary first steps towards a satisfactory treatment of the quantum dynamics of this model. They also worked on improving the constructions of the work above so as to incorporate diffeomorphism covariance. This work involved an intricate choice of regulating coordinate patches, an application of certain results on cyclic finite subgroups of the group of general linear transformations and a modification of the set of vertex smooth functions with restricted short distance behaviour.

Other research by Varadarajan was on the Koslowski-Sahlmann (KS) representation for quantum gravity. The KS representation is an LQG representation with a non-trivial background spatial geometry. The existence of hitherto unnoticed, yet crucial, operators which implement changes in this background were demonstrated. Using these operators, errors in the solutions of the gauge constraints were corrected. Varadarajan and his collaborators aim to use this representation to construct a quantum arena for asymptotically flat gravity in future work.

N Kumar’s areas of research interest cover randomness, dissipation and decoherence in condensed matter, both quantum and classical.

During the past year, his research was focused mainly on the absence of classical equilibrium orbital (dia) magnetism (the Bohr-van Leeuwen (BvL) Theorem that has been a surprise of physics). Work was done in continuing collaboration/conversation with colleagues (from the TP, AA and LAMP groups) and some VSP students. The stated absence of classical orbital (dia) magnetism was traced to Detailed Balance (the second fluctuation dissipation, II-FD, theorem due to Kubo – that there are no cycles in equilibrium). As a complement to the BvL theorem, it was shown that a stochastic-dissipative system of charged particles can indeed give a non-zero orbital magnetic moment in the classical steady-state, and that the moment can even be paramagnetic for certain deviations from the II-FD theorem. This was consistent with Kumar’s numerical simulation for a dissipative



stochastic system driven by the Kubo-Anderson (non-Markovian) process. The positive feedback possible due to paramagnetism suggests a mechanism for the generation of magnetic fields, possibly the seed field in the classical astrophysical context. Experimental realisation in the laboratory using optical traps and laser pulsing was suggested.

Another area of N Kumar's research during the year was the study of propagation of light through a ferrofluid (suspension on ~single-domain nm-scale magnetite particle in kerosene), which scattered dielectrically and was tuneable magnetically. An experimental study was carried out in RRI's LAMP Group to measure the intensity of forward/backward scattering and the polarisation of the scattered light as a function of the applied transverse magnetic field. These results were qualitative in agreement with the analytical calculations based on invariant imbedding for a model system.

Sanjib Sabhapandit's research interests cover various fields of statistical physics, including statistical physics of out-of-equilibrium systems, disordered systems, stochastic processes, extreme value statistics, integer partitions, granular media, dynamics of polymers, and large deviations of rare events for various non-equilibrium additive processes.

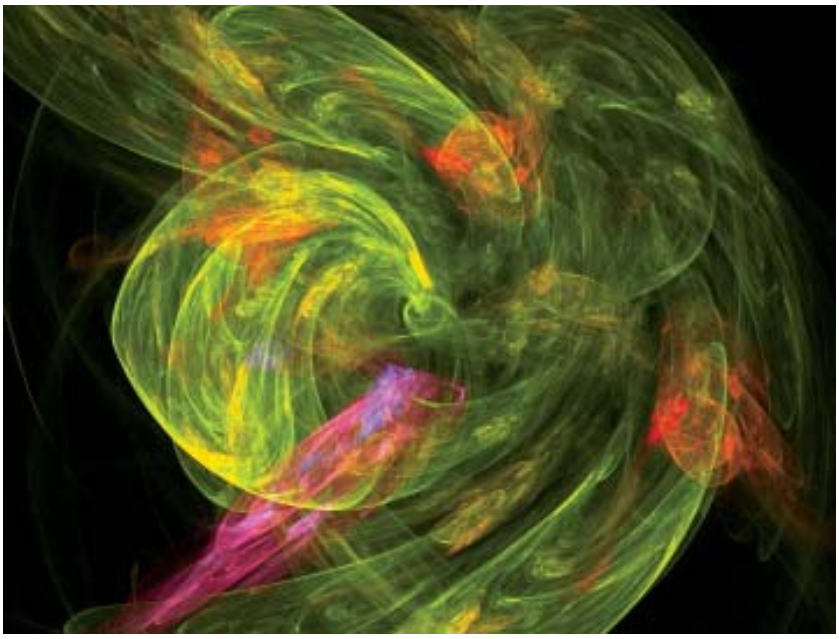
During the past year, Sabhapandit studied the fluctuations of the work done by an external Gaussian random force on a harmonic oscillator that is also in contact with a thermal bath. He obtained the exact large deviation function as well as the complete asymptotic forms of the probability density function. The distribution of the work done was found to be non-Gaussian. The steady state fluctuation theorem holds only if the ratio of the variances of the external random forcing and the thermal noise, respectively, is less than 1/3. On the other hand, the transient fluctuation theorem holds (asymptotically) for all the values of that ratio. The theoretical asymptotic forms of the probability density function were found to be in very good agreement with the numerics as well as with an experiment.

In collaboration with P Hejmady, R Bandyopadhyay and A Dhar, Sabhapandit conducted experiments on granular matter. Granular materials are ubiquitous in nature. They are apparently "the second-most manipulated material in industry after water". Besides its obvious technological importance, granular matter is one of the most interesting examples of a driven dissipative system. Shaken granular matter exhibits various interesting phenomena such as convection, segregation and jamming. A striking experimental observation in vibrated granular materials is the Brazil-nut effect, where a large intruder particle immersed in a vertically shaken bed of smaller particles rises to the top, even when it is much denser. A related effect is the segregation obtained on vibrating a mixture of particles of different sizes and densities. Sabhapandit was involved with an experiment on the shaken granular matter, wherein experimental measurements were taken of the rise-time of an intruder in a vertically vibrated quasi-two-dimensional bed of mustard seeds. Very interesting scaling behaviour in the Brazil-nut effect was observed over a wide range of shaking frequencies and amplitudes.

Sumati Surya works on both classical and quantum aspects of gravity. The main focus of her research is on the causal set approach to quantum gravity. In this approach, the space-time continuum is replaced by a discrete substructure, the causal set, which is a locally finite poset. She is also interested in the related question of quantum interpretation in the context of quantum cosmology.

During the year gone by, Surya studied the emergence of the continuum in 2D causal set

quantum gravity. The analysis of two-dimensional models of causal set quantum gravity was done using numerical Markov Chain Monte Carlo methods suite of numerical algorithms constructed using the Cactus framework. It was shown that this simplified model of causal set quantum gravity overcomes many of the hurdles present in the general case. In particular, it was shown to be computationally erdogic and to therefore thermalise rapidly. Several tests were carried out to establish the stability of the code and the ergodicity of the Markov process. Recent progress indicates the existence of a new layered quantum gravity phase, and investigations are continuing to confirm this.



In tackling the question of full causal set quantum gravity in four dimensions, one deals with an unrestricted sample space of causal sets. This space is known to be dominated by causal sets which are nothing like space-time, and one of the big questions in CST is whether this entropy can be tamed by a suitable dynamics. In earlier studies of the 4D case, it was found that the Markov chain was getting "stuck" in these entropically dominant configurations for very long simulation times. This is also related to the high rate of rejection for the particular choice of Markov chain move that was used. Using slightly modified moves did not seem to make a significant difference in these results. Recently, however, a way around this was found by replacing the sample space of causal sets by a matrix representation which allows for a far more efficient set of Ising-like moves. The preliminary results are very promising and the hope is to use these to explore various aspects of full 4d causal set quantum gravity. This study was in collaboration with David Rideout of the University of California San Diego (USA) and Rafael Sorkin of the Perimeter Institute.

Supurna Sinha's areas of current professional research interest are statistical mechanics in particular and theoretical physics in general.

During the year gone by, she worked on atom interferometers and the gravitational redshift in collaboration with Joseph Samuel. Muller, Peters and Chu (MPC) claim that a reinterpretation of decade-old experiments with atom interferometers leads to a sensitive test of the gravitational redshift effect. This claim has been disputed by Wolf et al, who adduce arguments to show that MPC's claim is incorrect. In Sinha's study, this argument has been reduced to a single fundamental objection. It was shown that atom interferometric experiments conducted to date do not test the gravitational redshift effect with a sensitivity determined by the Compton frequency of atomic masses. The analysis is general and focuses on points of principle rather than on the present state of

technological possibility. It is then observed that it is in principle possible to use atom lasers to produce sensitive tests of the redshift effect at the Compton frequency. Such tests may become technologically realisable in the future.

An experimental study of the non-local geometric phase in Hanbury Brown-Twiss polarised intensity interferometry was also carried out during the year. The experiment involved two independent, polarised, incoherent sources, illuminating two polarised detectors. Varying the relative polarisation angle between the detectors introduced a geometric phase equal to half the solid angle on the Poincare sphere traced out by a pair of single photons. Local measurements at either detector do not reveal the effect of the geometric phase, which appeared only in the coincidence counts between the two detectors, showing a genuinely non-local effect. It was shown experimentally that coincidence rates of photon arrival times at separated detectors can be controlled by the two photon geometric phase. This effect can be used to manipulate and control photonic entanglement. This study was carried out in collaboration with A Martin, O Alibart, JC Flesch, S Tanzilli and A Kastberg of Laboratoire de Physique de la Matiere Condense, Universite de Nice (France) and Joseph Samuel of RRI.

The existence of a non-local geometric phase was demonstrated in the intensity-intensity correlations of classical incoherent light. This is not seen in the lower order correlation. This two-photon Pancharatnam phase was observed and modulated in a Mach-Zehnder interferometer. Using acousto-optic interaction, independent phase noise was introduced to light in the two arms of the interferometer to create two independent incoherent classical sources from laser light. The experiment is the classical optical analogue of the multi-particle Aharanov-Bohm effect. As the trajectory of light over the Poincare sphere introduces a phase shift observable only in the intensity-intensity correlation, it provides a means of deflecting the two-photon wavefront, while having no effect on single photons. Sinha worked with Nandan Satapathy, Deepak Pandey, Joseph Samuel and Hema Ramachandran of RRI and Poonam Mehta of the Department of Physics, Delhi University.

Along with Joseph Samuel, Sinha carried out an analytical study of the role of thermal fluctuations in shaping molecular elastic properties of semiflexible polymers. The study interpolates between mechanics and statistical mechanics in a controlled way and shows how thermal fluctuations modify the elastic properties of biopolymers. The research involved:

1. A study of the minimum energy configurations with explicit expressions for their energy and writhe and plots of the extension versus Link for these configurations.
2. A study of fluctuations around the local minima of energy and approximate analytical formulae for the free energy of stretched twisted polymers.

The central new result of the study is a closed form expression for the leading thermal fluctuation correction to the free energy around the non-perturbative writhing family solution for the configuration of a biopolymer. From the derived formulae, the predictions of the Worm Like Chain (WLC) model for molecular elasticity can be worked out for comparison against numerical simulations and experiments.

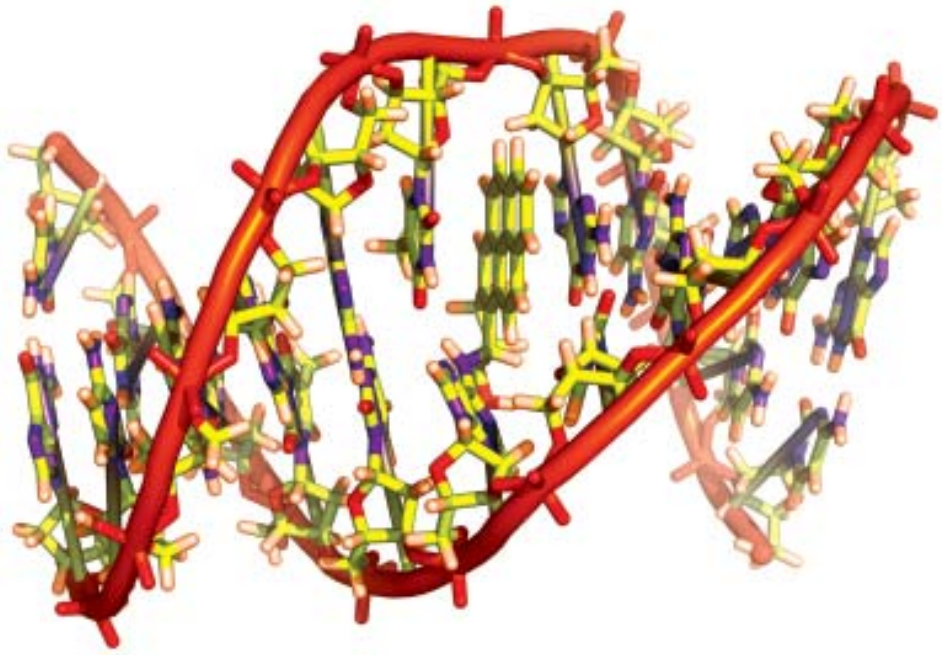
Sinha, along with Abhijit Ghosh of the Department of Chemical and Biomolecular Engineering, South Korea, and Joseph Samuel, derived an analytical closed form expression that gives a good approximate propagator for diffusion on the sphere. This formula is the spherical counterpart of the Gaussian propagator for diffusion on the plane. While the analytical formula was derived using saddle point methods for short times, it works well even for intermediate times. This study suggests

a new and efficient algorithm for numerical integration of the diffusion equation on a sphere. Monte Carlo simulations were performed to compare the numerical efficiency of the new algorithm with the older Gaussian one.

Post doctoral fellow **Sandipan Sengupta**'s research interests are in the field of guage theory of gravity and its canonical quantization.

It is well known that the theory of gravity (in four dimensions) can be written as a SU(2) guage theory. This involves a canonical description of gravity in terms of SU(2) guage fields and their conjugate momenta. In his project, Sengupta and his collaborators attempted to find the most general SU(2) description of gravity in four dimensions. It was found that such a framework required topological deformations in the gravity action. Possible implications of such modifications in the gravity action are currently also under investigation. This study was done in collaboration with Romesh K Kaul of IMSc, Chennai.

Ryuichi Fujita's professional research interests include gravitational waves and general relativity. During the past year, he derived gravitational waveforms needed to compute the 14th post-Newtonian (14PN) order energy flux for a particle in circular orbit around a Schwarzschild black hole. This involved investigating the convergence of the energy flux in the PN expansion and suggesting a fitting formula that could be used to extract unknown higher order PN coefficients from accurate numerical data for more general orbits around a Kerr black hole. In first order black hole perturbation theory, for extreme mass ratio inspirals which are one of the main targets of Laser Interferometer Space Antenna, the 14PN expressions will lead to the data analysis accuracies comparable to the ones resulting from high precision numerical waveforms.



FACILITIES

Laboratories

Radio Astronomy Lab

The Radio Astronomy Lab (RAL) at RRI consists of three divisions – Digital Signal Processing (DSP), Millimeter Wave and RF, and X-Ray Astronomy.

DSP Lab

The DSP lab is involved in the design, development and testing of digital receivers for astronomy. The DSP lab team comprises skilled engineers with expertise in the field of digital circuit design and digital signal processing. RRI has a long history of design and development of a variety of digital systems (receivers, spectrometers, correlators) that have improved the capabilities of national and international telescope facilities. The lab has modern CAD design packages for the development of FPGA-based digital systems.

Millimeter Wave and RF Lab

The engineers from the RF lab are experienced professionals with diverse skill-sets in the design and development of millimeter wave and RF systems. The lab is equipped with all necessary fabrication and testing facilities for RF systems characterisation. The group has designed and built feeds, broadband antennas as well as standard and special purpose front end receiver systems operating at wavelengths from decameter to millimeter.

X-Ray Astronomy Lab

This lab is fully equipped for the development and testing of X-ray astronomical instrumentation. The infrastructure includes a clean room, X-ray generator, beam line, polariser and monochromator, vacuum systems, mounts and electronics for performance evaluation of X-ray detectors.

LAMP Group Labs

Each faculty member of the LAMP group at RRI runs lab facilities specific to his/her individual research. These are:

- The Laser Cooling, Light Scattering Lab
- The Ultrafast and Nonlinear Optics Lab
- The Quantum Optics Lab
- The Quantum Interactions (QUAINT) Lab

The well-established facilities for laser cooling and trapping of atoms include vacuum systems, commercial and custom-made lasers, spectroscopy equipment, standard electronics and real time operating systems. The lab that hosts an experimental system to investigate quantum walks of light consists of three Michelson optical interferometers, various optical components and acoustic-optical modulator. Two labs allow for experimental research of nonlinear optical properties of nanocomposites and dynamics, and spectral behaviour of laser induced plasmas. Standard and custom-made facilities in the lab include a femtosecond laser system with amplifier, nanosecond Nd:YAG laser, spectrometers, monochromators, laser beam profiler, ultra high vacuum chamber, X-ray and gamma ray detectors, experimental set up for z-scan and pump probe measurements, and more.

SCM Group Labs

Chemistry Lab

This lab has state-of-the-art facilities necessary for the synthesis and structure characterisation of novel liquid crystal materials. Major equipment in the lab includes polarising optical microscopes, high performance liquid chromatograph, differential scanning calorimeter, elemental analyser, infrared and UV-visible spectrophotometer. Over 700 mesomorphic molecules have been synthesised and characterised in the Organic Chemistry Lab at RRI.

Physical Measurements Lab

The Physical Measurements Lab is equipped with standard facilities for phase transition studies in liquid crystals, liquid crystal nanocomposites and various micellar solutions. The lab members are actively involved in the development of new precise techniques for a variety of phase transition measurements. Available equipment includes a polarising optical microscope, dielectric impedance analyser and confocal microscope. Currently, there are experimental set-ups for conoscopic, switching current and various electro-optical measurements.

Liquid Crystal Display Lab

The LCD lab has basic facilities for the fabrication of liquid crystal cells and small size (100mmX100mm) displays as well as standard electronics equipment for their testing. Spin coating system, vacuum deposition unit, rubbing machine and temperature controlled ovens are frequently used by the lab members.

Rheology and Light Scattering Lab

The lab utilises rheology and light scattering techniques to study the dynamics of soft glassy materials and amphiphilic systems. The most frequently used instrumentation in the lab includes a dynamic light scatterometer and a rheometer. Rheology, dynamic light scatterometry and diffusing wave spectroscopy are some of the measurement techniques used in the lab.

X-Ray Diffraction Lab

The X-ray lab is for investigating the phase behaviour of various surfactants using X-ray diffraction. Polarising light microscopy and small angle X-ray scattering techniques are often used in the lab. To perform precise X-ray measurements, the lab is equipped with a

confocal microscope, X-ray diffractometer and a small angle X-ray scatterometer.

Biophysics Lab

The Biophysics lab is a self-sufficient lab where various cells can be grown, manipulated and analysed. It is equipped with two fully motorised microscopes allowing for fluorescence and face contrast microscopy measurements, confocal microscope, biosafety cabinet for growing cells, incubators, centrifuge and a 3D microscope for dissections.

Electrochemistry and Surface Science Lab

The lab performs controlled experiments on test surfaces in electrochemical cells using electrochemical instruments such as a potestiostat, frequency response analyser and lock-in amplifier. An electrochemical quartz crystal microbalance is used to measure mass changes. Thin film characterisation is done with a variety of scanning probe techniques like scanning tunnelling microscopy, atomic force microscopy and others.

During this year, two major experimental research facilities were set up under the aegis of the SCM group. One is a state-of-the-art Field Emission Electron Microscope (FESEM) with cryo facilities from Carl Zeiss/Quorum and the other is a Raman spectrograph, both of which are functioning well.

Mechanical Engineering

The mechanical workshop at RRI meets the mechanical design and fabrication needs of RRI experimental activities. It has the necessary machinery and a team of skilled personnel who can undertake fabrication of various sophisticated mechanical hardware components for electronics instrumentation as well as sheet metal work for component, receiver enclosures, and system racks. The expertise of the mechanical workshop team has been used in large projects like the fabrication and installation of 1,100 helical antennas for the Mauritius Radio Telescope, the design and fabrication of a low frequency antenna feed system for GMRT, and fabrication of a multi-band feed for the Green Bank Telescope, West Virginia. Specific tasks such as fabrication of precision mounts, positioners and cooling stages for the LAMP and SCM groups have been undertaken by the mechanical workshop team as well.

Library

The library of RRI was also founded by Sir CV Raman, and ever since, has been a constant source of both specialised and general knowledge for its users. Over the years, the library has continuously expanded to keep pace with the increasing requirement of literature of the scientific community of the institute. Currently, the library's total collection stands at 66,713. This collection consists of 26,875 books and 39,838 bound volumes of journals. In addition, the library has in its possession 1,613 non-book materials that include scientific slides, CD-ROMS, DVDs and audio/video tapes.

The library continued its partnership in both FORSA and CSIR-DST National Knowledge Resource Consortium. The current access to users of the library extends to 17 publishers and their journals of over 4,000. To keep pace with this increase, the library webpage has been redesigned for easy navigation.

Digital Library Activities

Digitisation of archival materials, which was taken up in the previous year was continued. 146 papers published during this year and 300 photographs of Sir CV Raman also were uploaded in the current year, thus increasing the number of records to 4,320.

"Imprints Collection" – a bio bibliographical database of retired scientists of RRI has been developed. At present, 22 scientists and their research work is captured in this database. This database provides access to 1,470 research papers and 80 PhD theses, in addition to a number of photographs, lectures (audio/video/text), newspaper clippings and biographic profiles of individual scientists.

Photo Gallery – a photo exhibition, as an ongoing exercise, was initiated on 3 October 2011. Scanning photos of historical importance, digitising them, exhibiting them and then adding those photos to the digital repository has started. So far, around 300 photos have been added using J-album, a free software.

