RAMAN RESEARCH INSTITUTE

ANNUAL REPORT
2012 - 2013

BANGALORE

Raman Research Institute, 2012
Annual Report : 2012 – 2013
Bangalore, RRI

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Raman Research Institute
Bangalore

Sir C V Raman

(Portrait by Homi Jehangir Bhabha)

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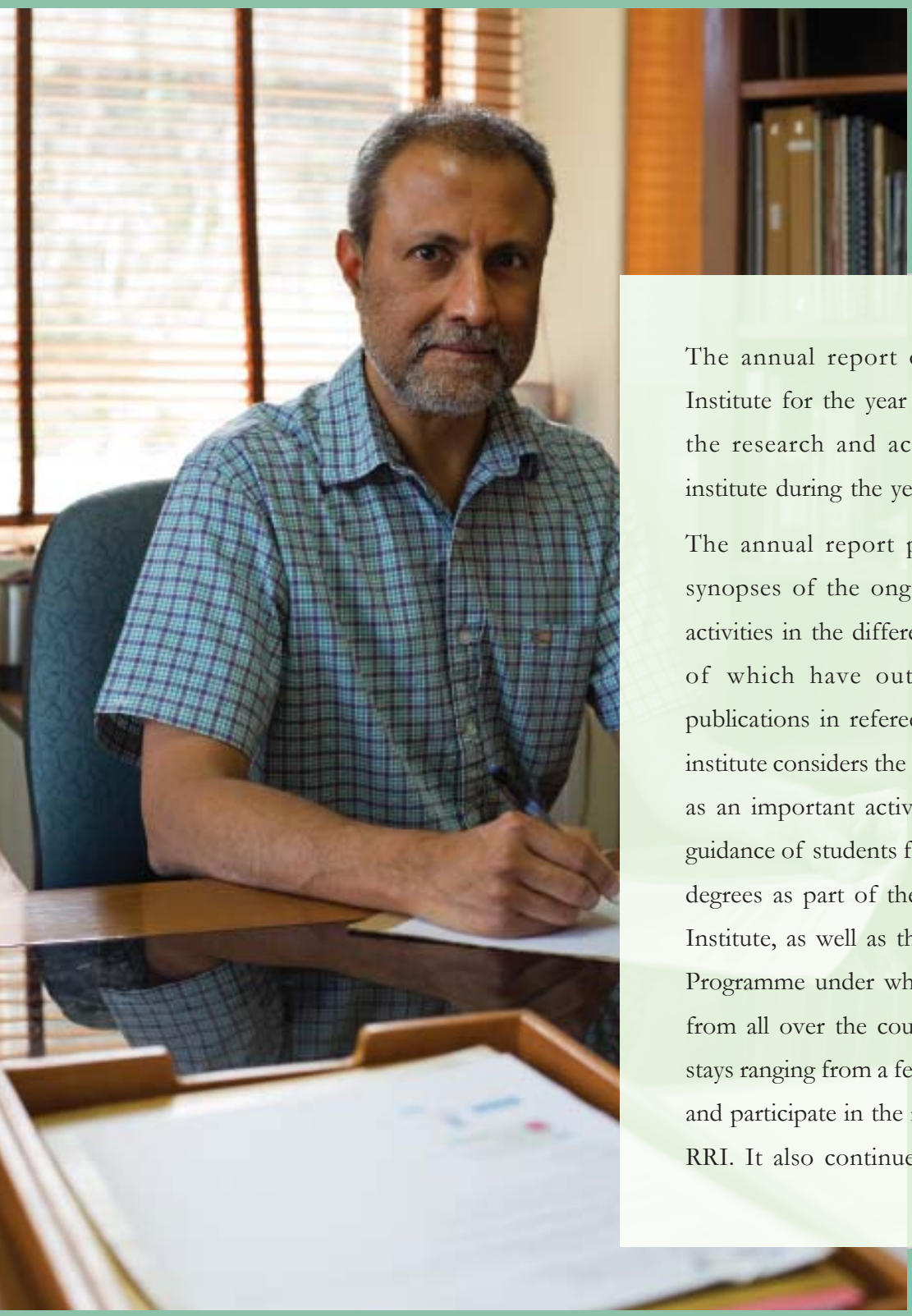


The annual report of the Raman Research Institute for the year 2012-13 is a summary of the research and academic activities of the institute during the year.