Computer Facilities

The various computing needs of different research and development groups and the library at RRI are handled by the computer division team. The campus network consists of a switched gigabit backbone on fibre and wired 10/100 Mbps Ethernet to the desktops. Further mobility is also assured by the secured wireless network available on the campus premises.

The campus is connected to the internet and the National Knowledge Network via a high speed 1 Gbps link. It is also connected to the internet via a dedicated 10 Mbps link. A 2 Mbps leased line connects the institute to the observatory at Gauribidanur. Users are also provided with VPN access to the LAN.

The computing facilities consist of multi-CPU multi-core systems accessed by users from their desktops through a high speed internal LAN. Application-specific software packages along with development tools are available on these platforms. A cluster of 16 nodes, 32 Intel Xeon X5570 processors, 256GB RAM and 8TB storage caters to the heavy computation needs of users.

The computer facilities on campus continued to be upgraded and improved during

the last year. Backup and storage requirements were addressed to meet increased storage needs. Operating system and hardware upgrades were undertaken for key servers, and scientific and other application packages were procured and upgraded. The group also provided and managed services such as email, web, printing, VPN and digital repository, among others.

Campus

The RRI campus is located in the northern part of Bangalore city. The campus covers an area of around 20 acres, where the bustling noise of the fast growing metropolis gives way to the soothing sounds of nature, creating the necessary peaceful environment for creative work and research. The campus hosts all the office buildings, laboratories, a canteen, guest house and the 10.4m telescope but when walking around, one is left with the impression that they are all tiny additions to the prevailing natural garden.

Most of the campus was landscaped by Sir CV Raman and the RRI Trust is proud to enforce policies that protect its unique natural environment. The guest house on campus has facilities to comfortably accommodate distinguished visitors and visiting academics, including visiting doctoral students. A canteen is also present on campus to provide meals to all guests as well as lunch and refreshments to all RRI employees. Various gatherings, visitor talks, informal meetings, concerts and dinners take place at the Village – an ethnically designed area providing a warm rustic touch to the overall atmosphere on campus.

The building adjacent to the canteen houses a small clinic where consultant medical practitioners pay visits at fixed hours on most working days of the week. Sports activities are envisioned to be an important part of campus life. Therefore, there are two badminton courts available for use by the research faculty, staff and students. Extensive renovations of major facilities and buildings on campus have been taking place during the last couple of years.

academic

PROGRAMMES

PhD Programme

RRI offers a PhD programme that gives enthusiastic and motivated students the opportunity to join the global research community. The unique atmosphere of intellectual freedom allows the students at RRI to pursue their individual interests within the broad areas of research conducted at the institute. As a result, students are challenged to engage their full creative potential and develop the ability to conduct independent research. Constant formal and informal interactions with the faculty and other students take the learning process outside of the classroom and individuals' office space, encouraging students to think and question critically others' and their own understanding and knowledge. Such interactions also promote an open-minded attitude towards science and research. Attendance on national and international conferences exposes RRI students to a much larger and diverse research community where they get a perspective of what the "big picture" in their field of research is.

Students at RRI are registered for a PhD degree with the Jawaharlal Nehru University, New Delhi. RRI is also a participant in the Joint Astronomy Programme (JAP) with the Indian Institute of Science, Bangalore and the Physics in Biology Programme with the National Centre for Biological Sciences, Bangalore. Further details about the PhD programme, admission requirements and process can be found on the website.

Currently, there are nearly 60 students from all over India enrolled in the PhD programme and conducting research with faculty members from the four groups in the institute. Last year seven PhD degrees were awarded and four were submitted for review.

Post Doctoral Fellowship Programme

RRI offers a post doctoral fellowship programme which is open for applications throughout the year. The initial duration of the fellowship is two years and is often extended to three. Post doctoral fellows work independently and have the academic freedom of choice in research area and collaboration. Even though post doctoral fellows are not required to work in any specific research programme or be attached to specific research staff of the institute, it is desirable that they have professional research interests and a proven track record in areas with significant overlap or association with the ongoing and envisaged activities at the institute. Participation of the fellows in the academic activities of the institute, student supervision as co-guides and collaboration with other research staff is encouraged.

Candidates who have already held at least one position as a post doctoral researcher can also apply for the limited number of Pancharatnam Fellowships offered at RRI. Applications are accepted throughout the year and the processing time takes between four to six months. The selected candidates are awarded the Pancharatnam Fellowship for a period of three years. Further details about the post doctoral and Pancharatnam fellowships at RRI can be found on the website www.rri.res.in.

Currently, there are 11 post doctoral fellows at RRI from the country and abroad. Their research background, diverse scientific interests and future goals play an important role in the overall academic and research dynamics of the institute.

Visiting Student Programme (VSP)

VSP is aimed at offering research experience to highly motivated students pursuing their undergraduate or postgraduate studies. The duration of the programme varies on a case-by-case basis and can range from anywhere between six weeks to a whole year. Students seeking such opportunities, mainly during their summer vacations, also continue to be supported under this programme.

During the period of the visit, the student works closely with at least one staff member of the institute on a suitable project, or on part of a project, as appropriate. The student's work and the interaction with the staff and other graduate students at the institute are expected to provide her/him a flavour of the research pursuits at the institute, in general, and a first-hand experience in research, in particular.

The total number of visiting students at a time is limited by the availability of projects, mentors and relevant resources. During the year 2011-2012, a total of 112 students from different parts of the country participated in the programme. The VSP at RRI runs throughout the year.

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NR Srinath

PUBLICATIONS

The Raman Research Institute publishes the research activities carried out over the year in national and international peer-reviewed journals. Each of the four research groups at RRI finds their work published in distinguished journals that focus on their specific research area. For the Theoretical Physics group these include, but are not limited to, *Physical Review*, *Classical and Quantum Gravity*, *Journal of Physics*, *Journal of Statistical Mechanics* and *Biophysics Journal*. Research faculty and students from the Soft Condensed Matter group have their work published in journals like *Physical Review*, *Liquid Crystals*, *Journal of Physical Chemistry*, *Journal of Chemical Sciences*, *Journal of Applied Physics*, *European Physical Journal*, *Journal of Nanoscience and Nanotechnology* and many more.

Publications of the Light and Matter Physics group can be found in *Physical Review*, *Journal of Nanophotonics*, *Optical Express* and *Canadian Journal of Physics*. The astronomers and astrophysicists use the *Physical Review*, *Monthly Notices of the Royal Astronomical Society*, *Astrophysical Journal*, *Journal of Astrophysics and Astronomy* and others as a means to share their work with the scientific community around the world. 132 papers featuring RRI members as their authors and/or co-authors were published during the year. There were 17 publications in conference proceedings and 39 (30 in journals and 9 in conference proceedings) publications are in press. Members at the institute expand and diversify their work beyond the scope of highly specialised technical and science journals by publishing books and/or articles for popular science magazines.

A full list of the publications by each of the institute members is provided in Appendix I.

other ACTIVITIES

Conferences

Conferences and visits to various institutions at home and abroad play a significant role in the research activities of the institute members. Such events provide opportunities for the exchange of ideas and are often a starting point for future fruitful collaborations with other researchers from various institutions within India and abroad. Last year, faculty and students of the institute attended numerous conferences in India, Australia, Japan, USA and Europe.

In addition, lectures and invited talks were given at a variety of workshops, international programmes, multinational project meetings and training programmes. Members of the institute visited colleges around the country and specially organised workshops on different science and research topics to deliver lectures, talks and presentations.

A full list of the conferences visited by each of the institute members is provided in Appendix II.

Seminars and Colloquia

Thursday colloquia are one of the numerous activities promoted at the institute as a way to increase the interactions between the various research groups within RRI as well as those between RRI members and invited speakers and their institutions. Apart from covering relevant science topics, the colloquia often introduce new and interesting themes from various other disciplines.

During the last year, RRI invited speakers from all over the globe to deliver the Thursday colloquia. The topics covered a range of topics, including “Measuring Quantum Gravity”, “Data Assimilation – Interplay between Nonlinearity and Statistics”, “Neutrinos Breaking the Light Barrier?”, “Advanced Polymers for 3D Telepresence and Energy Conversion”, and “Water and a City”.

A complete list of the speakers, their lecture topics and when they visited RRI is given in Appendix III.

Seminars at the institute are often delivered by visiting faculty and researchers. Unlike colloquia, seminars are intended to deepen the understanding and generate discussions on a very specific research theme. Usually, the topics cover the current progress of collaborative projects between RRI and the visitor’s institution, or themes of particular interest to RRI members.

A list of the visiting research faculty and researchers to RRI during the last year is given in Appendix IV.

In-house Meetings

The RRI In-House Meeting is an annual event that aims to bring together the members of the different research divisions, laboratories and support services of RRI to foster an appreciation amongst the community of the diversity of the scientific activities on campus. During the Meeting days, an assortment of talks, poster presentations and informal discussions on a wide spectrum of topics is arranged. There are, sometimes, talks by invited speakers on topics of general interest and outside the direct research themes of members of the institute in addition to a social gathering.

Visiting Scholars

High priority is given to increasing the stream of visiting scholars to the institute. In today’s high-tech world of global connectivity the academic and research community is more open than ever before. Maintaining a nationally and internationally open environment is crucial for the success of every research institution.

Members at RRI recognise that and work tirelessly toward creating more opportunities for a larger number of scientists, researchers and engineers to visit the institute, contribute new ideas and skills, while benefitting from the expertise of RRI’s own members. Visits at RRI can last from a few days to a few months and often lead to important collaborative results and/or the conception of new, interesting projects.

Last year, there were 117 scholars who visited RRI from dozens of Indian and international institutions. RRI is happy to have so many friends and thanks all of them for making the environment in the institute so diverse, dynamic and vibrant.

A list of all visitors, where they come from and when they visited RRI can be found in Appendix IV.

Other activities

PhD Awarded

Satyam Kumar Gupta: Synthesis and characterisation of some non-conventional discotic liquid crystals

Nagaraju DH: Electrochemical studies of some redox active bio-molecular and small organic molecules on nanomaterials modified surfaces

Bibhu Ranjan Sarangi: Organisation of sterols in model membranes

Ruta Kale: A multi-wavelength study of radio halos and relics in clusters of galaxies

Rakesh Kumar Pandey: Electron transfer and electro catalytic studies on some organic and conducting polymer nanocomposite thin films

Anupam Kundu: Problems in transport theory

AV Radhakrishnan: Investigations on the polymorphism of surfactant-DNA complexes

Submitted

Peeyush Prasad: A network centric receiver architecture for low frequency arrays

Md. Arif Kamal: Influence of some membrane-active biomolecules on the phase behaviour of model lipid membranes

Antara Pal: Studies on the self-assembled structures of ionic amphiphiles in water – influence of strongly binding counterions and polymers

Tripta Bhatia: Experimental studies on statistics and dynamics of some novel instabilities in lyotropic systems

General

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

	(Amount in lakhs)
PLAN (Recurring & Non Recurring)	Rs.3,898.00
NON-PLAN (Recurring)	Rs.142.00
TOTAL	Rs.4,040.00

Journal Club

The Journal Club at RRI, initiated in 1981, aims at drawing the attention of members of the institute to exciting and interesting papers that appear in scientific literature. Given the large number of papers published these days, it is nearly impossible for an individual to keep track of developments outside their research specialities. The Journal Club tries to partly remedy this situation by offering presentations of a variety of recent papers of general interest.

The last Journal Club slot of the year is traditionally reserved to review the year's Nobel Prize Award in Physics. While speakers present their selected papers, informal discussions, questions and demonstrations are strongly encouraged as often they are the seeds of better understanding that can lead to better quality research.

A list of the papers reviewed during the Journal Club meetings last year is attached to the annual report as Appendix V.

Hindi Cell

Under the guidance of the Official Language Implementation Committee of the institute, efforts were intensified to meet the targets fixed by the Annual Programme of the Ministry of Home Affairs, Government of India. In this direction, all the concerned employees of the administration were instructed to monitor the usage of the official language. Hindi workshops were conducted to impart training on computers to work in Hindi at the institute. The "Official Language Training Programme" was reoriented more towards enhancing the working skills in the usage of Hindi. Most of the targets were achieved during the year.

Reservations

The institute follows the reservation policy as followed by the Government of India scientific departments like the Department of Space and Department of Atomic Energy.

Others

The RRI community is involved in various other activities ranging from organising special conferences, meetings and workshops, and inviting college students to the campus, to having formal and informal dinners, sports tournaments, and a variety of cultural programmes both with invited performers and members of RRI themselves. Such activities are considered to be an integral part of the members' experience at the institute. Other events and activities such as in-house meetings, concerts, formal faculty farewell dinners, college visits and more continue to enrich and diversify the academic life and atmosphere at the Raman Research Institute.

Public Outreach

Global Jet Watch

RRI has become a partner in an international initiative that also includes students from a local school. Global Jet Watch (http://www.globaljetwatch.net/) is a new project that links astronomers at Oxford University with school children around the world in order to carry out cutting edge research. Members of RRI are involved in the setting up of a 20-inch optical telescope, the largest of its kind in Karnataka. One of the many exciting things about the Indian telescope is that its location allows it to observe the whole of the northern hemisphere as well as a significant portion of the southern hemisphere, the only telescope in the project network to do so.

The aim of Global Jet Watch is to make the world's first continuous, round-the-clock, detailed monitoring programme for the prototypical micro-quasar SS433, also known as the "Cosmic Corkscrew". Observing the object throughout entire orbital periods, precession periods, and flaring events will allow a detailed understanding of the interplay between accretion, jets and winds. SS433 persistently ejects jets of plasma at a quarter of the speed of light, about an axis which precesses approximately every six months to produce the characteristic corkscrew shape. A technique has been developed to study individual "bullets" of matter as they emerge, but the exploitation of this incredible scientific resource is hindered by the near-impossibility of obtaining sustained monitoring with sufficient time-resolution to follow the rapid changes. It is immensely tricky to coax different observatories to coordinate observations, and so Global Jet Watch was developed as a unique solution to this problem.

Special small telescopes have been strategically deployed in schools in India, Chile, Australia and South Africa with local professional astronomers also being involved. Each night, the telescopes will obtain a spectrum of the high-speed jets which are emitted from SS433.

As part of the project, the telescope in India has been set up at Jawahar Navodaya Vidyalaya (JNV) school in Dodaballapur, approximately an hour's drive away from Bangalore. The school's participation will make possible the monitoring of this unique object every few hours, something which would otherwise be impossible given the time constraints imposed on the use of professional telescopes. Data obtained by the school observatory will be processed by computers in Oxford, and a web interface will be developed to provide the schools with results so that the school children can monitor the progress of the rapidly evolving jets themselves, and understand how their observations tie up with those obtained by the other schools around the world. Rather than simply learning about scientific discoveries, the participating pupils will be making the discoveries themselves.

The International Science School

The Professor Harry Messel International Science School (ISS) has been conducted by the Science Foundation for Physics, University of Sydney, Australia, since 1962. It brings together about 140 students from around the world for two weeks of advanced study on topics of modern science. The foundation sets aside five scholarships at the ISS for Indian high school students. This programme is conducted once every two years. All ISS scholars are chosen on their academic ability and, depending on their country, must compete for an ISS scholarship through a written essay, an interview or an exam.

RRI has been coordinating this event from India since 2007 and has been identifying students wishing to participate in the ISS. RRI has an intensive selection process to choose the five students for the ISS, which includes a written test with general questions and an essay as well as an interview. The selected students are awarded a scholarship and are also given travel charges to the University of Sydney and back to India. RRI has been taking the help of the Kishore Vaigyanik Protsahan Yojana (KVPY) of the Indian Institute of Science to shortlist prospective candidates (usually in classes XI and XII) for the ISS from across the country.

APPENDIX 1

Publications

Papers in Journals

1 Atom interferometry and the gravitational redshift
Sinha, Supurna; Samuel, Joseph
Classical and Quantum Gravity **28**, 145018, 2011

2 Non-local geometric phase in two-photon interferometry
Martin A; Alibart O; Flesch JC; Samuel, Joseph; Sinha, Supurna; Tanzilli S; Kastberg A
Europhysics Letters **97**, 10003, 2012

3 Focus section on quantum gravity - 25 years of quantum gravity
Samuel, Joseph
Classical and Quantum Gravity **28**, 150301, 2011

4 Tops and writhing DNA
Samuel, Joseph; Sinha, Supurna
Journal of Statistical Physics **143**, 399, 2011

5 Gravitational radiation for extreme mass ratio inspirals to the 14th post-Newtonian order
Fujita, Ryuichi
Progress of Theoretical Physics **127**, 583, 2012

6 The Japanese space gravitational wave antenna-DECIGO
Kawamura, Seiji*; Ando M*; Seto N*; Sato S*; Nakamura T*; Fujita, Ryuichi and 132 co-authors
Classical and Quantum Gravity **28**, 094011, 2011

7 The 2.5PN linear momentum flux and associated recoil from inspiralling compact binaries in quasi-circular orbits: nonspinning case
Mishra CK; Arun KG; Iyer BR
Phys. Rev. D **85**, 044021, 2012

8 Gravitational waveforms for binary black holes
Iyer BR
International Journal of Modern Physics D **10**, 2081, 2011

9 Classical orbital magnetic moment in a dissipative stochastic system
Kumar N
Physical Review E **85**, 011114, 2012

10 Light scattering from a magnetically tunable dense random medium with dissipation: ferrouid
Shalini M*; Sharma D*; Deshpande AA; Mathur D*; Ramachandran, Hema; Kumar N
Europhysics Journal D **66**, 30, 2012

11 Comment on Classical Langevin dynamics of a charged particle moving on a sphere and diamagnetism: A surprise
Kumar N; Kumar K Vijay; Deshpande AA
Europhysics Letters **97**, 17003, 2012

12 Effect of injected noise on electromagnetically induced transparency and slow light
Ranjith V; Kumar N
Current Science **101**, 653, 2011

13 Stochastic pump of interacting particles
Chaudhuri, Debasish*; Dhar, Abhishek
Europhysics Letters **94**, 30006, 2011

14 Generating function formula of heat transfer in harmonic networks
Saito, Keiji*; Dhar, Abhishek
Physical Review E **83**, 041121, 2011

15 Tunable thermal conductivity in defect engineered nanowires at low temperatures
Dhara, Sajal*; Solanki, Hari S*; Pawan R Arvind*; Singh, Vibhor*; Sengupta, Shamashis*; Chalke BA*; Dhar, Abhishek and 3 co-authors
Physical Review B **84**, 121307, 2011

16 Nonequilibrium density-matrix description of steady-state quantum transport
Dhar, Abhishek; Saito, Keiji*; Hanggi, Peter*
Physical Review E **85**, 011126, 2012

17 Work fluctuations for a harmonic oscillator driven by an external random force
Sabhapandit, Sanjib
Europhysics Letters **96**, 20005, 2011

18 Heat and work fluctuations for a harmonic oscillator
Sabhapandit, Sanjib
Physical Review E **85**, 021108, 2012

19 Record statistics of continuous time random walk
Sabhapandit, Sanjib
Europhysics Letters **94**, 20003, 2011

20 Additivity Principle in High-Dimensional Deterministic Systems
Saito K; Dhar, Abhishek
Phys. Rev. Lett. **107**, 250601, 2011

21 Dynamics of a flexible polymer in planar mixed flow
Das, Dipjyoti; Sabhapandit, Sanjib; Das, Dibyendu
J. Phys.: Conf. Ser. **297**, 012007, 2011

22 Causal topology in future and past distinguishing spacetimes
Parrikar, Onkar*; Surya, Sumati
Classical and Quantum Gravity **28**, 155020, 2011

23 The diffeomorphism constraint operator in loop quantum gravity
Laddha, Alok; Varadarajan, Madhavan
Classical and Quantum Gravity **28**, 195010, 2011

24 Early-time particle dynamics and non-affine deformations during microstructure selection in solids
Sengupta, Surajit*; Rao, Madan; Bhattacharya, Jayee*
Journal of Physics: Condensed Matter **23**, 295402, 2011

25 Multispecies model with interconversion, chipping, and injection
Sachdeva, Himani*; Barma, Mustansir*; Rao, Madan
Physical Review E **84**, 031106, 2011

26 Bidirectional transport in a multispecies totally asymmetric exclusion-process model
Muhuri, Sudipto; Shagolsem, Lenin*; Rao, Madan
Physical Review E **84,** 031921, 2011

27 Topological parameters in gravity
Kaul, Romesh K; Sengupta, Sandipan
Phys. Rev. D. **85**, 024026, 2012

28 Spatiotemporal regulation of chemical reactions by active cytoskeletal remodeling
Chaudhuri, Abhishek; Bhattacharya B*; Gowrishankar, Kripa; Mayor, Satyajit*; Rao, Madan
Proceedings of the National Academy of Sciences of the United States of America **108**, 14825, 2011

29 Integrin adhesion drives the emergent polarization of active cytoskeletal stresses to pattern cell delamination
Meghana C*; Ramdas, Nisha*; Hameed FM*; Rao, Madan; Shivashankar GV*; Narasimha M*
Proceedings of the National Academy of Sciences **108**, 9107, 2011

30 ATLBS extended source sample: the evolution in radio source morphology with flux density
Saripalli L; Subrahmanyan R; Thorat K; Ekers RD; Hunstead RW; Johnston HM; Sadler EM
Astrophysical Journal Supplement **199**, 27, 2012

31 PeV gamma rays from interactions of ultra high energy cosmic rays in the milky way
Gupta, Nayantara
Astroparticle Physics **35**, 503, 2012

32 Discovery of a giant radio halo in a massive merging cluster at z = 0.443
Dwarakanath KS; Malu SS; Kale, Ruta
Journal of Astrophysics and Astronomy **32**, 529, 2011

33 Multi-frequency studies of radio relics in the galaxy clusters A4038, A1664 and A786
Kale, Ruta; Dwarakanath KS
The Astrophysical Journal **744**, 46, 2012

34 HI in Arp 72 and similarities with M51-type systems
Sengupta, Chandreyee; Saikia DJ; Dwarakanath KS
Monthly Notices of the Royal Astronomical Society **420**, 2, 2012

35 Dust-driven wind from disk galaxies
Sharma, Mahavir; Nath BB; Shchekinov, Yuri*
Astrophysical Journal Letters **736**, L27, 2011

36 Intracluster gas pressure, entropy injection and redshift evolution
Nath BB; Majumdar, S*
Monthly Notices of the Royal Astronomical Society **416**, 279, 2011

37 The Australia Telescope Compact Array Broadband Backend (CABB)
Wilson, Warwick E; Ferris RH; Axtens P; Brown A; Davis E; Hampson G; Leach, M; Roberts P; Saunders S; Koribalski BS; Caswell JL; Lenc E; Stevens J; Voronkov, MA; Wieringa MH; Brooks K; Edwards PG; Ekers RD; Emonts B; Hindson L; Johnston S; Maddison ST; Mahony EK; Malu SS; Massardi, M; Mao MY; McConnell D; Norris RP; Schnitzeler D; Subrahmanyan R; Urquhart JS; Thompson MA; Wark RM
Monthly Notices of the Royal Astronomical Society **416**, 832, 2011

38 The Australia telescope 20 GHz survey: hardware, observing strategy, and scanning survey catalog
Hancock, Paul Jacob*; Roberts, Paul*; Kesteven, Michael J*; Ekers, Ronald D*; Subrahmanyan R; 15 Co-authors
Experimental Astronomy **32**, 147, 2011

39 Imaging the epoch of reionization: limitations from foreground confusion and imaging algorithms
Vedantham, Harish; Udaya Shankar N; Subrahmanyan R
The Astrophysical Journal **745**, 176, 2012

40 18 GHz SZ measurements of the bullet cluster
Malu SS; Subrahmanyan R
Journal of Astrophysics and Astronomy **32**, 541, 2011

41 Design and optimization of a cylindrical X-ray detector using finite element method
Duraichelvan R; Srinivas AR; Ateequlla; Paul, Biswajit; Rishin PV; Cowsik R
Journal of Mechanical Engg Vol. **9**, p55-64, 2011

42 Studies of quasi-periodic oscillations in the black hole transient XTE J1817-330
Roy, Jayashree*; Agrawal PC*; Paul, Biswajit; Duorah, K*
Monthly Notices of the Royal Astronomical Society **412**, 1011, 2011

43 Eclipse Timings of the LMXB XTE J1710-281: Orbital period glitches
Jain, Chetana; Paul, Biswajit
Monthly Notices of the Royal Astronomical Society **413**, 2, 2011

44 Suzaku observation of the transient X-ray pulsar GRO J1008-57Naik, Sachindra*; Paul, Biswajit; Kachhara, Chetan*; Vadawale, Santosh V*
Monthly Notices of the Royal Astronomical Society **413**, 241, 2011

45 RXTE-PCA observations of 1A 1118-61: timing and spectral studies during an outburst
Devasia, Jincy*; James, Marykutty; Paul, Biswajit; Indulekha Kavila*
Monthly Notices of the Royal Astronomical Society **414,** 1023, 2011

46 Prospect of polarization measurements from black hole binaries in their thermal state with a scattering polarimeter
Maitra, Chandreyee; Paul, Biswajit
Monthly Notices of the Royal Astronomical Society **414**, 2618, 2011

47 Pulse profile stability of the Crab pulsar
Jain, Chetana*; Paul, Biswajit
Research in Astronomy and Astrophysics **11**, 1134, 2011

48 Search for pulsations in the LMXB EXO 0748-676
Jain, Chetana; Paul, Biswajit
Research in Astronomy and Astrophysics **11,** 577, 2011

49 Interference detection in Gaussian noise
Baddi, Raju R
Astronomical Journal **141**, 190, 2011

50 Helium line detections from extended low-density warm-ionized medium at 1.4 ghz
Baddi, Raju R
Astronomical Journal **142**, 154, 2011

51 A survey of radio recombination lines using the Ooty radio telescope at 328 mhz in the inner galaxy
Baddi, Raju R
Astronomical Journal **143**, 26, 2012

52 RRL Observations with ORT at 328 MHz and WSRT at 1.4 GHz from Eldwim
Baddi, Raju R
Astronomical Journal **143**, 45, 2012

53 QUBIC: The QU bolometric interferometer for cosmology
Battistelli E*; Bau A*; Malu SS and 61 co-authors
Astroparticle Physics **34**, 705, 2011

54 X-ray spectroscopy of the high-mass x-ray binary pulsar centaurus x-3 over its binary orbit
Naik, Sachindra*; Paul, Biswajit; Ali, Zulfikar*
Astrophysical Journal, **737**, 79, 2011

55 Transient high mass x-ray binaries
Paul, Biswajit; Naik, Sachindra
Bulletin of the Astronomical Society of India **39**, 429, 2011

56 Timing and spectral studies of the transient x-ray pulsar GX 304-1 during an outburst
Devasia, Jincy; James, Marykutty; Paul, Biswajit; Indulekha, Kavila
Monthly Notices of the Royal Astronomical Society **417**, 348, 2011

57 Solar cycle phase dependence of supergranular fractal dimension
Paniveni U*; Krishan, Vinod*; Singh J*; Srikanth R
Journal of Astrophysics and Astronomy **32**, 265, 2011

58 A high speed networked signal processing platform for multi-element radio telescopes
Prasad, Peeyush; Subrahmanya CR
Experimental Astronomy **31**, 1, 2011

59 Radio-Optical imaging of ATLBS survey
Thorat, Kshitij
Journal of Astrophysics and Astronomy **32**, 495, 2011

60 Double relics in the outskirts of A3376: accretion ows meet merger shock?
Kale, Ruta; Dwarakanath KS; Bagchi, Joydeep*; Paul, Surjit*
Journal of Astrophysics and Astronomy **32**, 533, 2011

61 A zoo of radio relics: cluster cores to filaments
Kale, Ruta; Dwarakanath KS
Journal of Astrophysics and Astronomy **32**, 537, 2011

62 Carbon recombination lines towards the Riegel-Crutcher cloud and other cold H I regions in the inner galaxy
Roshi, D Anish; Kantharia NG*
Monthly Notices of the Royal Astronomical Society **414**, 519, 2011

63 Detecting neutral hydrogen in emission at redshift z ' 1
Kandai, Nishikanta*; Sethi, Shiv K; Matteo TD*; Croft, Rupert AC*; Springel, Volker*; Jana, Anirban*; Gardner, Jeffrey P*
Monthly Notices of the Royal Astronomical Society **415**, 2580, 2011

64 Theoretical estimates of two-point shear correlation functions using tangled magneticfields
Pandey, Kanhaiya; Sethi SK
Astrophysical Journal **748,** 27, 2012

65 The nonmodular topological phase and phase singularities
Bhandari, Rajendra
Physical Letters A **375,** 3562, 2011

66 Ehrenfest's Theorem and Nonclassical States of Light. 1. Ehrenfest's theorem in quantum mechanics.
George, Lijo T; Sudheesh C*; Lakshmibala S*; Balakrishnan V*
Resonance **17(1),** 23, 2012

67 Ehrenfest's theorem and nonclassical states of light: 2 Dynamics of nonclassical states of light
George, Lijo T; Sudheesh C*; Lakshmibala S*; Balakrishnan V*
Resonance **17(2),** 192, 2012

68 Non-Gaussianity and direction-dependent systematics in HST key project data
Shashikant; Saini TD
Monthly Notices of the Royal Astronomical Society, **415**, 2594, 2011

69 Transport coefficients for the shear dynamo problem at small Reynolds numbers
Singh, Nishant K; Sridhar S
Physical Review E **83**, 056309, 2011

70 Magnetohydrodynamics turbulence: An astronomical perspective
Sridhar S
Pramana **77,** 185, 2011

71 Timing and broad-band spectroscopy of 1A 1118-61 with Suzaku
Maitra C; Paul, Biswajit; Naik, Sachindra
Monthly Notices of the Royal Astronomy Society **420**, 2307, 2012

72 Active galactic nuclei feedback and clusters
Nath BB
Journal of Astronomy & Astrophysics, **32**, 545, 2012

73 Non equilibrium carbon ionization states and the extragalactic far UV background with HeII absorption
Vasiliev EO*; Sethi SK; Nath BB
Astrophysics & Space Sciences, **335**, 211, 2011

74 Radiation and thermal pressure driven galactic winds
Nath BB
Astronomical and Astrophysical Transaction, **27**, 183, 2012

75 Dust in the IGM: pro and contra
Shchekinov, Y*; Nath BB
Astrophysics & Space Sciences, **335**, 207, 2011

76 4-(Benzyloxy) phenyl 4-hexadecyloxy-3-methoxybenzoate
Al-Eryani WFA; Srinivasa HT; Jeyaseelan S; Sadashivaiah T; Devarajegowda HC
Acta. Crystallographica E **67**, 840, 2011

77 Anticlinic smectic C phase in new and novel five-ring hockey stick-shaped compounds
Radhika S; Srinivasa HT; Sadashiva BK
Liquid Crystals **38**,785, 2011

78 Rheological properties of a chiral liquid crystal exhibiting type-II character
Rajeswari M*; Ananthaiah J*; Dabrowski R*; Sastry VSS*; Dhara S*; Sadashiva BK
Molecular Crystals and Liquid Crystals **547**, 39, 2011

79 Calorimetric study of the effect of bent-shaped dopant molecules on the critical behavior at the nematic-smectic-Ad phase transition
Sasaki Y*; Ema K*; Le KV*; Takezoe H*; Dhara S*; Sadashiva BK
Physical Review E **83**, 061701, 2011

80 Magnetic susceptibility studies on a ternary lyotropic liquid crystal system
Vijayaraghavan D
Molecular Crystals and Liquid Crystals **547**, 181, 2011

81 Magnetic susceptibility and electrical conductivity studies on the aqueous solutions of two nonionic surfactants
Vijayaraghavan D
Journal of Molecular Liquids **166**, 76-80, 2012

82 Observation of hysteresis in the properties of a ternary lyotropic liquid crystal system
Vijayaraghavan D
Molecular Crystals and Liquid Crystals **547**, 189, 2011

83 Experimental studies of the jamming behaviour of triblock copolymer solutions and triblock copolymer-anionic surfactant mixtures
Basak, Rajib; Mukhopadhyay, Nabaneeta; Bandyopadhyay, Ranjini
European Physical Journal E **34**, 103, 2011

84 Bit slice addressing of fast switching bi-stable displays and multi-bit slice addressing of active matrix liquid crystal displays
Ruckmongathan TN
Journal of Display Technology **8**, 198, 2012

85 Cross pairing of select and data voltages to display grayscales in liquid crystal displays
Ruckmongathan TN
Journal of Display Technology **7**, 633, 2011

86 Method to display gray shades in rms responding matrix display
Ruckmongathan TN
Patent No. US8081179B2 date Dec. 20, 2011

87 A simple and low-cost ultramicroelectrodes fabrication and characterization method for undergraduate students
Sur, Ujjal Kumar+; Dhason A; Lakshminarayanan V
Journal of Chemical Education **89**, 168, 2012

88 Structure-property correlation of a hockey stick-shaped compound exhibiting N-SmA-SmCa phase transitions
Sathyanarayana P*; Radhika S; Sadashiva BK; Dhara, Surajit*
Soft Matter **8**, 2322, 2012

89 H-shaped azoester-oxymethylene containing twin liquid crystalline compounds
Varia MC; Kumar, Sandeep; Prajapati AK
Liquid Crystals, **39**, 365, 2012

90 Electron transfer studies of redox probes in bovine milk
Shrikrishnan S; Lakshminarayanan V
Journal of Colloid and Interface Science **370**, 124, 2012

91 A simple electro-optic technique for studying the electroclinic effect in the smectic A* phase
Datta, Soma; Roy, Arun
Liquid Crystals **38**, 1193, 2011

92 Anthraquinone-based discotic liquid crystals: new monomers and dimers
Prasad, Veena*; Roy, Arun; Nagaveni NG*; Gayathri K*
Liquid Crystals **38**, 1301, 2011

93 Electro-optical investigations and effect of asymmetry in bent-core liquid crystals
Balamurugan S*; Kannan P*; Yadupati K; Roy, Arun
Liquid Crystals **38**, 1199, 2011

94 Randomly polarised smectic A phase exhibited by bent-core molecules: experimental and theoretical studies
Gupta, Meenal; Datta, Soma; Radhika S; Sadashiva BK; Roy, Arun
Soft Matter **7**, 4735, 2011

95 CdSe quantum dots in a columnar matrix
Kumar, Sandeep; Sagar, Laxmi Kishore*
Chemical Communications **47**, 12182, 2011

96 Novel triphenylenoimidazole discotic liquid crystals
Kumar, Sandeep; Gupta, Satyam Kumar
Tetrahedron Letters **52**, 5363, 2011

97 Discovery of a novel ferrielectric phase of five-layer periodicity in binary mixtures of chiral smectic liquid crystals exhibiting unusual reversed phase sequence
Chandani ADL*; Fukuda, Atsuo*; Kumar, Sandeep; Vij, Jagdish K*
Liquid Crystals **38**, 663, 2011

98 Electro-optical switching studies on 1,3-phenylene based banana shaped liquid crystals
Balamurugan S; Kannan P; Yadupati Y; Roy, Arun
J. Mol. Struct, **1001**, 118, 2011

99 Theory of the asymmetric ripple phase in achiral lipid membranes
Kamal, Md. Arif; Pal, Antara; Raghunathan VA; Rao, Madan
Europhysics Letters **95**, 48004, 2011

100 Collapse and coacervation of a lamellar phase by inter-headgroup bridging
Pal, Antara; Bharath P*; Dastidar SG*; Raghunathan VA
Soft Matter **8**, 927, 2012

101 Temperature driven annealing of perforations in bicellar model membranes
Nieh, Mu-Ping*; Raghunathan VA; Pabst, Georg*; Harroun, Thad*; Nagashima, Kazuomi*; Morales, Hannah*; Katsaras, John*; Macdonald, Peter*
Langmuir **27**, 4838, 2011

102 Effect of an electric field on defects in a nematic liquid crystal with variable surface anchering
Kumar, Arun T*; Sastry VSS*; Ishikawa, Ken*; Takezoe, Hideo*; Madhusudana NV; Dhara, Surajit*
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Vishnumurthy KA*; Sunitha MS*; Safakath K; Philip, Reji; Adhikari AV*
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121 Two-photon assisted excited state absorption in multiferroic YCrO3 nanoparticles
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2. Orbital evolution of X-ray binaries and quasi-periodic oscillations in X-ray pulsars
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2. Book Review for Annual Review of Astronomy & Astrophysics
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3. Reminiscing Rad
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2 In search of a covariant quantum measure
Surya, Sumati
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3 Phononic heat conduction in disordered crystals
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Ruckmongathan TN
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5 Time-resolved spectroscopy of femtosecond laser-induced carbon plasma in the rough, medium and high vacuum regimes
Anoop KK; Remya R Mohan; Rose, Priya T; Philip, Reji
Proceedings of National Laser Symposium-20, January 2012

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12 Indigo carmine dye-polymer nanocomposite films for optical limiting applications
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Philip, Reji; Thomas, Jayan*
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1 A 'Gaussian' for diffusion on the sphere
Ghosh, Abhijit; Samuel, Joseph; Sinha, Supurna
Europhysics Letters **98**, 30003, 2012

2 Biopolymer elasticity: Mechanics and thermal fluctuations
Sinha, Supurna; Samuel, Joseph
Phys. Rev. E **85**, 041802, 2012

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4 Cylindrical cellular geometry ensures fidelity of division site placement in fission yeast
Mishra M; Huang Y; Srivastava P; Srinivasan R; Sevugan M; Shlomovitz R; Gov N; Rao M; Balasubramanian M
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8 The uncertainty product of position and momentum in classical dynamics
Karthik HS; Devi, Usha*
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10 Strain glass analogue in a bent-core liquid crystal exhibiting the dark conglomerate phase
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Kavitha C; Avinash BS; Kumar, Sandeep; Lakshminarayanan V
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Soft Matter, **8**, 8952, 2012

15 Modulated phases of phospholipid bilayers induced by tocopherols
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Biochem. Biophys. Acta, **1818**, 2486, 2012

16 Effect of ring-substituted oxysterols on the phase behavior of dipalmitoylphosphatidylcholine membranes
Kamal, Md. Arif; Raghunathan VA
Euro. Biophys. J.

17 Achiral bent-core azo compounds: effect of different types of linkage groups and their direction of linking on liquid crystalline properties
Nagaveni NG; Roy, Arun; Prasad, Veena
J. Mater. Chem, **22**, 8948-8959, 2012

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Uhlig M; Pfrommer C; Sharma, M; Nath BB; Ensslin TA; Springel, V
Monthly Notices of Royal Astronomical Society, **423**, 2374, 2012

19 Simulation of radiation driven winds from disc galaxies
Chattopadhyay, Indranil; Sharma, Mahavir; Nath BB; Ryu, Dongsu
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20 Energy deposition profiles and entropy in galaxy clusters
Chaudhuri A; Nath BB; Manjumdar, Subhabratra
Astrophysical Journal, 2012

21 The roles of radiation and Ram Pressure in driving galactic winds
Sharma, Mahavir; Nath BB
Astrophysical Journal **750**,55,2012

22 Pulsed Radio Emission from the Fermi-LAT Pulsar J1732-3131: Search and A Possible Detection at 34.5 MHz
Maan, Yogesh; Aswathappa HA; Deshpande AA
Monthly Notices of the Royal Astronomy Society, 2012

23 Unstable m = 1 modes of counter-rotating Keplerian discs
Gulati, Mamta; Saini, Tarun Deep; Sridhar S
Monthly Notices of the Royal Astronomical Society, **424**, 348, 2012

24 A new layout optimization technique for arrays, applied to the MWA
Beardsley AP; Hazelton BJ; Morales MF; Cappallo RC; Goeke R; Emrich D; Lonsdale CJ; Arcus W; Barnes D; Bernardi G; Bowman JD; Bunton JD; Corey, BE; Deshpande AA; deSouza L; Gaensler BM; Greenhill LJ; Herne D; Hewitt, JN; Kaplan, DL; Kasper JC; Kincaid BB; Koeing R; Kratzenberg E; Lynch MJ; McWhirter SR; Mitchell DA; Morgan E; Oberoi D; Ord SM; Pathikulangara, J; Prabu T; Remillard RA; Rogers AE E; Roshi A; Salah JE; Sault RJ; Udaya Shankar N; Srivani KS; Stevens J; Subrahmanyan R; Tingay SJ; Wayth RB; Waterson M; Webster RL; Whitney AR; Williams A; Williams CL; Wyithe JSB
Monthly Notices of the Royal Astronomy Society

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26 Single-pulse analysis of PSR B1133+16 at 8.35 GHz and carousel circulation time
Honnappa, Sneha; Lewandowski, Wojciech; Kijak, Jaroslaw; Deshpande AA; Gil, Janusz; Maron, Olaf; Jessner, Axel
Monthly Notices of the Royal Astronomy Society, **421**, 1996, 2012

27 Neutrinos from Decaying Muons, Pions, Kaons and Neutrons in Gamma Ray Bursts
Moharana, Reetanjali; Gupta, Nayantara
Astroparticle Phys. **36,** 195, 2012

28 Spectrum and ionization rate of low energy Galactic cosmic rays
Nath BB; Nayantara, Gupta; Peter L Biermann
Monthly Notices of the Royal Astronomy Society

29 Counter-rotating stellar discs around a massive black hole: self-consistent, time-dependent dynamics
Jihad Touma R; Sridhar S
Monthly Notices of the Royal Astronomy Society, **423**, 2083, 2012

30 Mean field dynamo action in renovating shearing flows
Kolekar S; Subramanian K; Sridhar S
Physical Review E, **86**, 026303, 2012

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1 OH Maser sources in W49N: probing differential anisotropic scattering with Zeeman pairs
Deshpande AA; Goss WM; Mendoza-Torres JE
Proceedings IAU Symposium No. 287, 2012, Cosmic masers - from OH to H0

2 Binary systems: implications for outflows & periodicities relevant to masers
Singh, Nishant K; Deshpande AA
Proceedings IAU Symposium No. 287, 2012, Cosmic masers - from OH to H0

3 Unique collections at Raman Research Institute Library: a case study
Benegal, Vrinda
National Conference Soference-2011, Tata Consultancy Services, Bangalore, 15 October 2011

4 Open access digital institutional repository of Raman Research Institute
Benegal, Vrinda
57th All India Library Conference Proceedings, St. Agnes Centre for Post Graduate Studies and Research, Mangalore, 23-25 February 2012; ISBN: 81-85216-45-6

5 Digital information services and products: a case of Raman Research Institute, Bangalore
Meera BM; Manjunath M; Savanur, Kiran
National seminar on Content Management and Libraries: new vistas for harnessing information, Kerala Library Association, 14 – 16 July 2011

6 Imprints collection: a cyberscholarship of RRI
Meera BM; Savanur, Kiran; Manjunath M
Soference 2011: a social conference, Tata Consultancy Services, 15 October 2011

7 H-index as research performance indicator: a study at Raman Research Institute
Meera BM
National Workshop on using different metrics for assessing research productivity by Indian Statistical Institute, New Delhi, 16 – 17 February 2012

8 Tuning the amphiphile-DNA condensate structure with strongly binding counterions
Radhakrishnan AV; Ghosh, Sajal; Pabst, Georg; Raghunathan VA; Sood, Ajay
Proc. Natl. Acad. Sci., 2012

9 SU(2) gauge theory of gravity with topological invariants
Sengupta, Sandipan
J. Phys.: Conf. Ser. **360**, 012024, 2012

Book chapters

1. Methods to reduce power consumption of liquid crystal displays
Chapter in the book Progress in LC Science and Technology, in Honor of Prof Kobayashi 80th Birthday
Ruckmongathan TN
World Scientific Publishing Co. (WSPC) under the Liquid Crystal Book Series around Q3/ 2012

2. Directions in Causal Set Quantum Gravity
Surya, Sumati
Recent Research in Quantum Gravity Nova Science Pub. Inc., Hauppauge, USA, 2012

3. Chemistry of Columnar Liquid Crystals in Liquid Crystalline Semiconductors
Kumar, Sandeep
Canopus Academic Publishing Ltd., Bristol, UK.

** denotes co-authors who do not belong to RRI*
+ denotes Visiting Professors of RRI

APPENDIX 2

Conferences attended

Name	Conferences attended / Institutions visited	Title of paper / talk
Abhishek Dhar	Workshop on Fourier Law Field's Institute, Toronto 4 – 8 April 2011	Heat conduction in disordered harmonic lattices with energy conserving noise (*invited*)
	Workshop on Foundations and Applications of Non-equilibrium Statistical Mechanics Nordic Institute for Theoretical Physics Stockholm 19 – 30 September 2011	Current fluctuations and large deviation functions in heat transport (*invited*)
	Rutgers University, USA 1 – 12 October 2011	Current fluctuations and large deviation functions in heat transport
	Tokyo University, Japan 14 – 26 October 2011	
	International Centre for Theoretical Sciences, Bangalore 14 November 2011	Current fluctuations and large deviation functions in heat transport (*invited*)
	Conference on Concepts and Challenges in Astronomy and Astrophysics Sundarban Mahavidyalaya, West Bengal 24 – 25 November 2011	Brownian motion (*invited*)

	DST-SERC School on Nonlinear Dynamics Indian Institute of Science Education and Research, Pune 19 – 23 December 2011	Linear-response theory (five lectures)
	ICTS school on Nonequilibrium Physics Indian Institute of Science Education and Research, Kolkata 3 – 4 January 2012	Current fluctuations in heat transport (invited)
	6th International Conference on Unsolved Problems on Noise and Fluctuations Saha Institute of Nuclear Physics, Kolkata 20 – 24 February 2012	Additivity principle in three-dimensional deterministic systems
	TIFR-CAM, Bangalore 20 March 2012	Heat flow and current fluctuations in harmonic systems with Langevin dynamics
	School on Statistical Physics Raman Research Institute Bangalore 26 March – 7 April 2012	Introduction to stochastic processes and dynamical systems (*three lectures*)
Anagha Datar	Tata Institute of Fundamental Research, Mumbai November 2011	
	Indian Institute of Science Education and Research, Pune 20 – 26 February 2012	
Andal Narayanan	Indian Institute of Science Education and Research, Pune 28 March – 15 April 2011	
	University of Calgary, Canada August 2011 – July 2012	
Anirban Polley	Conference on Dynamics of Phase Transformations Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore 28 – 30 November 2011	
	Conference on An Interdisciplinary Approach to Soft Matter and Biological Physics Indian Association for the Cultivation of Science, Kolkata 2 – 3 December 2011	

	Annual Meet National Centre for Biological Sciences Bangalore 2 – 3 January 2012	
	JAKS School: Unifying Concepts in Materials Jawaharlal Nehru Centre for Advanced Scientific Research and National Centre for Biological Sciences, Bangalore 30 January – 8 February 2012	
	School on Statistical Physics Raman Research Institute, Bangalore 26 March – 7 April 2012	
Anjan Roy	ICTS School on Random Matrix Theory and Applications Indian Institute of Science, Bangalore 17 January – 1 February 2012	
	3rd School on Statistical Physics Raman Research Institute, Bangalore 26 March – 7 April 2012	
Arnab Pal	ICTS International School on Topology in Quantum Matter Indian Institute of Science, Bangalore 29 June – 13 July 2011	
	ICTS International School and Conference on Random Matrix Theory Indian Institute of Science, Bangalore 17 January – 1 February 2012	
	3rd School on Statistical Physics Raman Research Institute, Bangalore 26 March – 7 April 2012	
Arun Roy	National Conference on Materials for Advanced Technology, Gwalior 27 – 29 February 2012	Aciral fluid lamellar phases with triclinic symmetry (*invited*)
Avinash BS	Kyushu Institute of Technology, Japan 12 November 2011	
Avinash Deshpande	Radio Astronomy School 2011 National Centre for Radio Astronomy, Pune 3 – 6 July 2011	Antennas and receivers (2 lectures)

	The URSI GA and Scientific Symposium of International Union and Radio Science, Turkey 13 – 20 August 2011	RRI-GBT multi-band receiver and pulsar emission cone tomography
	IAU Symposium 2012 Cosmic Masers – from OH to H0Stellenbosh, South Africa 29 January – 3 February 2012	1. OH maser sources in W49N: probing differential anisotropic scattering with Zeeman pairs 2. Binary systems: implications for outflows and periodicities relevant to masers
	SKA-SA, South Africa 4 – 11 February 2012	1. Radio frequency interference: to avoid or attack 2. The 4 Cs: coherence, correlation, convolution, calibration
Biman B Nath	Max Planck Institut for Astrophysics Garching 19 March – 15 June 2011	Galactic outflows with thermal and radiation pressure
	Instut Astrophysique de Paris, France 21 – 23 April 2011	Galactic outflows with radiation pressure
	University of Leiden, The Netherlands 2 – 4 May 2011	Galactic outflows
	Scuola Normale Superiore of Pisa, France 23 – 24 May 2011	
	Nehru Planetarium, New Delhi 26 July 2011	Stars in the hood; the story of our neighbourhood stars
	Astrophysics Seminar Indian Institute of Science 8 August 2011	Galactic outflows with radiation pressure
	Galaxy Forum 2012 Jawaharlal Nehru Planetarium 9 August 2011	Our universe (*invited*)
	IIA Theoretical Astrophysics Group Mini Workshop on Cosmology & Galaxies Indian Institute of Astrophysics 28 November 2011	Galactic winds and the intergalactic medium (*invited*)
	Conference on Dust in Astrophysics Assam University 31 January – 2 February 2012	Dust driven outflows from galaxies (*invited*)

	National Space Science Symposium Sri Venkateswara University, Tirupati 14 – 17 February 2012	Cosmology – recent advances and challenges ahead
Biswajit Paul	Be X-ray Binaries Workshop University of Valencia Spain 11 – 14 July 2011	1. Quasi periodic oscillations in high magnetic field accretion powered pulsars (two lectures) 2. Intensity and energy dependent profiles of transient HMXB pulsars 3. Orbital evolution and apsidal motion of HMXBs
	Conference on Exploring the COSMOS North Bengal University, Darjeeling 15 – 16 December 2011	An overview of neutron stars
	Astrosat Workshop Indian Institute of Space Science and Technology, Trivandrum 9 – 12 January 2012	1. An overview of Astrosat 2. Fundamentals of X-ray Timing Analysis
	Advanced Workshop on X-ray Timing Inter University Centre for Astronomy & Astrophysics, Pune 23 – 28 January 2012	1. Astrosat LAXPC 2. X-ray timing with LAXPC
	Winter School on High Energy Astrophysics: Accretion onto compact objects Harishchandra Research Institute Allahabad 6 – 18 February 2012	X-ray Binaries (series of lectures)
	Conference on Advances in Astroparticle Physics and Cosmology 2012, Darjeeling 7 – 12 March 2012	High Energy Astrophysics with Astrosat and ongoing projects for future missions
Chaitra Shreepad Hegde	School on Topology and Quantum Matter Indian Institute of Science, Bangalore 29 June – 13 July 2011	
	School on Random Matrix Theory Indian Institute of Science, Bangalore 17 January – 1 February 2012	
	School on Statistical Physics Raman Research Institute, Bangalore 26 March – 7 April 2012	

Chandrakant Mishra	7th International Conference on Gravitation and Cosmology, Goa 14 – 19 December 2011	Nonspinning inspiralling compact binaries in quasi-circular orbits
Chandreyee Maitra	Advanced Workshop on X-ray timing Inter University Centre for Astronomy & Astrophysics, Pune 23 – 28 January 2012	Pulse phase resolved spectroscopy of HMXB accretion powered pulsars
	Winter School on High Energy Astrophysics Symposium Harishchandra Research Institute, Allahabad 18 February 2012	Pulse phase resolved spectroscopy of HMXB accretion powered pulsars
Debasish Saha	International Workshop on Soft Matter Chemistry, Raman Research Institute, Bangalore 9 – 11 November 2011	
	International Conference on Dynamics of Phase Transition Jawaharlal Nehru Centre for Advanced Research, Bangalore 28 – 30 November 2011	
	SERC School and National Symposium on Rheology and Complex Fluids Indian Institute of Technology, Guwahati 3 – 7 January 2012	Caging dynamics in colloidal glasses of laponite
	IUTAM Symposium on Mobile Particulate Systems Hotel Lalith Ashok, Bangalore 23 – 27 January 2012	Caging dynamics in colloidal glasses of laponite
Deepak Pandey	University of Pisa, Italy 17 – 21 June 2011	Quantum walk of light in frequency space and its controlled dephasing
	Institut d'Optique, France 22 June – 21 July 2011	
	University of Basel, Switzerland 15 – 18 July 2011	Implementation of quantum algorithms and quantum logic gates using ultracold atom and light
Dhason A	17th National Seminar of ISSG 'Glass moulds/devices for chemical analysis in NR industry' Rubber Research Institute of India, Kerala 2 – 3 May 2011	1. A versatile multifunctional glass adapter for use in chemistry laboratories 2. Structure of glass and how does it break

Dwarakanath KS	The Path to SKA-low Workshop International Centre for Radio Astronomy Research, Western Australia 6 – 9 September 2011	Cluster halos and relics at low frequencies – current status and future prospects (*invited*)
	National Center for Radio Astrophysics Pune 10 November 2011	Current activities and future plans in low-frequency astronomy
	Inter University Center for Astronomy and Astrophysics, Pune 11 November 2011	
Geetha S	Panel Discussion on Challenges ahead of librarians in serving its readers Tripuravasini Auditorium, Bangalore 7 September 2011	
	Conference Infovision 2011 – Data for Differentiation Infosys, Bangalore 24 September 2011	
Girish BS	The Path to SKA-low Workshop International Centre for Radio Astronomy Research, Western Australia 6 – 9 September 2011	A 144-element receiver system for the RRI AA demonstrator
	The SKA India Meet 2011 National Centre for Radio Astronomy, Pune 10 – 11 November 2011	Analog receiver systems for ORT upgrade – the road traversed
	Radio Astronomy Centre, Ooty 12 January 2012	
Hema Ramachandran	Tata Institute of Fundamental Research Mumbai 7 September 2011	Quantum walks
	Mumbai University, Mumbai 8 September 2011	Atoms and light performing quantum walks
	University of Hyderabad, Hyderabad 31 January 2012	The classical analogue of the non-local Aharanov-Bohm effect
	Faculty Development Program on Cognitive Science and Brain Computer Interface M.S. Ramaiah Institute of Technology Bangalore 26 March 2012	Brain computer interfaces

	SERC School on Laser Physics and Technology Raja Ramanna Centre for Advanced Technology, Indore 28 March 2012	Light in random media
Iyer BR	Bangalore University, Bangalore 19 April 2011	Gravitational waves: A century of waiting
	Institute for Plasma Research, Ahmedabad 2 May 2011	The search for gravitational waves: a century of waiting
	Jawaharlal Nehru Planetarium, Bangalore 31 May 2011	Einstein's Theory of Gravitation and Gravitational Waves, I, II
	Annual GWIC Meeting Cardiff University, United Kingdom 10 July 2011	The case for IndIGO membership of GWIC (*invited*)
	Cardiff University, United Kingdom 1 – 15 July 2011	
	Amaldi 9 Cardiff University, United Kingdom 13 – 17 July 2011	Parametrized tests of post-Newtonian theory using Advanced LIGO and Einstein Telescope
	Indian Institute of Science, Bangalore 18 August 2011	
	Hind High Vacuum, Bangalore 18 August 2011	
	IndIGO Meeting on LIGO-India Homi Babha Centre for Science Education Mumbai 19 August 2011	IndIGO and LIGO-India
	Institute for Plasma Research, Ahmedabad 17 August 2011 19 October 2011	
	Tata Institute of Fundamental Research Mumbai 19 August 2011 20 October 2011	
	Raja Ramanna Centre for Advanced Technology, Indore 23 August 2011 1 – 3 March 2012	

Indian Institute of Technology, Gandhinagar 12 September 2011	
EGO-IndIGO meeting on GW Inter University Centre for Astronomy & Astrophysics, Pune 1 – 2 November 2011	IndIGO and LIGO-India, Introductory remarks (*invited*)
Astronomy Mega-Projects under XIIth Plan Meeting Department of Science and Technology Delhi 21 November 2011	
Mid-Term Review Meeting Indo French Centre for Promotion of Advanced Research (CEFIPRA), Udaipur 22 November 2011	Gravitational waves from binary black holes – mid term report
9th International Conference on Gravitation and Cosmology, Goa 14 – 19 December 2011	Nonspinning inspiralling compact binaries in quasi circular orbits: 2.5 PN linear momentum loss and associated recoil
ICTS Workshop on Gravitational Waves Inter University Centre for Astronomy & Astrophysics, Pune 20 – 22 December 2011	LIGO-India: current status (*invited*)
Karnataka State Disaster Management Centre, Bangalore 30 December 2011	
IndIGO meeting on LIGO-India Institute for Plasma Research, Ahmedabad 3 February 2012	LIGO-India: current status
Indian Institute of Science Education and Research, Pune 14 February 2012	Gravitational waves: when theory met experiment
Inter University Centre for Astronomy & Astrophysics, Pune 1 – 2 April 2011 22 – 23 September 2011 6 – 8 October 2011 21 – 22 October 2011 19 – 22 December 2011 13 February 2012 4 – 6 March 2012 17 March 2012 18 – 24 March 2012	

Jacob Rajan	National Workshop on Cloud Computing Centre for Development of Advanced Computing, Knowledge Park 21 May 2011	
Joseph Samuel	Chennai Mathematical Institute, Chennai 16 – 17 August 2011	The nonlocal Pancharatnam phase
	Indian Institute of Science Education and Research, Trivandrum 3 – 8 January 2012	Atom interferometry and the gravitational red shift
	Indian Institute of Science, Bangalore 12 January 2012	The nonlocal Pancharatnam phase in two photon interferometry
	Chennai Mathematical Institute, Chennai 28 February 2012	Atom interferometry and the gravitational red shift
Jyothi S	3rd International Conference on Current Developments in Atomic, Molecular, Optical and Nano Physics 2011 University of Delhi 14 – 16 December 2011	Cavity mode emission from cold trapped atoms
Kanhaiya Lal Pandey	ASI Symposium (ICCGF) Indian Institute of Science Education and Research, Mohali 5 November 2011	Constraints on primordial magnetic fields using cosmic shear statistics
Karthik HS	International Workshop on Quantum Information Harishchandra Research Institute Allahabad 20 – 26 February 2012	Classical uncertainties
Lakshminarayanan V	Oracle Science Foundation Talk BGS National Public School, Bangalore 10 June 2011	Seeing atoms and molecules (*invited*)
	12th IDE-NICE Conference Dezaifu, Japan 20 October 2011	Electrical conductivity studies on discotic liquid crystals and composites
	Graduate School of Biological and Life Sciences Kyushu Institute of Technology, Japan 24 October 2011	Electrochemistry of nanomaterials for biosensors and catalysis (*invited*)

	International Workshop on Soft Matter Chemistry Raman Research Institute 10 November 2011	Electrochemical studies in self-organized soft matter systems (*invited*)
	1. Physics Convention 2. Convergence in Chemistry Sri Sathya Institute of Higher Learning, Prasanthi Nilayam, Bangalore 1. 6 August 2011 2. 28 November 2011	1. Electrochemistry of nanomaterials for biosensors (*invited*) 2. Disc like liquid crystals for molecular electronics and photonic applications (*invited*)
	Central Electrochemical Research Institute Karaikudi 7 – 8 February 2012	Electrochemistry of nanomaterials for biosensors and catalysis
	First International Symposium on Physics and Technology of Sensors Centre for Materials for Electronics Technology, Pune 7 March 2012	Mechanism of electrochemical sensors (*invited*)
	UGC Faculty Improvement Programme Bangalore University, Bangalore 14 March 2012	1. Electrochemical methods in biosensing and catalysis 2. Scanning probe microscopy and its applications in chemistry
Laxmi Kishore Sagar	International Workshop on Soft Matter Chemistry Raman Research Institute 9 – 11 November 2011	
Lakshmi Saripalli	Netherlands Institute for Radio Astronomy The Netherlands 1 September–30 November 2011	On growth and form: radio galaxy morphologies and the ATLBS radio continuum survey
	Radboud Universiteit, The Netherlands 8 November 2011	Towards probing AGN lifecycles: Radio galaxy morphologies and the ATLBS radio continuum survey
	LOFAR Magnetism Key Science Project Workshop Isituto di Radioastronomia, Bologna 24 – 25 November 2011	Aspects of radio galaxies and lifecycles (*invited*)
	University of Western Australia, Australia 30 January – 29 February 2012	

Madhavan Varadarajan	Loops 11CSIC, Spain 23 – 28 May 2011	The diffeomorphism constraint in loop quantum gravity
	St. Stephen's College, New Delhi 21 – 28 October 2011	
	7th International Conference on Gravitation and Cosmology, Goa 14 – 19 December 2011	Towards a consistent quantum dynamics for canonical loop quantum gravity
Mahavir Sharma	Indian Conference on Cosmology and Galaxy Formation 2011 Indian Institute of Science Education and Research, Mohali 5 November 2011	Galactic winds
Mahesh Kumar Varia	International Workshop on Soft Matter Chemistry Raman Research Institute 9 – 11 November 2011	1. T-shaped unsymmetrical azoester based substituted biphenyl 2. Hexasubstituted truxene with branched alkyl peripheral spacers
	18th National Conference on Liquid Crystals North-eastern Regional Institute of Science and Technology, Itanagar 15 – 17 November 2011	T-shaped unsymmetrical azoester based mesogenic dimers
Manjunath M	National Seminar on Content Management and Libraries: New Vistas for Harnessing Information Kerala Library Association Thiruvananthapuram 14 – 16 July 2011	
	Workshop on Statistical Analysis of Research Data Institute for Management Development Mysore 3 – 4 February 2012	
	Workshop on Statistical Methods for Communication Science Karnataka University, Dharwad 27 February – 1 March 2012	
Mayuri S	Winter School on Astroparticle Physics Bose Institute, Kolkata 17 – 29 December 2011	
	Advanced Workshop on X-ray Timing Inter University Centre for Astronomy & Astrophysics, Pune 23 – 28 January 2012	

	Winter School on High Energy Astrophysics Harishchandra Research Institute Allahabad 6 – 18 February 2012	
Meena MS	Apex Technical Seminar Cirrus Logic/Apex Microtechnology, Bangalore 19 September 2011	
	Conference NIDays 2011 Nimhans Convention Center, Bangalore 14 October 2011	
	Technical Seminar ADWTS 2012 Agilent Technologies, Bangalore 17 April 2012	
Meera BM	National Seminar on Content Management and Libraries: new vistas for harnessing information Kerala Library Association Thiruvananthapuram 14 – 16 July 2011	Digital Information services and products: a case of Raman Research Institute
	SoFerence 2011 Tata Consultancy Services, ITPL, Bangalore 15 October 2011	Imprints collection: a cyberscholarship of RRI
	NKRC Nodal Officers Meeting National Institute of Oceanography, Goa 18 – 20 October 2011	
	Workshop on Open Access to Academic Research Indian Institute of Science, Bangalore 2 November 2011	
	National Workshop on using different metrics for assessing research productivity Indian Statistical Institute, New Delhi 16 – 17 February 2012	H-Index as research performance indicator: A study at Raman Research Institute
Nagaraj MN	Workshop on Training on Content Management using Open Source Tool-Drupal National Aerospace Laboratories, Bangalore 19 – 21 April 2011	

	National Conference on Information Literacy Competencies for Higher Learning and Research Tumkur University, Tumkur 21 – 22 October 2011	Implementation of Library 2.0 technology to information literacy
	Workshop on SPSS for Data Analysis Mangalore University, Mangalore 19 November 2011	
Nazma Islam Syeda	Advanced Workshop on X-ray Timing Inter University Centre for Astronomy & Astrophysics, Pune 23 – 28 January 2012	Effect of variability of X ray binaries on X-ray luminosity functions for our galaxy
	Winter School on High Energy Astrophysics Symposium Harish Chandra Research Institute Allahabad 18 February 2012	Effect of variability of X ray binaries on X ray luminosity functions for our galaxy
Nithyanandan Thyagarajan	Bi-annual MWA Project Meeting University of Melbourne, Australia 5 – 8 December 2011	A study of foreground contamination in the EoR window
	Workshop on MWA Data Analysis Australia National University, Australia 7 – 9 February 2012	
	Curtin University, Australia 14 February 2012	1. Study of foreground contamination of the EoR 2. A search for radio transients and variables in the FIRST survey
Prabu T	MWA Meeting Massachusetts Institute of Technology, USA 7 June 2011	Digital receiver enhancements – a status update
	CASPER Workshop 2011 National Centre for Radio Astrophysics Pune 13 – 14 October 2011	1. MWA digital receiver development at RRI 2. FPGA based projects at RRI – a review
	Bi-annual MWA Project Meeting University of Melbourne, Australia 7 – 8 December 2011	1. Digital receiver – an update 2. Thoughts on commissioning the MWA digital receiver
Pragya Srivastava	Annual Meet National Centre for Biological Sciences Bangalore 2 – 3 January 2012	Patterns of actin filaments on cylindrical and spherical geometries: asters, helices, rings

	JAKS School: Unifying Concepts in Materials Jawaharlal Nehru Centre for Advanced Scientific Research and National Centre for Biological Sciences, Bangalore 30 January – 8 February 2012	Patterns of active polar filaments in curved geometries
Pramod Pullarkat	NUS-NCBS Collaboration Exploration Meeting National Centre for Biological Sciences Bangalore 13 April 2011	A novel optical fiber based force apparatus
	Conference on Mathematics and Physics of Soft and Biological Matter International Centre for Theoretical Physics Italy 9 – 13 May 2011	Active mechanics of axons
	University of Freiburg, Germany 14 – 20 May 2011	
	Technical University, Munich 18 May 2011	Active mechanics of axons
	International Conference on Mathematical and Theoretical Biology Indian Institute of Science Education and Research, Pune 23 – 27 January 2012	Mechanics of living matter
Prasad VV	School on Random Matrix Theory and Applications Indian Institute of Science, Bangalore 17 January – 1 February 2012	
	JAKS School: Unifying Concepts in Materials Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore 30 January - 5 February 2012	
	School on Statistical Physics Raman Research Institute 26 March – 7 April 2012	
Pratibha R	International Workshop on Soft Matter Chemistry Raman Research Institute 9 – 11 November 2011	Glassy nature of the dark conglomerate liquid crystalline phase (*invited*)

	National Conference on Condensed Matter Physics Birla Institute of Technology and Science Pilani 24 – 25 February 2012	Layer structure stabilized gold nanosphere – smectic liquid crystal colloids (*invited*)
Priya Rose T	HCU-TIFR Discussion Meeting Central University of Hyderabad, Hyderabad 1 – 3 August 2011	
	DAE-BRNS National Laser Symposium-20 Anna University, Chennai 9 – 12 January 2012	Time-resolved spectroscopy of femtosecond laser-induced carbon plasma in the rough, medium and high vacuum regimes
Raghunathan A	The URSI GA and Scientific Symposium of International Union and Radio Science Turkey 13 – 20 August 2011	1. Zero spacing interferometer to detect cosmological reionization signatures 2. Observatory reports
Raghunathan VA	8th Liquid Matter Conference University of Vienna, Austria 6 – 11 September 2011	Polymorphism of two-dimensional crystals of oppositely charged cylindrical macroions
	Conference on Current Topics in Condensed Matter Indian Institute of Science Education and Research, Kolkata 7 – 9 October 2011	A novel phase of amphiphile bilayers (*invited*)
	Conference on Frontiers in Physics University of Hyderabad, Hyderabad 28 – 29 October 2011	Electrostatic self-assembly of oppositely charged macroions (*invited*)
	Sixth National Symposium on Rheology of Complex Fluids Indian Institute of Technology, Guwahati 6 – 7 January 2012	A defect-mediated lamellar to isotropic transition of amphiphile bilayers (*invited*)
	Institute of Biophysics and Nanosystems Research, Austria 1 – 5 September 2011	A disordered phase of surfactant bilayers
Rajib Basak	SERC School and National Symposium on Rheology of Complex Fluids Indian Institute of Technology, Guwahati 3 – 7 January 2012	Effect of anionic surfactant on the jamming behavior of triblock copolymer system
Ranjini Bandyopadhyay	Conference on Current Trends in Condensed Matter Physics Indian Institute of Science and Education Research, Kolkata 9 October 2011	Mustard seeds shaken hard: a segregation phenomenon in a vibrated quasi two-dimensional granular column (*invited*)

	University of Tokyo, Japan 18 October 2011	Experiments on aging soft colloidal glasses and rising Brazil nuts
	Toyohashi Institute of Technology, Japan 20 October 2011	Experiments on aging soft colloidal glasses and rising Brazil nuts (*invited*)
	International Workshop on Soft Matter Chemistry Raman Research Institute 11 November 2011	Rise of an intruder in a quasi 2D granular column is driven by granular convection
	Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore 30 November 2011	Rising Brazil nuts in a quasi two-dimensional granular column: dynamics of phase transformations (*invited*)
	Bose Institute, Kolkata 3 January 2012	Convection-driven rise of an intruder in a quasi two dimensional granular bed (*invited*)
	SERC School-cum-Symposium on the Rheology of Complex Fluids Indian Institute of Technology, Guwahati 6 January 2012	Rizing Brazil nuts in a quasi two-dimensional granular column: dynamics of phase transformations (*invited*)
	Indian Institute of Science, Bangalore 1 February 2012	Scaling behavior in convection-driven Brazil nut effect: contemporary issues in condensed matter science (*invited*)
	Maharani Lakshmi Ammanni College Bangalore 6 March 2012	How so soft materials move when pushed really hard (*invited*)
Ravi K	Conference on New Trends in Quantum Matter with Cold Atoms and Molecules Instituto de Fisica de Sao Carlos, Brazil 4 – 14 April 2011	An experimental setup to study ion-atom processes
	Institut d' Optique, France 6 January 2012	
	Conference on Physics with Trapped Charged Particles Ecole de Physique des Houches, France 9 – 20 January 2012	Collisional cooling of ions by cold atoms in a combined trap
	Universitat Basel, Switzerland 21 January 2012	
	Institut fur Physik, Germany 21 January – 4 February 2012	

	Max-Planck-Institut fur Kernphysik, Germany 2 February 2012	Cooling of rubidium ions by cold Rubidium atoms in a combined trap
	Universistat Ulm, Germany 3 February 2012	Cooling of rubidium ions by cold Rubidium atoms in a combined trap
Ravi Subrahmanyan	MWA Meeting Massachusetts Institute of Technology, USA 5 – 8 June 2011	Extragalactic low surface brightness radio sky
	Penticton Workshop on Novel Telescopes for 21cm Cosmology Dominion Radio Astrophysical Observatory Canada 13 – 16 June 2011	
	The URSI GA and Scientific Symposium of International Union and Radio Science Turkey 13 – 20 August 2011	1. Long wavelength radio science (*invited*) 2. The Murchison Widefield Array
	MWA Project Meeting University of Melbourne 5 – 8 December 2011	
	SKA ANZ Meeting 2012 New Zealand 13 – 16 February 2012	The Murchison Widefield Array (*invited*)
	University of Western Australia, Australia February 2012	
	Curtin University, Australia February 2012	
Ruckmongathan TN	SID Symposium 2011 Society for Information Display, USA 15 – 20 May 2011	Gray scales by cross pairing of select and data voltages in liquid crystal displays
	EURODISPLAY, International Display Research Conference Ecole Polytechnique, France 21 September 2011	Bit slice addressing and multi-bit slice addressing of AMLCD (*invited*)
	XIVth International Workshop on Physics of Semiconductor Devices Indian Institute of Technology, Kanpur 19 – 22 December 2011	Bit slice addressing and multi-bit slice addressing of AMLCD (*invited*)

	International Conference on Luminescence and its Applications Rajiv Gandhi University of Knowledge Technologies, Hyderabad 7 – 10 February 2012	Low power, high performance liquid crystal displays with simple data drivers (*invited*)
Sadiqali Rangwala	Conference on New Trends in Quantum Matter with Cold Atoms and Molecules Instituto de Fisica de Sao Carlos, Brazil 4 – 14 April 2011	An experimental setup to study ion-atom processes
	EGO-IndIGO Meeting on GW Inter University Centre for Astronomy & Astrophysics, Pune 1 – 2 November 2011	Experiments with cold atoms in Fabry Perot Cavity in Ultra High Vacuum
	3rd International Conference on Current Developments in Atomic, Molecular, Optical and Nano Physics with Applications (CDAMOP-2011) University of Delhi, New Delhi 14 – 16 December 2011	1. Collisional cooling of ions with cold atoms of equal mass 2. Cavity mode emission from cold trapped atoms
	Topical Conference of the ISAMP-TC2012 - Laser Interaction with Atoms, Molecules and Clusters University of Hyderabad, Hyderabad 9 – 12 January 2012	From cold atoms and cold ions to cold molecules and cold molecular ions
	Conference on Physics with Trapped Charged Particles Ecole de Physique des Houches, France 9 – 20 January 2012	Collisional cooling of ions by cold atoms in a combined trap
	The India-UK Scientific Seminar Scheme Bhuvaneshwar 7 – 9 March 2012	Cold atoms, cold ions and cold molecules
Samim Ali	International Conference on Dynamics of Phase Transition Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore 28 November 2011	
	SERC School and National Symposium on Rheology of Complex Fluids Indian Institute of Technology, Guwahati 3 January 2012	Effect of electrolyte on the settling behavior of charged colloidal particles in aqueous suspensions

	JAKS School: Unifying Concepts in Materials Jawaharlal Nehru Centre for Advanced Scientific Research, Bangalore 6 February 2012	Effect of electrolyte on the settling behavior of charged colloidal particles in aqueous suspensions
	RRI School on Statistical Physics, Bangalore 26 March 2012	
Sandeep Kumar	CRSI Zonal Meet National Chemical Laboratory, Pune 13 – 14 May 2011	Discotic decorated nanoparticles: advanced materials for organic electronics (*invited*)
	University of Hyderabad, Hyderabad 4 July 2011	Discotic liquid crystals as advanced materials for organic electronics (*invited*)
	National Symposium on Chemistry and Humanity 2011 Manipal Institute of Technology, Manipal 11 – 12 July 2011	Liquid crystals: paradoxical states of matter (*invited*)
	BSG National Public School, Bangalore 22 July 2011	Can crystals be liquid: the fascinating world of liquid crystals (*invited*)
	Institute of Advance Study in Science & Technology, Guwahati 28 July 2011	
	Bannari Amman Institute of Technology Satyamangalum 24 August 2011	Liquid crystals: from curiosity to commodity (*invited*)
	3rd National Conference on Recent Trends in Polymer Science and Technology 2011 PSG College of Technology, Coimbatore 26 – 27 August 2011	Dispersion of nanoparticles in monomeric and polymeric columnar liquid crystals (*invited*)
	Amrita University, Coimbatore 27 August 2011	The fascinating world of liquid crystals (*invited*)
	19th Conference on Liquid Crystals Chemistry, Physics and Applications Miedzyzdroje, Poland 19 – 23 September 2011	Discotic liquid crystals nanoscience (*invited*)
	Department of Information Technology Delhi 18 October 2011	

	18th National Conference on Liquid Crystals North-eastern Regional Institute of Science and Technology, Itanagar 15 – 17 November 2011	Nanoparticles in columnar mesophases (*invited*)
	International Conference on Synthetic & Structural Chemistry Mangalore University, Mangalore 8 – 12 December 2011	Nanoparticles in columnar matrix
	National Workshop on Soft Materials JMJ College for Women, Tenali 24 January 2012	The art and science of liquid crystals (*invited*)
	International Conference on Supramolecules and Nanomaterials – Research and Applications Gujarat University, Ahmedabad 6 – 8 February 2012	Incorporation of nanoparticles in the supramolecular order of discotic liquid crystals (*invited*)
	Symposium on Liquid Crystalline Organic Semiconductors Tokyo Institute of Technology, Japan 21 – 22 February 2012	Discotic liquid crystal nanocomposites: a new class of organic semiconductors (*invited*)
	University of Allahabad, Allahabad 9 August 2011 12 March 2012	
	Material Research Society Workshop Centre for Material Science, Allahabad 12 March 2012	Discotics: a new class of soft materials for organic electronics (*invited*)
Sanjib Sabhapandit	5th Indo-Israeli Meeting on Condensed Matter Physics, Cochin 15 – 18 October 2011	Record statistics of continuous time random walk (*invited*)
Santosh Prasad Gupta	International Workshop on Soft Matter Chemistry Raman Research Institute 9 – 11 November 2011	
	18th National Conference on Liquid Crystals North-eastern Regional Institute of Science and Technology, Itanagar 15 – 17 November 2011	Effect of strongly bound species on the phase behavior of a cationic surfactant
Somashekar R	Radio Astronomy Centre, Ooty 10 – 13 January 2012	

Sridhar S	American University of Beirut, Lebanon 6 – 30 April 2011	MHD turbulence (3 lectures)
	American University of Beirut, Lebanon 4 July – 5 August 2011	
	Indian Institute of Science Education and Research, Mohali 30 January – 3 February 2012	1. Interstellar, interplanetary and MHD turbulence 2. Fluid turbulence
Srinivasa HT	International Workshop on Soft Matter Chemistry 2011 Raman Research Institute, Bangalore 9 – 11 November 2011	Acid and ester functionalized triphenylene discotics: synthesis and mesomorphic characterization
	Symposium on New Developments in NMR and International Conference of National Magnetic Resonance Society of India Indian Institute of Science, Bangalore 5 – 8 February 2012	
Srivani KS	The Path to SKA-low Workshop International Centre for Radio Astronomy Research, Western Australia 6 – 9 September 2011	
Suman Gaurab Das	School on Random Matrix Theory and Applications Indian Institute of Science, Bangalore 17 January – 1 February 2012	
	School on Statistical Physics Raman Research Institute, Bangalore 26 March – 7 April 2012	
Sumati Surya	University of California, USA 17 May 2011	Constructing a dynamics for causal set quantum gravity
	McGill University, Canada 8 September 2011	Results in 2D causal set quantum gravity
	7th International Conference on Gravitation and Cosmology, Goa 14 – 19 December 2011	2D causal set quantum gravity on the computer
	Indian Institute of Astrophysics, Bangalore 24 February 2012	Phenomenology from quantum gravity: a brief introduction to causal set theory

Supurna Sinha	St. Joseph's College Post Graduate Centre Bangalore 29 July 2011	Order out of disorder: an introduction to soft matter physics
	Poorna Learning Center, Bangalore November 2011	Light
	Indian Institute of Science Education and Research, Trivandrum 6 January 2012	Nonlocal Pancharatnam phase in two photon interferometry
	Workshop on Weaves of Waves: Physics of Music Raman Research Institute, Bangalore 18 January 2012	
	3rd RRI School of Statistical Physics Raman Research Institute, Bangalore 26 March – 7 April 2012	
Swamynathan K	Kyushu Institute of Technology, Japan 14 November 2011 – 31 January 2012	
Tridib Ray	EGO-Indigo Meeting Inter University Centre for Astronomy & Astrophysics, Pune 1 – 2 November 2011	
	3rd International Conference on Current Developments in Atomic, Molecular, Optical and Nano Physics 2011 University of Delhi, New Delhi 14 – 16 December 2011	Cavity mode emission from cold trapped atoms
Udaya Shankar N	Conference on Understanding Galactic and Extragalactic Foregrounds: A road to success for cosmological experiments Croatia 26 May 2011	Effect of the three dimensional point spread function on the statistical detection of EoR
	MWA Project Meeting MIT Kavli Institute for Astrophysics and Space Research USA 5 – 8 June 2011	Imaging the EoR
	Workshop on Novel Telescopes for 21 Cm Cosmology Dominion Radio Astrophysical Observatory Canada 15 June 2011	Limitations from foreground contamination and imaging algorithms

	MWA Project Meeting University of Melbourne, Australia 5 – 8 December 2011	Cosmic distance ladder
	Aarohana Science Festival BMS College for Women, Bangalore 24 February 2012	
Venkata Jagadeesh Rachuri	Conference on Current Trends in Nanoscience and Technology National Institute of Technology, Warangal 23 – 24 December 2011	
	Conference on Interfaces between Chemical Sciences and Technologies National Institute of Technology, Warangal 29 – 30 December 2011	
Vijayaraghavan D	International Workshop on Soft Matter Chemistry Raman Research Institute 11 November 2011	Magnetic susceptibility studies on micelles, vesicles and bicelles (*invited*)
Vrinda J Benegal	Workshop on Web of Science 5.2 Raman Research Institute 12 May 2011	
	Panel Discussion on Challenges Ahead of Librarians in Serving its Readers Tripuravasini Auditorium, Bangalore 7 September 2011	
	SoFerence 2011 Tata Consultancy Services, ITPL, Bangalore 15 October 2011	
	Workshop on Open Access to Academic Research Indian Institute of Science, Bangalore 2 November 2011	
	57th All India Library Conference St. Agnes Centre for Post Graduate Studies and Research, Mangalore 23 – 25 February 2012	
Yashodhan Hatwalne	International Workshop on Soft Matter Chemistry Raman Research Institute 9 – 11 November 2011	Structure of twist grain boundary phases (*invited*)

APPENDIX 3

Colloquia

Name	Title	Date
Amit Apte TIFR Centre for Applicable Mathematics, Bangalore	Data assimilation – interplay between nonlinearity and statistics	19.4.2011
Sandeep Menon Perinchery Macquarie University Australia	Diagnostic potential of autofluorescence: an explorative study with human urine, stem cells and bacteria	2.5.2011
Sandipan Sengupta Institute of Mathematical Sciences, Chennai	Quantum realizations of Hilbert-Palatini second-class constraints	2.5.2011
Priya Rose T Universita di Napoli "Federico II" Italy	Design and characterization of photonic quasi-crystals for the microwave to optical regime	11.5.2011
Satya Sudhakar Yedlapalli Indian Institute of Science Bangalore	The line spectral frequency model of a finite length sequence and its applications	20.5.2011
Sanjay Gupta Bose Institute Kolkata	Dimensional and temperature dependence of metal-insulator transition in correlated and disordered systems	24.05.2011

Harshal Bhadkamkar Tata Institute of Fundamental Research, Mumbai	Collective properties of X-ray binary populations in nearby galaxies	24.05.2011
Dana Z Anderson University of Colorado Boulder, USA	Atomtronics, atom chips and the microwave oscillator	26.05.2011
Ravi Chandra V Israel Institute of Technology Israel	A memory saving algorithm for computing eigenvalue approximations of quantum systems	27.05.2011
Jayan Thomas University of Arizona USA	Advanced polymers for 3D telepresence and energy conversion	30.05.2011
Gopal NO National Dong Hwa University, Taiwan	Visible light active nanoparticles for environmental purification	31.05.2011
Urbasi Sinha University of Waterloo Canada	Applications of quantum optics to quantum mechanics and quantum information processing	31.05.2011
Abhik Ghosh Indian Institute of Technology Kharagpur	Characterizing the foregrounds for red shifted 21-cm HI signal: GMRT 150 MHz & 610 MHz observations	13.06.2011
Archan Dey Eindhoven University of Technology The Netherlands	Supramolecular nano materials: Inspiration from crystal engineering and biomineralizaion	15.06.2011
Iyer BR Raman Research Institute Bangalore	An introduction to general relativity and gravitational waves I, II	27.06.2011
Chandrashekar CM Institute of Mathematical Sciences, Chennai	Quantum walk with spatial, temporal and fluctuating disordered operations	28.06.2011
Priyam Das Indian Institute of Science Education and Research Kolkata	Dynamics of Bose-Einstein condensates: A mean-field approach	01.07.2011
Arvind Ayyer UC Davis, USA	An exactly solvable open reaction-diffusion process	01.07.2011
Sujoy Kumar Modak S.N. Bose National Centre for Basic Sciences, Kolkata	Quantum tunneling and thermodynamic approach to black hole entropy	11.07.2011

Srinivas Sridhar Northeastern University USA	Controlling light with nanoscale negative metamaterials	12.07.2011
Rema Krishnaswamy Jawaharlal Nehru Centre for Advanced Scientific Research Bangalore	Shear thickening in fractal aggregates of carbon nanotubes	12.07.2011
William Clark Clark-MXR Inc. USA	Ultra pulse lasers and system development at Clark-MXR Inc.	19.07.2011
Sandeep Krishna National Centre for Biological Sciences, Bangalore	Counting genomes: the lysis-lysogeny decision in temperate bacteriophage	26.07.2011
Seshadri TR University of Delhi, Delhi	CMB as a probe for cosmic magnetic fields	29.07.2011
Arundati Dasgupta University of Lethbridge Canada	Measuring quantum gravity	04.08.2011
Srivathsan Vasudevan National Technical University Singapore	Monitoring of individual biological cells using photothermal response and photothermal imaging techniques	11.08.2011
Indranil Chattopadhyay Aryabhatta Research Institute of Observational Sciences, Nainital	Effect of composition and equation of state on relativistic fluids	12.08.2011
Onuttom Narayan University of California, USA	Curvature of finite graphs and its consequences	17.08.2011
Deepshika Jaiswal Nagar Goethe Universitat, Germany	Magnetocaloric effect and magnetic cooling near a field-induced quantum-critical point	17.08.2011
Prem Kiran P University of Hyderabad Hyderabad	Propagation of ultrafast laser pulses under tight focusing conditions	26.08.2011
Mahadevan L Harward University, USA	On growth and form: geometry, physics and biology	26.08.2011
Arunima Banerjee Indian Institute of Science Bangalore	Vertical structure of disk galaxies and their dark matter halos	26.08.2011
Anders Kastberg Universite Nice Sophia Antipolis, France	Experimental demonstration of the Pancharatnam phase in intensity interferometry and quantum information at University of Nice	29.08.2011

Nampoori VPN Cochin University of Science and Technology, Cochin	Bionanotechnology: tools and applications	06.09.2011
Paramita Barai University of Nevada USA	Simulating supermassive black hole accretion: spherical flow to cold clumps and hot bubbles	09.09.2011
Subhasish Dutta Gupta University of Hyderabad Hyderabad	25 years of plasmonics and nano-optics at University of Hyderabad	16.09.2011
Subhasis Maity Jadavpur University Kolkata	Dye sensitized photo electrochemical cell as organic photovoltaic	20.09.2011
Sourav Haldar Centre for Cellular and Molecular Biology Hyderabad	Monitoring orientation and dynamics of membrane-bound melittin utilizing dansyl fluorescence	26.09.2011
Hari Dass ND Chennai Mathematical Institute, Chennai	Neutrinos breaking the light barrier?	13.10.2011
Dan Werthimer University of California, USA	The collaboration for radio astronomy signal processing and electronic research (CASPER)	17.10.2011
Andreas Fuhrmanek CNRS- Institut d'Optique Graduate School, France	From single atom to many atoms in a microscopic optical dipole trap	18.10.2011
Bernard de Wit Utrecht University The Netherlands	Elementary particles, strings and black holes	26.10.2011
Ravindra Venkatramani Duke University USA	Moving charges through nucleic acid sequences: making sense of mechanisms and rates in dynamic media	28.10.2011
Changbom Park Korea Institute for Advanced Study Republic of Korea	Simulation of the SDSS survey region of the universe	09.11.2011
Yuri A Shchekinov Southern Federal University, Russia	Enrichment history of the Universe as seen from GRB statistics	14.11.2011
Karthik Shankar Boston University, USA	Torsion induced modification to gravity can avert singularities	15.11.2011

Sudhir Vempati Indian Institute of Science Bangalore	Higgs or No Higgs?	17.11.2011
Rajesh R Institute of Mathematical Sciences Chennai	Isotropic-nematic-disorder transitions in a system of long rods	29.11.2011
Sanjay Kumar Banaras Hindu University Varanasi	Mechanical separation of short double stranded DNA: Effect of pulling geometry	01.12.2011
Subinay Dasgupta University of Calcutta Kolkata	Quantum Ising Chain under periodic field: an exact solution	08.12.2011
Manjari Bagchi West Virginia University USA	A study of observed luminosities of millisecond pulsars in globular clusters aiming a better understanding of this population	09.12.2011
Fernando Barbero Instituto de Estructura de la Materia, Spain	Black holes: combinatorics and the thermodynamic limit	09.12.2011
Sukanya Chakrabarti Florida Atlantic University, USA	A new probe of the distribution of dark matter in galaxies	12.12.2011
Rafael D Sorkin Perimeter Institute Canada	Expressing entropy globally in terms of field- correlations	13.12.2011
Rajaram Nityananda National Centre for Radio Astrophysics, Pune	Electromagnetic transmission through a parallel array of wires	13.12.2011
Malay Bandyopadhyay University of Toronto Canada	Quantum transport at nanoscale: two models for energy and charge transfer	15.12.2011
Anantha Ramakrishna S Indian Institute of Technology, Kanpur	Broadband extra-ordinary transmission of light through checkerboard plasmonic films	19.12.2011
Yogesh Bangalore University Bangalore	Investigations on rotations and interactions between microscopic objects by optical tweezer based techniques	19.12.2011
Yogendran KP Indian Institute of Science Education and Research, Mohali	Black holes and string theory	02.01.2012

Kartik Sheth National Radio Astronomy Observatory, USA	The starring role of bars in understanding galaxy evolution: Results from S4G, COSMOS, DEEP2 and AEGIS	05.01.2012
Nimesh A Patel Harvard-Smithsonian Center for Astrophysics, USA	Probing circumstellar chemistry with the submillimeter array	09.01.2012
Pinaki Chaudhuri Universitat Dusseldorf, Germany	Confined flow of soft jammed materials	10.01.2012
Madhusudan Singh University of Texas, USA	A few illuminating adventures with OLEDs	10.01.2012
Debashree Ghosh University of Southern California, USA	Understanding electron transfer processes in complex environments- Hybrid QM/EFP approach	16.01.2012
Pavan Kumar Aluri Indian Institute of Technology Kanpur	Directional and power anisotropies in CMB	17.01.2012
Ashish V Orpe National Chemical Laboratory Pune	Dynamics of dense granular material flowing within a fluid	20.01.2012
Sharmila Kamat Columbia University, USA	Hunting for WIMPs – the search for dark matter in the universe	23.01.2012
Ron Ekers Australia Telescope National Facility, Australia	1. Lunar radio Cerenkov observations of UHE neutrinos 2. Experiments in Radio Astronomy	24.01.2012 16.01.2012 30.01.2012
Sharanya Sur Inter University Centre for Astronomy & Astrophysics, Pune	Magnetic fields during the formation of the first stars	31.01.2012
Jane Roscoe Institute of Physics Publishing United Kingdom	Visibility - beyond the published article	31.01.2012
John Philip Indira Gandhi Centre for Atomic Research, Kalpakkam	Nanofluid- a wonderful model system for physicists	02.02.2012
Preeti Kharb Rochester Institute of Technology USA	Examining AGN unification and jet propagation in Radio-loud AGN	06.02.2012
Mark Bowick Syracuse University, USA	Facets of order	07.02.2012

Iyer BR Raman Research Institute Bangalore	LIGO-India Centre at RRI-Flagship Project	08.02.2012
Swati Dandekar Independent Filmmaker	Water and a city	16.02.2012
Miguel Campiglia Pennsylvania State University, USA	Loop quantum cosmology in the spinfoam paradigm	02.03.2012
Michael A Dopita Australian National University Australia	The quantum vacuum, dark energy and dark matter	12.03.2012
Gaiti Hasan National Centre for Biological Sciences, Bangalore	The calcium store(y) in neurons	15.03.2012
Subhadeep De University of Maryland, USA	Mixture of Bose-condensed rubidium and degenerate fermionic lithium	21.03.2012

Soft Matter Chemistry Workshop

held at the Raman Research Institute between 9-11 November 2011

Speaker	Title
Takashi Kato	Development of nanostructured liquid crystals exhibiting photonic, ionic and electronic functions
Madhusudana NV	An overview of liquid crystals with novel physical properties synthesized in the Raman Research Institute
Duncan Bruce	New liquid-crystalline materials via heterocyclic compounds
Paul Kouwer	Hierarchical organization in soft matter
Yo Shimizu	Liquid crystals: dynamics systems towards novel semiconducting materials
Ehud Keinan	Towards chemical capsids and cucurbituril-based chemical sensors
Rajiv Manohar	Ferroelectric liquid crystals versus nano particles doped ferroelectric liquid crystals
Pratibha R	Glassy nature for the dark conglomerate liquid crystalline phase

Surajit Dhara	Viscoelastic properties of some unconventional nematic liquid crystals
Manickam M	Molecular materials: triphenylene-based discotic liquid crystals
Raj Kumar Gupta	Surface pressure induced nanostructure formation in langmuir-blodgett films of tricycloquinazoline based mesogen
Ravindra Dhar	Dielectric and electro-optical parameters of the mixtures of R and S enantiomers of an anti-ferroelectric liquid crystalline material
Chien LC	Light embossed nano patterns for liquid crystal alignment
Suresh KA	Novel discotic mesogen films at interfaces
Lakshminarayanan V	Electrochemical studies in self-organized soft matter systems
Manjula Devi	Effect of functionalized carbon nanotube on physical properties of a liquid crystal
Corrie Imrie	Liquid crystal polymer electrolytes
Sri Singh	Phase transitions in liquid crystals
Raghunathan VA	Tuning DNA-amphiphile condensate architecture with strongly binding counterions
Sadashiva BK	Liquid crystals of compounds composed of bent core molecules
Ramakrishnan S	*Janus hybramers*: self-adapting amphiphilic hyper-branched polymers
Jayaraman N	Fluorescent poly(ether imine)-based dendritic liquid crystals
Narayan KS	Correlating electrical transport and morphology in bulk hetorstructure polymer blends
Neelotpal Sen Sarma	Development of thermistor device from the liquid crystalline polymers
Ohta K	Development of discotic liquid crystals based on phthalocyanine-fullerene dyad
Satyendra Kumar	What are cybotactic groups, swarms, clusters, correlated regions, and pretransitional fluctuations?
Vij JK	Field induced switching in non-tilted polar orthogonal smectic phases in bent-core liquid crystals
Ruckmongathan TN	A path to high performance liquid crystal displays
Bandyopadhyay R	Rise of an intruder in a quasi 2D granular column is driven by granular convection
Dabrowski R	High birefringent nematic liquid crystals with positive, neutral and negative dielectric anisotropy

Ashish Prajapati	Symmetric and non-symmetric liquid crystal dimers: synthesis and mesomorphism
Tandel RC	Effect of amide linkage on mesomorphism
Arun Roy	The triclinic lamellar phases of the bent-core hockey stick shaped molecules
Thaker BT	Calamatic metallomesogens: metal containing liquid crystals
Raina KK	Optical enhancement investigations of polymer stabilized and guest – host liquid crystals
Kula P	Synthesis and properties of laterally fluoro-substituted 4"-alkyl-[1,1':4',1"]terphenul-4-yl alkyl carbonates
Hari K Bisoyi	Carbon-based liquid crystals
Vijayaraghavan D	Magnetic susceptibility studies on micelles, vesicles and bicelles
Hatwalne Y	The structure of twist grain boundary phases

3rd RRI School on Statistical Physics

held at the Raman Research Institute between March 26 - April 7, 2012

Speaker	Title
Samuel J Raman Research Institute Bangalore	Brownian motion on curved surfaces
Bhattacharjee SM Institute of Physics Bhubaneshwar	Physics of polymers
Abhishek Dhar Raman Research Institute Bangalore	Introduction to methods of stochastic processes - I
Sabhapandit S Raman Research Institute Bangalore	Introduction to methods of stochastic processes - II
Jarzynski C University of Maryland, USA	Nonequilibrium work relations and fluctuations

Ciliberto S
École normale supérieure
France

Measuring nonequilibrium fluctuations

Gallavotti G
University of Rome, Italy

Dynamical systems and fluctuation relations

APPENDIX 4

Visitors

Name and Institution	Duration of stay
Nithyanandan T Columbia University, USA	6 April – 16 May 2011
Divya Sharma Birla Institute of Technology & Science-Pilani, Hyderabad	10 – 12 April 2011
Unnikrishnan CS Tata Institute of Fundamental Research, Mumbai	14 – 19 April 2011 23 – 24 June 2011
Umakanth Rapol Indian Institute of Science Education and Research, Pune	15 – 16 April 2011
Sudipta Sarkar University of Maryland, USA	17 – 19 April 2011
Amit Apte Centre for Applicable Mathematics, Bangalore	19 April 2011
Sandipan Sengupta Institute of Mathematical Sciences, Chennai	1 – 5 May 2011 29 – 30 November 2011
Sandeep Menon Perinchery Macquarie University, Australia	2 May 2011

Reetanjali Moharana Indian Institute of Technology, Mumbai	5 May – 5 June 2011 10 November – 31 December 2011
Arun KG Chennai Mathematical Institute, Chennai	15 – 23 May 2011 24 – 27 September 2011 21 – 26 February 2012
Sanjay Gupta S N Bose Centre for Basic Sciences, Kolkata	22 -27 May 2011
Brian Crosse Curtin University, Western Australia	23 – 25 May 2011
Harshal Bhadkamkar Tata Institute of Fundamental Research, Mumbai	23 – 26 May 2011
Edward Morgan Massachusetts Institute of Technology, USA	23 – 28 May 2011
Jinto Thomas Institute for Plasma Research, Ahmedabad	25 – 27 April 2011 2 – 26 May 2011
Ginson Joseph St. Thomas College, Pala, Kerala	17 – 18 May 2011
Ravi Chandra V Israel Institute of Technology, Israel	27 May 2011
Dana Anderson University of Colorado, USA	20 – 28 May 2011
Seshadri TR Delhi University, New Delhi	29 May – 2 June 2011 26 – 31 July 2011 1 – 8 October 2011 3 – 9 March 2011
Jayan Thomas University of Arizona, USA	29 – 31 May 2011
Gopal NO National Dong Hwa University, Taiwan	31 May 2011
Ashish Lele National Chemical laboratory, Pune	31 May – 3 June 2011
Mughda Gadgil National Chemical Laboratory, Pune	2 – 3 June 2011
Ghosh A Indian Association for the Cultivation of Science, Kolkata	3 – 5 June 2011

Anindya Banerjee St. Xavier's College, Pune	7 – 11 June 2011
Ganesh V Central Electrochemical Research Institute, Karaikudi	10 – 16 June 2011 22 – 24 June 2011
Abhik Ghosh Indian Institute of Technology, Kharagpur	12 – 13 June 2011
Archan Dey Eindhoven University of Technology, The Netherlands	14 – 15 June 2011
Vikram Vyas St. Stephen's College, Delhi	20 June – 13 July 2011
Priyam Das Indian Institute of Science Education and Research, Kolkata	30 June – 3 July 2011
Arvind Ayyer University of California, USA	1 July 2011
Marykutty James MG University, Kerala	1 July - 30 October 2011 10 - 31 March 2012
Chetana Jain Delhi University, New Delhi	1 – 10 July 2011
Surajit Dhara University of Hyderabad, Hyderabad	5 – 6 July 2011
Abhijit Sen Institute for Plasma Research, Ahmedabad	8 – 10 July 2011
Sujoy Kumar Modak S N Bose National Centre for Basic Sciences, Kolkata	10 – 15 July 2011
Sibhasish Gosh The Institute of Mathematical Sciences, Chennai	10 – 14 July 2011
Srinivas Sridhar Northeastern University, USA	12 July 2011
Krishnan N Tata Institute of Fundamental Research, Mumbai	14 – 15 July 2011 21 July 2011
Guillaume Faye Institut d' Astrophysique de Paris, Paris	16 July – 13 August 2011
Rao DVGLN University of Massachusetts, USA	28 July – 5 August 2011 30 August 2011

Anders Kastberg Universite Nice Sophia Antipolis, France	29 July - 31 August 2011
Arundati Dasgupta University of Lethbridge, Canada	3 – 5 August 2011
Casey Tomlin Pennsylvania State University, USA	6 August – 7 October 2011
Govind Swarup National Centre for Radio Astrophysics, Pune	7 – 9 August 2011
Indranil Chattopadhyay Aryabhatta Research Institute of Observational Sciences, Nainital	8 – 16 August 2011
Srivathsan Vasudevan National Technical University, Singapore	11 August 2011
Onuttom Narayan University of California, USA	17 August 2011
Ruta Kale Inter University Centre for Astronomy & Astrophysics, Pune	20 – 31 August 2011
Robert Goeke MIT Kavli Institute of Astrophysics & Space Research, USA	22 – 23 August 2011 14 – 16 November 2011 11 – 14 March 2012
Paramita Barai International Centre for Theoretical Physics, Italy	5 September – 2 October 2011
Dutta Gupta University of Hyderabad, Hyderabad	14 – 16 September 2011
Avasthi DK Inter University Accelerator Centre, New Delhi	15 – 17 September 2011
Richard Dodson International Centre for Radio Astronomy Research, Australia	24 September – 1 October 2011
Subhasis Maity Jadavpur University, Kolkata	19 – 20 September 2011
Sourav Haldar Centre for Cellular & Molecular Biology, Hyderabad	25 – 26 September 2011
Andreas Fuhrmanek CNRS-Institut d'Optique Graduate School, France	5 – 26 October 2011
Hari Dass ND Chennai Mathematical Institute, Chennai	13 – 16 October 2011

Anya Choudhury Tata Institute of Fundamental Research, Mumbai	15 – 31 October 2011 18 – 23 February 2012
Dan Werthimer University of California, USA	17 – 19 October 2011
Ramesh K Max-Planck Institute for Radio Astronomy, Germany	17 – 20 October 2011
Jayaram N Chengalur National Centre for Radio Astronomy, Pune	19 – 21 October 2011
Yuri Schekinov Southern Federal University, Russia	26 October – 19 November 2011
Ravindra Venkatramani Duke University, USA	26 – 29 October 2011
Abhijit Ghosh Weizmann Institute of Science, Israel	28 October – 30 November 2011 3 – 7 January 2012
Aditya Dharmadhikari Tata Institute of Fundamental Research, Mumbai	31 October – 4 November 2011
Balakrishna K Defence Research & Development Organisation, Mumbai	7 – 9 November 2011
Jurek Malareki University of Western Australia, Australia	10 November – 10 December 2011
Karthik Shankar Boston University, USA	15 – 16 November 2011
Haripadmam PC Indian Institute of Space Science and Technology, Trivandrum	15 – 16 November 2011
Visweshwar Ram Marthi National Centre for Radio Astrophysics, Pune	16 – 19 November 2011
Gaurav Jagtap Pune University, Pune	21 – 30 November 2011
Poonam Mehta Delhi University, Delhi	21 November – 6 December 2011
Rajesh R Institute of Mathematical Sciences, Chennai	29 November 2011
Subinay Dasgupta Calcutta University, Kolkata	29 November – 10 December 2011

Sanjay Kumar Banaras Hindu University, Varanasi	1 December 2011
Manu M Indian Institute of Technology, Kanpur	1 – 15 December 2011
Karupuchamy Kyushu Institute of Technology, Japan	8 December 2011
Jack Douglas National Institute of Standards and Technology, USA	8 December 2011
Jesus Fernando Barbero Gonzalez Instituto de Estructura de la Materia, Spain	3 – 14 December 2011
Rafael Sorkin Syracuse University, USA	7 December 2011 – 3 January 2012
Manjari Bagchi University of West Virginia, USA	8 – 13 December 2011
Rajaram Nityananda National Centre for Radio Astrophysics, Pune	9 – 14 December 2011
Nalini H Issur University of Mauritius, Mauritius	11 – 26 December 2011
Sukanya Chakraborti Florida Atlantic University, USA	13 – 14 December 2011
Malay Bandyopadhyay University of Toronto, Canada	15 – 16 December 2011
Anirudh Krishna Chennai Mathematical Institute, Chennai	15 – 30 December 2011 26 – 29 January 2012
Ashish Asgekar Netherlands Institute for Radio Astronomy, The Netherlands	18 – 21 December 2011
Yogesh Bangalore University, Bangalore	19 December 2011
Ryuichi Fujita Universitat des Baleares, Spain	20 December 2011
Subbarao Kambhampati Arizona State University, USA	20 – 24 December 2011
Suresh Doravari R California Institute of Technology, USA	23 December 2011 12 – 29 January 2012

Himangshu Paul Indian Institute of Science Education and Research, Kolkata	25 – 26 December 2011
Supriyo Mitra Indian Institute of Science Education and Research, Kolkata	25 – 26 December 2011
Joanna M Rankin University of Vermont, USA	27 December 2011 – 10 January 2012
Abhijit Ghosh Weizmann Institute of Science, Israel	3 – 30 January 2012
Nimesh Patel Harvard-Smithsonian Center for Astrophysics, USA	6 – 10 January 2012
Ronald Ekers Commonwealth Scientific and Industrial Research Organisation Australia	8 – 30 January 2012
Pinaki Chaudhuri Universitat Dusseldorf, Germany	9 January 2012
Madhusudan Singh University of Texas, USA	10 January 2012
Pavan Kumar Aluri Indian Institute of Technology, Kharagpur	11 January – 15 February 2012
Sharanya SurInter Inter University Centre for Astronomy & Astrophysics, Pune	16 January – 5 February 2012
Debashree Ghosh University of Southern California, USA	16 – 18 January 2012
Tarun Souradeep Inter University Centre for Astronomy & Astrophysics, Pune	18 January 2012
Ashish V Orpe National Chemical Laboratory, Pune	20 – 21 January 2012
Sharmila Kamat Columbia University, USA	22 – 26 January 2012
Jane Roscoe Institute of Physics Publishing, United Kingdom	31 January 2012
Kavitha M K Indian Institute of Space Science and Technology, Trivandrum	31 January – 2 February 2012
John Philip Indira Gandhi Centre for Atomic Research, Kalpakkam	1 – 3 February 2012

Preeti Kharb Rochester Institute of Technology, USA	5 – 7 February 2012
Mark Bowick Syracuse University, USA	7 February 2012
Katherine Blundell Oxford University, United Kingdom	12 – 22 February 2012
Steve Lee Oxford University, United Kingdom	12 – 22 February 2012
Kumar M P Manipal University, Manipal	13 – 29 February 2012
Michael A Dopita Australian National University, Australia	12 – 15 March 2012
Subhadeep De University of Maryland, USA	20 – 22 March 2012
Anitha R Warrier Indian Institute of Technology-Madras, Chennai	22 – 25 March 2012
Vandna Gokhroo Tata Institute of Fundamental Research, Mumbai	23 February – 12 July 2012

APPENDIX 5

Journal Club

Discussed by	Paper discussed	Date
Udaya Shankar N	The application of compressive sampling to deconvolution T.J. Cornwell and F.de Hoog Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia *Astronomy & Astrophysics,* **528**, (April 2011)	07.04.2011
Arnab Pal	On the orientational ordering of long rods on a lattice A.Ghosh and D. Dhar, TIFR *Euro Physics Letters*, **78** 20003 (2007)	07.04.2011
Madhukar S	Universality in the evolution of orientation columns in the visual cortex Mathias Kaschube *et al.,* *Science,* **330**, 1113 (2010)	28.04.2011
Abhishodh Prakash	Hawking radiation and the boomerang behavior of massive modes near a horizon G. Jannes *et al.,* *Physical Rev. D,* Apr 13, 2011	28.04.2011
Shashikant Gupta	Gravity modes as a way to distinguish between hydrogen and helium-burning red giant stars Timothy R. Bedding *et al.,* *Nature*, **471**, 608-611 (2011)	12.05.2011

Ramesh B	Supermassive black holes do not correlate with dark matter halos John Kormendy (University of Texas, USA) Ralf Bender (Universitats-Stemwarte, Germany) *Nature,* **469**, 377-380 (2011)	12.05.2011
Abhishek Dhar	Experimental demonstration of information-to-energy conversion and validation of the generalized Jarzynski equality Shoichi Toyabe *et al.,* *Nature Physics*, **6**, 988-992 (2010)	26.05.2011
Pramod Pullarkat	Measurement of the instantaneous velocity of a Brownian particle Tongcang Li *et al*., *Science,* **328**, 1673-1675 (2010)	26.05.2011
Sanjib Sabhapandit	Leindenfrost on a Ratchet Guillaume Lagubeau *et al*., *Nature Physics*, **7**, 395-398 (2011)	23.06.2011
Andal Narayanan	Observing the average trajectories of single photons in a two-slit interferometer Kocsis *et al*., *Science,* **332** (6034), 1170-1173 (2011)	23.06.2011
Vijayaraghavan D	All-photonic multifunctional molecular logic device Joakim Andreasson *et al*., *J.Am. Chem. Soc.,* In Press (2011)	14.07.2011
Jyothi S	Optical precursor of a single photon Shengwang Du *et al*., *Phy. Rev. Lett.,* **106**, 243602-243605 (2011)	14.07.2011
Ranjini Bandyopadhyay	Competing interactions in arrested states of colloidal clays B.Ruzicka, L. Zulian, E. Zaccarelli, R. Angelini, M. Sztucki, A. Moussaid and G. Ruocco *Phys. Rev. Lett.,* **104**, 85701-85704 (2010)	28.07.2011
Tridib Ray	Millikelvin cooling of an optically trapped microsphere in vacuum Tongcang Li, Simon Kheifets and Mark G. Raizen *Nature Physics*, **7**, 527–530 (2011)	28.07.2011
Joseph Samuel	Gentle Measurement J.Volz *et al.,* *Nature,* **475**, 210-213 (2011)	11.08.2011
Kanhaiya Lal Pandey	A new challenge for the LCDM model of the Universe (Novel test of modified Newtonian dynamics with gas rich galaxies) Stacy S. McGaugh *Phys. Rev. Lett.,* **106**, 121303-306 (2011)	11.08.2011

Arun Roy	Glass transitions in quasi-two-dimensional suspensions of colloidal ellipsoids Zhongyu Zheng, Feng Wang and Yilong Han *Phys. Rev. Lett*., **107**, 65702-65705 (2011)	25.08.2011
Nithyanandan Thyagarajan	It's all done with mirrors: reflections on the familiar and yet deeply enigmatic nature of the looking glass Vilayanur S Ramachandran and Diane Rogers-Ramachandran *Scientific American Mind*, **18**, 16-18 (2007)	25.08.2011
Supurna Sinha	Bose-Einstein condensation of photons in an optical microcavity Jan Klaers *et al*., *Nature,* **468**, 545-548 (2010)	08.09.2011
Solomon Ivan J	Minimum output entropy of Gaussian Channel S. Lloyd *et al.,* *arXiv:* **0906.2762**	08.09.2011
Anjan Roy	Suppression of the coffee-ring effect by shape-dependent capillary interactions Peter J. yunker *et al*., *Nature,* **476,** 308-311 (2011)	22.09.2011
Nipanjana Patra	A luminous quasar at redshift 7.085 Daniel J. Mortlock *et. al*., *Nature*, **474**, 616-619 (2011)	22.09.2011
Shiv Sethi	The Nobel Prize in Physics – 2011 Special Journal Club Session	20.10.2011
Srinivasa R	The Nobel Prize in Chemistry – 2011 Special Journal Club Session	03.11.2011
Satyajit Rath National Institute of Immunology, New Delhi	The Nobel Prize in Medicine- 2011 Special Journal Club Session	24.11.2011
Kumar N	Time of first passage (ToFP)	12.01.2012
Debasish Saha	Infinite penetration of a projectile into a granular medium F.Paecheco-Va'zquez *et al*., *Phys. Rev. Lett.,* **106**, 218001-218004 (2011)	09.02.2012
Rajib Basak	Thermal jamming of a colloidal glass Praveen Agarwal *et al.,* *Phys. Rev. Lett.,* **107**, 268302-268306 (2011)	09.02.2012
Prabu T	Detection of pulsed gamma rays above 100 GeV from the crab pulsar (The Veritas collaboration) E.Aliu *et al*., *Science*, **334**, 69-72 (2011)	23.02.2012

Sandipan Sengupta	The geometry of sound rays in a wind G.W. Gibbons, C.M. Warnick *Contemporary Physics*, ***52***, 197-209 (2011)	23.02.2012
Biswajit Paul	Two populations of X-ray pulsars produced by two types of Supernovae Christian Knigge *et al.,* *Nature*, **479**, 372-375 (2011)	22.03.2012
Shiv K. Sethi	Generation of scaled protogalactic seed magnetic fields in laser-produced shock waves Gregori *et al*., *Nature*, **401**, 480-483 (2012)	22.03.2012

Statement of Accounts

2011-2012

Raman Research Institute Bangalore

B.R.V. Goud & Co.
Chartered Accountants

Date: 12.09.2012

AUDITORS' REPORT TO THE MEMBERS OF
RAMAN RESEARCH INSTITUTE, BANGALORE

1. We have audited the attached Balance Sheet of **Raman Research Institute, Bangalore,** as at 31st March 2012 and the Income and Expenditure Account for the year ended on that date, annexed thereto. These Financial Statements are the responsibility of the Institute's management. Our responsibility is to express an opinion on these Financial Statements based on our Audit.

   We have conducted our audit in accordance with Auditing standards generally accepted in India. Those Standards require that we plan and perform the audit to obtain reasonable assurance about whether the Financial Statements are free of material misstatement. An Audit includes examining, on a test basis, evidence supporting the amounts and disclosures in the Financial Statements. An audit also includes assessing the accounting principles used and significant estimates by Management, as well as evaluating the overall Financial Statement presentation.
   We believe that our audit provides a reasonable basis for our opinion.

2. We have obtained all the information and explanations, which to the best of our knowledge and belief were necessary for the purpose of our Audit.

3. In our opinion, proper Books of Accounts as required by law have been kept by the Management so far as appears from our examination of such books.

4. The Balance Sheet and the Income and Expenditure Account dealt with by this report are in agreement with the books of account.

5. In our opinion and to the best of our information and according to the explanations given to us, the said accounts read with the schedules thereon give a true and fair view:

   a) In the case of the Balance Sheet, of the state of affairs of the Institute as at 31st March 2012.

   A N D

   b) In the case of Income and Expenditure Account, of the **DEFICIT** for the year ended on that date.

for B.R.V. GOUD & CO.,
Chartered Accountants,
FRN 000992S

B.R.V. GOUD & Co. Chartered Accountants Bangalore-1

(A.B.SHIVASUBRAMANYAM)
P A R T N E R
M.NO. 201108

No 37/1, 1st Floor, M.N.K. Rao Road
Basavanagudi, Bangalore - 560 004
Phone: 080 - 26566448, 26577448

TeleFax: 080 - 26566337
E-mail: audit@brvgoud.co.in
Website: www.brvgoud.co.in

RAMAN RESEARCH INSTITUTE

Bangalore

Balance Sheet as at 31st March 2012

I SOURCES OF FUNDS	SCH.	As at 31.3.2012 Rs.	As at 31.3.2011 Rs.
CAPITAL FUND	1	100,60,79,708	97,29,13,333
GENERAL FUND	2	67,05,448	84,13,805
RETIREMENT FUNDS	3	28,65,63,190	22,98,92,153
UNUTILISED GRANTS	4	3,85,75,999	15,48,632
SUNDRY CREDITORS	5	2,18,80,890	2,91,68,082
PROVIDENT FUND (contra)	6	8,70,84,116	7,62,42,636
PENSION FUND (contra)	7	5,54,90,088	4,64,44,267
TOTAL		150,23,79,439	136,46,22,908

II APPLICATION OF FUNDS			
FIXED ASSETS	8	88,07,02,141	75,75,78,498
INVESTMENTS - RETIRMENT FUND	9	28,65,63,190	22,98,92,153
CURRENT ASSETS, ADVANCES AND DEPOSITS	10	11,58,61,115	21,64,51,353
CASH AND BANK BALANCES	11	7,66,78,789	3,80,14,001
PROVIDENT FUND (contra)	12	8,70,84,116	7,62,42,636
PENSION FUND (contra)	13	5,54,90,088	4,64,44,267
TOTAL		150,23,79,439	136,46,22,908

Notes on accounts. 18

Schedules 1 to 18 form an integral part of the accounts

As per our Report of even date,
for B. R. V. GOUD & CO.,
Chartered Accountants
FRN 000992S

K. KRISHNAMA RAJU
Administrative Officer

RAVI SUBRAHMANYAN
Director

A. B. SHIVA SUBRAMANYAM
Partner
M. No. 201108

Place : Bangalore
Date : Sept. 12, 2012

RAMAN RESEARCH INSTITUTE
Bangalore

Income and Expenditure Account for the year ended 31.03.2012

A INCOME	SCH.	2011-2012 Rs.	2010-2011 Rs.
GRANT-IN-AID:			
Non-Plan-Recurring		1,42,00,000	1,80,00,000
Plan-Recurring		24,08,01,830	20,45,47,085
Interest & Miscellaneous Income	14	1,10,19,068	83,60,876
TOTAL (A)		26,60,20,898	23,09,07,961
B EXPENDITURE			
Salaries & Allowances	15	16,13,64,176	14,19,41,424
Working Expenses	16	10,63,65,079	8,73,33,363
TOTAL(B)		26,77,29,255	22,92,74,787
C Add/((Less) : Surplus/ (Deficit) for the year		(17,08,357)	16,33,174

Notes on accounts. 18
Schedules 1 to 18 form an integral part of the accounts

As per our Report of even date
for B. R. V. GOUD & CO.,
Chartered Accountants
FRN 000992S

K. KRISHNAMA RAJU
Administrative Officer

RAVI SUBRAHMANYAN
Director

A. B. SHIVA SUBRAMANYAM
Partner
M No. 201108

Place : Bangalore
Date : Sept. 12, 2012

RAMAN RESEARCH INSTITUTE
Bangalore

Receipts and Payments account for the year ended 31.03.2012

RECEIPTS	SCH.	2011-2012 Rs.	2010-2011 Rs.
Opening Balance	A	2,62,14,001	1,99,96,015
Grant-in-aid	B	40,82,81,533	37,96,01,958
Advance to Suppliers	C	9,99,57,268	-
Miscellaneous Receipts	D	1,20,03,414	93,07,427
Deposits and other Items	E	3,59,31,731	2,67,52,982
Short term Bank Deposits & Investments		56,16,90,510	62,47,10,000
TOTAL		114,40,78,457	106,03,68,382

PAYMENTS			
Recurring Expenditure (Plan and Non-Plan)	F	26,70,04,951	23,18,54,752
Plan - Non-Recurring Expenditure	G	16,99,34,536	7,59,71,738
Expenditure out of Grants/ Assistance from Government Agencies	H	1,24,35,746	48,32,768
Advance to Suppliers	I	-	3,40,05,317
Deposits and other items	J	3,61,40,390	2,74,05,301
Short term Bank Deposits & Investments		64,14,84,045	66,00,84,505
Closing Balance	K	1,70,78,789	2,62,14,001
TOTAL		114,40,78,457	106,03,68,382

Notes on accounts. 18
Schedules A to K & 18 form an integral part of the accounts

As per our Report of even date,
for B. R. V. GOUD & CO.,
Chartered Accountants
FRN 000992S

K. KRISHNAMA RAJU
Administrative Officer

RAVI SUBRAHMANYAN
Director

A. B. SHIVA SUBRAMANYAM
Partner
M No.201108

Place : Bangalore
Date : Sept. 12, 2012

RAMAN RESEARCH INSTITUTE

Bangalore

Schedules forming part of the Audited Statements of Account for the year ended 31st March 2012

PARTICULARS		As on 31.03.2012 Rs.	As on 31.03.2011 Rs.
SCHEDULE - 1			
Capital Fund			
Balance as on 1.4.2011		97,29,13,333	89,89,08,502
Add: Assets acquired/transferred during the year			
1) Plan - Non - Recurring		7,99,77,268	10,99,77,055
2) Scientific Publications acquired during the year		1,02,95,812	1,07,18,557
3) Amount Invested in SBI Life for past service Liability due to 6 CPC		3,19,93,535	4,81,84,505
		109,51,79,948	106,77,88,619
Less: Assets deleted during the year	23,70,464		
Less : Accu.depn.(Vide Sch.8 col. 9)	3,47,747	20,22,717	1,23,743
Less: Amount invested in SBI Life for past service Liability due to 6 CPC		3,19,93,535	4,81,84,505
		106,11,63,696	101,94,80,371
Less: Depreciation		5,50,83,988	4,65,67,038
TOTAL		100,60,79,708	97,29,13,333
SCHEDULE - 2			
General Fund			
Balance as on 1.4.2011		84,13,805	67,80,631
Add/((Less) : Surplus/ (Deficit) for the year		(17,08,357)	16,33,174
TOTAL		67,05,448	84,13,805

PARTICULARS		2011-2012 Rs.	2010-2011 Rs.
SCHEDULE - 3			
Retirement Funds - vested with SBI Life Insurance			
1. Gratuity Fund			
Opening Balance	5,87,43,719		
Add : Contributions for 2011-12	24,49,466		
Add : Addl.Contn. For impact of 6 CPC	50,00,000		
Add : Interest accrued	50,36,343		
Less: Claims paid	29,90,691		
		6,82,38,837	5,87,43,719
2. Leave Salary			
Opening Balance	3,12,49,866		
Add : Past service Liability due to 6 CPC	1,69,93,535		
Add : Contributions for 2011-12	37,96,257		
Add : Addl.Contn. For impact of 6 CPC	50,00,000		
Add : Interest accrued	26,87,610		
Less: Claims paid	18,59,692		
		5,78,67,576	3,12,49,866
3. Commutation of Pension Fund			
Opening Balance	13,98,98,568		
Add : Past service Liability due to 6 CPC	50,00,000		
Add : Contributions for 2011-2012	33,11,774		
Add : Interest accrued	1,22,46,435		
		16,04,56,777	13,98,98,568
TOTAL		28,65,63,190	22,98,92,153
SCHEDULE - 4			
Balance of Unutilized Grants			
Plan Non- Recurring		3,85,75,999	15,48,632
TOTAL		3,85,75,999	15,48,632

PARTICULARS		As on 31.03.2012 Rs.	As on 31.03.2011 Rs.
SCHEDULE - 5			
Sundry Creditors			
a. Un-Utilised Grants - Projects/Meetings etc.,			
1. DST-PAC Meetings		-	1,73,670
2. India Australia S & T Co-Operation		-	1,53,987
3. Enabling New Sciences- MWA		17,80,000	-
4. Swarana Jayanthi Fellowship		-	1,65,995
5. Ramanujan Fellowship		-	6,33,025
6. DBT - Biomechanics of synaptogensis		10,969	5,68,188
7. ISRO - for SSO Project		67,91,007	1,34,02,275
8. British Council Division		-	52,114
9. D A E Homi Bhaba Chair		-	87,707
10.CSIR - Extra Murual Research project		-	7,65,000
11. INSA Fellowship		83,465	-
12. TIFR		5,04,473	-
b. Others			
1. Earnest Money Deposits		5,01,505	12,30,000
2. Contractors' Security Deposits		5,45,427	10,21,317
3. Group Insurance Scheme		2,591	3,091
4. Indian Academy of Sciences (for Land)		1,00,00,000	1,00,00,000
5. Service benefits and other liabilities		6,39,927	6,81,518
6. Duties & Taxes (TDS)		74,616	1,00,195
7. Caution Deposits (Hostel)		1,44,000	1,30,000
8. R R I Pension A/c		8,02,910	-
		2,18,80,890	2,91,68,082
SCHEDULE - 6			
Provident Fund			
FUND BALANCES:			
A. Employees Subscription			
a) Contributory Provident Fund		3,29,10,086	2,87,60,100
b) General Provident Fund		1,48,27,689	1,42,06,188
B. Institute Contribution to Contributory Provident Fund		2,85,86,145	2,50,74,607
C. New Pension Scheme		2,98,223	3,503
GENERAL FUND -	77,15,379		
Add: Excess of income over expenditure for 2011-2012	8,09,747	85,25,126	77,15,379
RRI Pension Fund		19,36,847	4,82,859
TOTAL		8,70,84,116	7,62,42,636
SCHEDULE - 7			
Pension Fund			
Capital Fund-Opening Balance	3,81,57,005		
Add: Institute's Contribution for the year(Corpus Fund)	60,04,722		
Add: GPF Contribution for the year	39,07,507	4,80,69,234	3,81,57,005
Commutation of Pension Fund		74,20,854	74,20,854
Raman Research Institute			8,66,408
TOTAL		5,54,90,088	4,64,44,267

SCHEDULE - 8
Fixed Assets

Sl.No	DESCRIPTION	GROSS BLOCK					DEPRECIATION BLOCK				NET BLOCK	
		Original Cost as on 01.04.2011	Addition during the year	Deletion during the year	Original cost as on 31.03.2012	Rate	Total up to 01.04.2011	Less Accu.Depn.on Deletion (on col. No.5)	For the year 2011-2012 (on Col.No.6)	Total up to the end of 31.03.2012 (8-9+10)	As on 31.03.2012 (6-11)	As on 1.04.2011
1	2	3	4	5	6	7	8	9	10	11	12	13
		Rs.	Rs.	Rs.	Rs.	%	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.
1	Land											
	(a) R M V II Stage	3,78,735			3,78,735						3,78,735	3,78,735
	(b) Malleswaram	31,19,436			31,19,436						31,19,436	31,19,436
	(c) H M T, Jalahalli	8,00,63,261			8,00,63,261						8,00,63,261	8,00,63,261
2	Building	14,76,61,958	82,09,664	23,70,464	15,35,01,158	1.63	1,67,94,697	3,47,747	25,02,069	1,89,49,019	13,45,52,139	13,08,67,261
3	Capital Equipment	55,30,07,880	15,39,46,883		70,69,54,763	4.75	16,25,40,245		3,35,80,351	19,61,20,596	51,08,34,167	39,04,67,635
4	Canteen Infrastructure	42,76,021			42,76,021	4.75	2,03,111		2,03,111	4,06,222	38,69,799	40,72,910
5	Computers	11,61,08,246	55,49,595		12,16,57,841	16.21	10,62,61,432		81,07,357	11,43,68,789	72,89,052	98,46,814
6	Furniture & Fixture	1,08,77,151	8,78,956		1,17,56,107	6.33	40,65,984		7,44,162	48,10,146	69,45,961	68,11,167
7	Vehicles	43,09,188			43,09,188	9.50	25,13,796		4,09,373	29,23,169	13,86,019	17,95,392
8	Books and Journals	18,91,45,602	1,16,45,250		20,07,90,852	4.75	5,89,89,715		95,37,565	6,85,27,280	13,22,63,572	13,01,55,887
	TOTAL	1,10,89,47,478	18,02,30,348	23,70,464	1,28,68,07,362		35,13,68,980	3,47,747	5,50,83,988	40,61,05,221	88,07,02,141	75,75,78,498

PARTICULARS	As on 31.03.2012 Rs.	As on 31.03.2011 Rs.
SCHEDULE - 9		
Investments - Retirement Funds - vested with SBI Life Insurance		
Gratuity Fund	6,82,38,837	5,87,43,719
Leave Salary	5,78,67,576	3,12,49,866
Commutation of Pension Fund	16,04,56,777	13,98,98,568
TOTAL	28,65,63,190	22,98,92,153
SCHEDULE - 10		
Current Assets, Advances and Deposits		
a) Stock on Hand	11,46,301	11,40,664
b) Advances and Deposits:		
1. Advance to Suppliers	1,51,89,657	11,70,72,100
2. Advance for purchases of Land	8,89,61,800	8,89,61,800
3. Raman Research Institute - Pension Fund	-	8,66,408
4. Advances to Staff	34,62,158	50,70,421
5. Other Advances/Deposits	34,04,374	32,38,648
6. INSA Fellow Ship	-	64,397
7. Tax Deducted at Source	17,344	17,344
8. Indian Academy of Sciences (net)	6,271	19,571
9. Ramanujan Fellowship	4,71,086	-
10.Swarna Jayanthi Fellowship	4,11,004	-
11.Customs Duty Receivable	27,91,120	-
TOTAL (a+b)	11,58,61,115	21,64,51,353
SCHEDULE - 11		
Cash and Bank Balances		
Cash at Banks - In Savings Bank Accounts/MODs :		
State Bank of India	1,45,72,514	2,01,50,899
State Bank of Mysore	21,88,817	52,90,099
Canara Bank	2,14,163	2,06,099
Union Bank of India	5,96,60,174	1,23,37,253
Central Bank of India	16,347	15,745
Stamps on hand (Franking Machine)	26,774	13,906
TOTAL	7,66,78,789	3,80,14,001

PARTICULARS	As on 31.03.2012 Rs.	As on 31.03.2011 Rs.
SCHEDULE - 12		
Provident Fund		
Investments (At Cost)	8,00,79,986	6,74,55,676
Refundable Advances	16,95,760	16,36,920
Interest accrued on Investments	10,31,340	14,32,506
Income-tax Deducted at Source Receivable	3,09,549	3,56,035
Cash at Banks:		
State Bank of India	39,58,095	48,61,508
HDFC Bank	9,386	4,99,991
TOTAL	8,70,84,116	7,62,42,636
SCHEDULE - 13		
Pension Fund		
Investments (At Cost)	3,82,96,166	3,42,33,444
Interest Accrued on investments	11,06,546	7,16,968
Income-tax deducted at source	2,93,881	2,52,988
Raman Research Institute	1,24,45,692	95,22,589
Raman Research Institute (PF A/c)	19,36,847	4,82,859
Cash at Banks:		
Central Bank of India	4,58,179	4,27,976
State Bank of India	2,10,767	5,01,627
HDFC Bank	7,42,010	3,05,816
TOTAL	5,54,90,088	4,64,44,267
SCHEDULE - 14		
Interest & Miscellaneous Income		
Interest on :		
Letters of Credit Margins	40,49,914	7,15,781
Short Term Deposits & Savings Bank A/cs	41,27,832	55,88,192
Miscellaneous Income		
Grant-in-aid from -		
Raman Research Institute Trust	1,00,000	1,00,000
License fee from quarters	3,74,893	4,42,307
Other Receipts	10,52,779	12,00,157
Sale of unserviceable items	13,13,650	3,14,440
TOTAL	110,19,068	83,60,876
SCHEDULE - 15		
Salaries & Allowances		
Pay	5,93,46,007	5,83,90,511
Allowances	6,40,08,758	5,49,26,387
6th Pay Commission Arrears	-	10,41,112
Medical Reimbursement	41,73,312	48,06,274
Leave/Home Travel Concession	4,69,395	11,51,263
Leave Salary Encashment - LTC	99,015	7,43,646
Gratuity	-	19,09,739
Leave Salary on Retirement/Resignation	-	7,06,775
Contributions towards :		
Retirement Fund	95,57,497	30,31,938
Provident Fund	19,84,842	19,53,938
Pension Fund	1,11,60,833	61,87,631
N P S Contribution	9,03,132	2,97,215
SBI Life Insurance - Annual premia	1,38,796	1,43,610
Deficit in Pension Fund	95,22,589	66,51,385
TOTAL	16,13,64,176	14,19,41,424

PARTICULARS	As on 31.03.2012 Rs.	As on 31.03.2011 Rs.
SCHEDULE - 16 **Working Expenses**		
Travelling Expenses	33,65,984	16,74,635
Wages	2,89,810	3,74,483
Honoraria and Professional Fees	13,75,300	9,84,000
Printing, Stationery (Schedule - 17)	11,24,880	9,72,249
Telephone and Communication Charges	23,36,938	29,61,823
Electricity Charges (including maintenance of generators)	79,72,654	75,86,121
Water Charges	3,78,631	5,68,136
Advertisement	26,108	16,952
Vehicle Maintenance/Transport	13,96,729	15,89,835
Liveries and Uniforms	99,820	2,55,687
Postage and Courier Services	2,91,932	2,43,804
Seminars/Conferences/Colloquia, Summer School Programme etc.,	18,68,649	34,41,678
Bank Charges	5,492	11,202
Amenities	9,66,518	11,37,955
Creche	2,20,000	2,44,753
Entertainment and Hospitality	2,45,158	2,37,912
Audit fee	53,981	38,605
Repairs and Maintenance	69,79,865	56,69,094
Campus Maintenance	49,77,076	33,00,878
Payroll processing charges	7,00,295	6,44,500
Security	53,60,559	41,81,127
Stores and Consumables (Schedule - 17)	2,74,89,670	2,04,02,076
Project Working Expenses	1,32,90,300	89,38,720
Subscriptions to Journals & Publications	1,11,84,869	1,10,10,978
Ph.D. Programme	23,34,271	18,71,307
Lease Rent of Land	2,15,004	2,24,934
Corporation Taxes	3,04,257	2,87,661
Freight, etc.	1,52,866	1,07,212
Conveyance	3,34,132	3,37,796
Visiting Students Programme	57,89,001	53,68,473
Inter Institutional Collaboration & Visiting Scientists' expenses	14,66,611	8,17,369
Outreach	2,78,751	4,43,186
Patent Fees	21,98,161	6,62,379
Miscellaneous Expenses	6,00,633	5,25,843
Affiliation Fee for Universities	2,00,000	2,00,000
Pancharatnam Fellowship	4,90,174	-
TOTAL	10,63,65,079	8,73,33,363

SCHEDULE - 17

Stores / Consumables & Stationery items

SL. NO.	DESCRIPTION	OPENING STOCK AS ON 1.4.2011	PURCHASE DURING THE YEAR	LESS:CLOSING STOCK AS ON 31.3.2012	CONSUMPTION DURING THE YEAR
		Rs.	Rs.	Rs.	Rs.
1	Stores and Consumables	7,66,845	2,75,22,854	8,00,029	2,74,89,670
2	Printing & Stationery	3,73,819	10,97,333	3,46,272	11,24,880
	TOTAL	11,40,664	2,86,20,187	11,46,301	2,86,14,550

PARTICULARS	2011-2012 Rs.	2010-2011 Rs.
SCHEDULE - A		
Opening Balance		
Cash at Banks -		
State Bank of India	2,01,50,899	24,75,733
State Bank of Mysore	52,90,099	1,69,86,332
Canara Bank	2,06,099	4,96,339
Central Bank of India	15,745	15,250
Union Bank of India	5,37,253	9,097
Stamps on hand	13,906	13,264
TOTAL	2,62,14,001	1,99,96,015
SCHEDULE - B		
Grants-in-aid		
a) Ministry of Science & Technology (Department of Science & Technology)		
1. Non-Plan Recurring	1,42,00,000	1,80,00,000
2. Plan Recurring	24,08,01,830	26,70,04,951
3. Plan Non-Recurring	14,89,98,170	7,49,95,049
4. PAC/National Meetings SJF	13,00,000	1,00,000
5. India Australia S & T Co-Operation	-	3,00,000
6. Ramanujan Fellowship	-	14,60,000
7. DBT - Biomechanics of synaptogensis	-	8,27,000
8. Enabling New Sciences- MWA	17,80,000	-
b) ISRO - SSO Project	-	1,42,00,000
c) INSA - Fellowship	4,36,533	5,31,128
d) CSIR - Extra Murual Research project	7,65,000	5,85,000
e) Summer programme NISER	-	40,000
f) D A E Homi Bhaba Chair	-	15,58,830
TOTAL	40,82,81,533	37,96,01,958

PARTICULARS	2011-2012 Rs.	2010-2011 Rs.

SCHEDULE - C
Advance to suppliers - Credits/Adjustments

Plan - Non - Recurring	9,99,57,268	-
TOTAL	9,99,57,268	

SCHEDULE - D
Miscellaneous Receipts

Grant-in-aid from Raman Research Institute Trust	1,00,000	1,00,000
License fee from staff quarters	3,74,893	4,42,307
Interest on Letters of Credit Margins	40,49,914	7,15,781
Interest on Short term Deposits & SB Accounts	41,27,832	55,88,192
Other Receipts	10,52,779	12,00,157
Sale of unserviceable items	13,13,650	3,14,440
Recoveries/Adjustments of Advance		
Conveyance Advance	2,66,170	2,12,690
House Building Advance	4,39,228	4,78,922
Festival Advance	1,97,100	1,92,900
Computer Advance	81,848	62,038
TOTAL	1,20,03,414	93,07,427

SCHEDULE - E
Deposits and other items

Recoveries from Staff towards:		
Provident Fund-Subscriptions & loan repayments	1,34,46,386	1,25,40,940
Profession Tax	5,11,100	5,16,700
LIC - Salary Savings Scheme	23,74,157	22,82,286
Group Insurance Scheme (LIC)	13,55,876	8,70,190
Income Tax deducted at Source	85,08,674	67,51,748
Housing and other loans	5,14,824	10,82,952
Caution Deposits for Hostel	30,000	15,000
Staff/Miscellaneous Advances & Deposits (Net)		2,03,672
Sundry Creditors	8,16,673	
Recoveries from Contractors towards:		
Income Tax Deducted at Source	7,74,274	8,92,641
Earnest Money Deposits	7,61,505	12,10,000
Security deposits	3,38,262	3,86,853
Others (amounts received for meetings etc.,)		
Programme on Random Matrix Theory	25,00,000	-
TIFR - Bombay	40,00,000	-
TOTAL	3,59,31,731	2,67,52,982

PARTICULARS	2011-2012 Non-Plan Rs.	Plan Rs.	Total Rs.	2010-2011 Rs.
SCHEDULE - F				
Recurring Expenditure (Non-Plan and Plan)				
Pay	90,64,843	5,02,81,164	5,93,46,007	5,83,90,511
Allowances	1,38,45,988	5,01,62,770	6,40,08,758	5,49,26,387
6th Pay Commission Arrears	-	-	-	10,41,112
Medical Reimbursement	8,77,023	33,62,759	42,39,782	46,36,866
Leave/Home Travel Concession	26,176	4,41,709	4,67,885	11,66,363
Leave Salary Encashment - LTC tour	10,922	88,093	99,015	7,43,646
Gratuity	-	-	-	19,09,739
Leave Salary on Retirement/Resignation	-	-	-	7,06,775
SBI Life Insurance - Annual premia	-	1,38,796	1,38,796	1,43,610
Contribution towards:				
Provident Fund	10,182	19,74,660	19,84,842	19,53,938
Pension Fund	10,30,255	1,01,30,578	1,11,60,833	61,87,631
N P S Contribution	79,701	8,23,431	9,03,132	2,97,215
Retirement Fund	-	95,57,497	95,57,497	30,31,938
Deficit in Pension Fund	-	95,22,589	95,22,589	75,17,793
	2,49,45,090	13,64,84,046	16,14,29,136	14,26,53,524
Travelling Expenses	64,608	16,76,170	17,40,778	26,94,582
Wages	1,21,360	1,68,450	2,89,810	3,74,483
Honoraria & Profession fees	-	13,75,300	13,75,300	9,84,000
Printing Stationery & binding of Scientific journals	81,404	10,15,929	10,97,333	10,44,847
Telephone and Communication charges	-	23,36,938	23,36,938	29,61,823
Electricity Charges *(incl.Rs.2,28,074/- being outlay on maintenance of generators)*	-	79,72,654	79,72,654	75,86,121
Water Charges	-	3,78,631	3,78,631	5,68,136
Advertisement	-	26,108	26,108	16,952
Vehicle Maintenance/Transport	-	13,96,729	13,96,729	15,89,835
Liveries & Uniforms	-	99,820	99,820	2,55,687
Postage & Courier Services	-	2,91,932	2,91,932	2,43,804
Seminars, Conferences, Colloquia, etc.,	-	18,68,649	18,68,649	34,41,678
Bank Charges	5,492		5,492	11,203
Amenities	-	9,66,518	9,66,518	11,37,955
Creche expenses	-	2,20,000	2,20,000	2,44,753
Entertainment and Hospitality	-	2,45,158	2,45,158	2,37,912
Audit Fee	53,981		53,981	38,605
Repairs & Maintenance (incl. Maintenance of Computers)	-	69,79,865	69,79,865	56,69,094
Campus Maintenance	-	49,77,076	49,77,076	33,00,878
Payroll processing charges	-	7,00,295	7,00,295	6,44,500
Carried forward	2,52,71,935	16,91,80,268	19,44,52,203	17,57,00,372

PARTICULARS	2011-2012			2010-2011
	Non-Plan Rs.	Plan Rs.	Total Rs.	Rs.
Brought forward	2,52,71,935	16,91,80,268	19,44,52,203	17,57,00,372
Security	-	53,60,559	53,60,559	41,81,127
Stores & Consumables	-	2,75,22,854	2,75,22,854	2,05,48,583
Project Working Expenses	-	1,32,90,300	1,32,90,300	89,38,720
Subscription to Scientific Journals & other Publications	58,513	1,11,26,356	1,11,84,869	1,10,10,978
Ph.D. Programme	-	23,34,271	23,34,271	18,71,307
Pancharatnam Fellowship	-	4,90,174	4,90,174	
Lease Rent of Land	-	2,15,004	2,15,004	2,24,934
Corporation Taxes	-	3,04,257	3,04,257	2,87,661
Freight, etc.,	-	1,52,866	1,52,866	1,07,212
Conveyance	-	3,34,132	3,34,132	3,37,796
Inter Institutional Collaboration & Visiting Scientists' expenses and Visiting Students programme	-	72,55,612	72,55,612	61,85,842
Outreach		2,78,751	2,78,751	4,43,186
Patent Fees		21,98,161	21,98,161	6,62,379
Miscellaneous Expenses	42,368	5,58,265	6,00,633	5,25,843
Affiliation Fee for Universities		2,00,000	2,00,000	2,00,000
Advances to Staff (HBA, Vehicle, Festival & Computer advances)	8,30,305	-	8,30,305	6,28,812
TOTAL	2,62,03,121	24,08,01,830	26,70,04,951	23,18,54,752

PARTICULARS	2011-2012 Rs.	2010-2011 Rs.
SCHEDULE - G **Plan Non-Recurring Expenditure**		
Capital Equipment	15,94,96,478	5,83,90,437
Buildings, Works and Services	82,09,664	1,13,76,148
Canteen Infrastructure	-	42,76,021
Books	13,49,438	12,57,932
Furniture & Fixture	8,78,956	6,71,200
TOTAL	16,99,34,536	7,59,71,738
SCHEDULE - H **Expenditure out of Grants/Assistance from other Government Agencies**		
a) Ministry of Science & Technology -		
1) PAC/National Meetings /SJF Meetings	14,73,670	5,51,152
2) Indo-Ukraine/Indo-Russian project	-	4,59,200
3) Joint Programme of India Australia S & T Co-Operation	1,53,987	4,72,822
4) Ramanujam Fellowship	11,04,111	8,26,975
5) DBT - Biomechanics of synaptogensis	5,57,219	2,58,812
6) Swarna Jayanthi Fellowship	5,76,999	3,34,005
b) ISRO - SSO Project	66,11,268	7,97,725
c) Summer Project NISER	-	40,000
d) British Council Division	52,114	44,920
e) INSA - Fellowship	2,88,671	5,84,397
f) CSIR - Extra Murual Research project	15,30,000	-
g) D A E Homi Bhaba Chair	87,707	4,62,760
TOTAL	1,24,35,746	48,32,768
SCHEDULE - I **Advance to Suppliers (Net)**		
Plan -Non-Recurring	-	3,40,05,317
TOTAL	-	3,40,05,317

PARTICULARS	2011-2012 Rs.	2010-2011 Rs.
SCHEDULE - J		
Deposits & Other Remittances		
Remittances of recoveries from staff:		
Provident Fund Subscriptions and Loans	1,34,46,386	1,25,40,940
Professional Tax	5,11,100	5,16,700
LIC - Salary Savings Scheme	23,74,157	22,82,286
Group Insurance Scheme	13,56,376	8,69,090
Income Tax Deducted at Source	85,08,674	67,51,748
Housing and other loans	5,14,824	10,82,952
Caution Deposits for Hostel	16,000	18,000
Indian Academy of Sciences	-	9,43,985
Service benefits received from other Institutions & other liabilities	41,591	6,59,523
Sundry Creditors	-	463
Staff/Miscellaneous Advances & Deposits (Net)	2,71,750	-
Remittances/Refunds of recoveries from Contractors:		
Income Tax deducted at Source	7,99,853	7,92,446
Earnest Money Deposits	14,90,000	2,60,969
Security Deposits	8,14,152	6,86,199
Others (amounts received for meetings etc.,)		
Programme on Random Matrix Theory	25,00,000	-
TIFR - Bombay	34,95,527	-
TOTAL	3,61,40,390	2,74,05,301
SCHEDULE - K		
Closing Balance		
Cash at Bank:		
State Bank of India	1,45,72,514	2,01,50,899
State Bank of Mysore	21,88,817	52,90,099
Canara Bank	2,14,163	2,06,099
Union Bank of India	60,174	5,37,253
Central Bank of India	16,347	15,745
Stamps on hand	26,774	13,906
TOTAL	1,70,78,789	2,62,14,001

As per our Report of even date,
B. R. V. GOUD & CO.,
Chartered Accountants
FRN 000992S

B.R.V. GOUD & Co. Chartered Accountants Bangalore-1

K. KRISHNAMA RAJU
Administrative Officer

RAVI SUBRAHMANYAN
Director

A. B. SHIVA SUBRAMANYAM
Partner
M.No. 201108

Place : Bangalore
Date : Sept. 12, 2012

RAMAN RESEARCH INSTITUTE
BANGALORE

SCHEDULE: - 18

SIGNIFICANT ACCOUNTING POLICIES AND NOTES ON ACCOUNTS FOR THE YEAR ENDED 31.03.2012

A. SIGNIFICANT ACCOUNTING POLICIES:

1. ACCOUNTING CONVENTION:

The Financial Statements are prepared on the basis of Historical costs and on Cash basis of accounting. The guidelines given by the Government of India for drawing Financial Statements for central autonomous bodies have been adopted to the extent that they are directly applicable.

2. FIXED ASSETS:

Fixed assets are stated at cost of acquisition less depreciation.

3. DEPRECIATION:

Depreciation is provided on a **Straight Line Method** as per the rates laid down by Schedule XIV of the Companies Act, 1956. The amount of depreciation has been debited to the capital fund and not to the Income & Expenditure Account, since the amount spent on non recurring expenditure out of the grant received every year from DST has been credited to the capital fund, as stated in Accounting policy No.5 'Government Grants'

4. INVENTORY:

Stocks on hand such as spares, materials, consumables are valued at cost.

5. GOVERNMENT GRANTS:

Government grants received from DST are accounted on realization basis and the same have been separately shown under Plan and Non-Plan in the Annual accounts of the Institute. Out of the total Plan grant amount received, an amount equal to the amount of non recurring expenditure incurred during the year has been directly credited to the Capital Fund A/c, the balance of Plan grants is reckoned as Income and shown in Income & Expenditure Account.

6. INVESTMENTS

Investments which relate to Pension fund and Provident fund are 'Long Term Investments' and the same are stated at cost.

6. FOREIGN CURRENCY TRANSACTIONS:

Transactions denominated in foreign currency are accounted at the transacted exchange rates.

7. RETIREMENT BENEFITS:

Institute's Contribution to Provident Fund and Pension Fund are charged to Income and Expenditure Account of the Institute. Apart from this, any deficit in the Provident Fund and Pension Fund amount is being borne and provided for in the accounts of the Institute.

B.NOTES ON ACCOUNTS

a). CURRENT ASSETS, ADVANCES AND DEPOSITS:

In the opinion of the Management, the Current Assets, Advances and Deposits have a value on realization in the ordinary course of activities, equal at least to the aggregate amount shown in the Balance Sheet.

b) EMPLOYEES RETIREMENT BENEFITS:

Institute's Contribution for the years payable to Provident Funds (CPF & GPF) are charged to the Income and Expenditure Account of the Institute

I. As prescribed by the Govt. of India, the Institute has subscribed to Insurance Policies with the SBI Life Insurance, for quantifiable liabilities of service benefits viz., Gratuity, Leave Encashment.

II. The Institute has also taken a similar policy for commutable portion of the Pension with SBI Life Insurance.

III. The Institute has paid as an interim on an account contribution in case of those who are going to retire from the Institute after 2019-20.The Institute had subscribed to these policies initially based on emoluments that were applicable as per V CPC. On implementation of VI CPC scales of pay, the accumulated liabilities were revised for all those who are going to retire during this decade. For those who are going to retire later, Rs.50.00 lakhs each was made only as an ad hoc on an account contribution. This was resorted to as quantifying their retirement benefits that would be obtaining i.e., beyond 2019-20 is not possible at this point of time.

IV. The amounts standing to the credit of three policies are held by the Institute in a fiduciary capacity on behalf of the employees and hence the balance in these funds is disclosed as contra items. The interest earned on these funds is ploughed back to the funds and the claims are met out of these funds.

V. In pursuance of the directions of the Council, the amount representing the Institute's contribution to the Contributory Provident Fund in respect of eligible members of staff to be covered by GPF on their exercising due option is

continued to be transferred to GPF (Pension) corpus, the income on which is applied to meet part of the Pension liability, and only the deficit is met out of grant - in - aid.

C. ADVANCE FOR PURCAHSE OF LAND:

The Institute has paid Rs.8,89,61,800/- to M/s. H M T Ltd., being the full value for the land vide agreement dated 13th March 2009. An amount of Rs.1,00,00,000/- has been earmarked for registration, which is awaited for a No objection from the Government of India. As per the Memorandum of Understanding with the Indian Academy of Sciences a portion of this land is earmarked for the Academy. The Academy has remitted to the Institute an amount of Rs.1,00,00,000/- as an on account remittance which is reflected under Schedule 5 : Sundry Creditors.

D. CUSTOMS DUTY REFUND:

The Customs Department has levied Rs.27,91,120/- towards additional Customs Duty which the Institute was not liable to pay on certain imported equipments/apparatus. A refund claim has been made since the Institute is exempt from payment of this additional duty. Pending receipt of the refund, the same has been shown as refundable amount from customs department.

E. Figures pertaining to the previous year have been regrouped / reclassified to suit the current years classification.

F. Figures have been rounded off to the nearest rupee.

Vide our report of even date,
for B. R. V. GOUD & CO.,
Chartered Accountants
FRN000992S

K. KRISHNAMA RAJU	**RAVI SUBRAHMANYAN**	**A. B. SHIVA SUBRAMANYAM**
Administrative Officer	Director	Partner
		M.No. 201108

Place : Bangalore
Date : 12th Sept. 2012