The annual report presents, as in the past, 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 as 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 where

From the Director

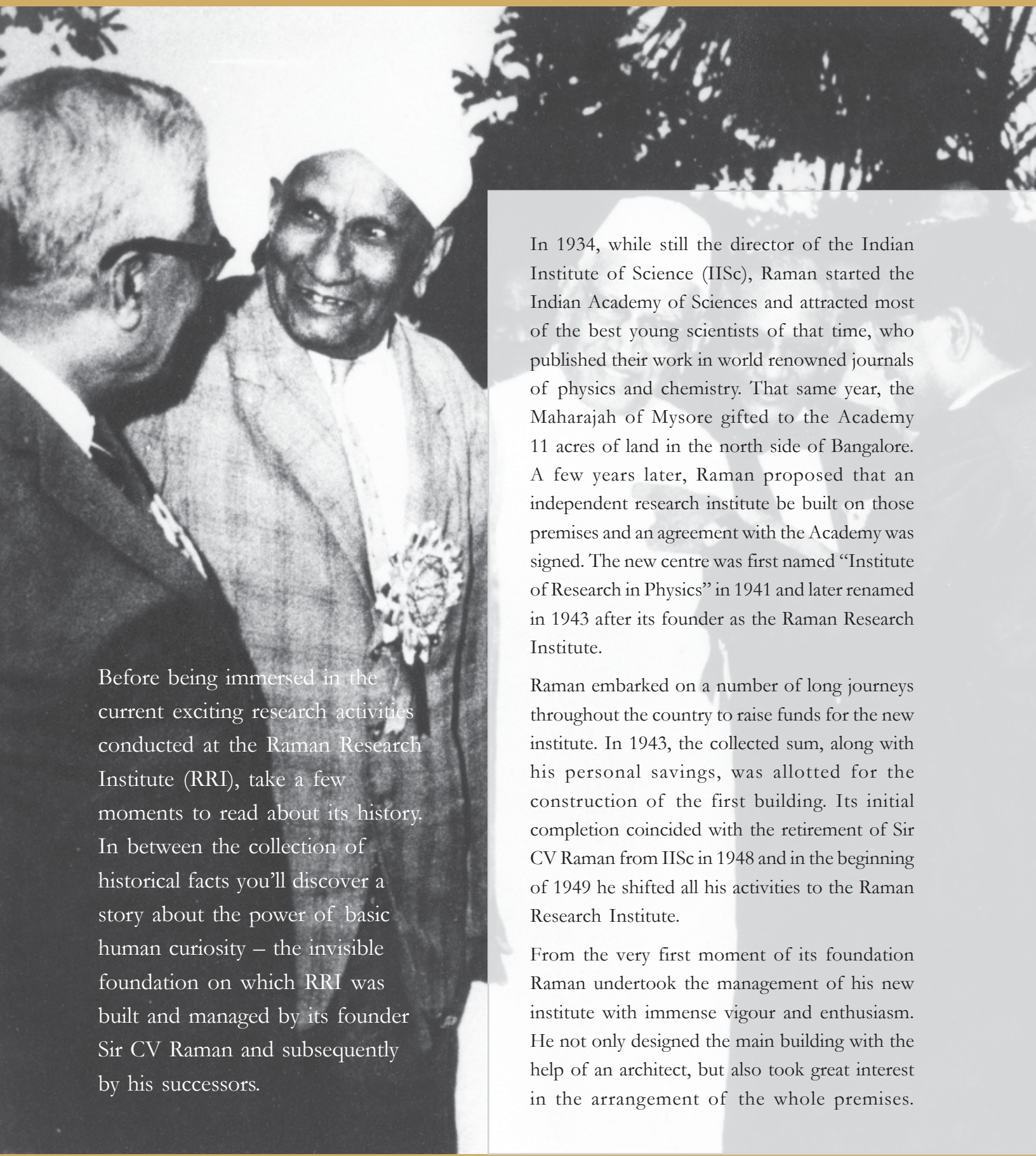
students and young scientists from across the country participated.

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 the 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 monographs, books and popular periodicals, PhD degrees awarded during the period 01 April 2012 to 31 March 2013 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, 2013



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 first named "Institute of Research in Physics" in 1941 and later renamed in 1943 after its founder as the 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 to the Raman Research Institute.

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.

History

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 movement 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

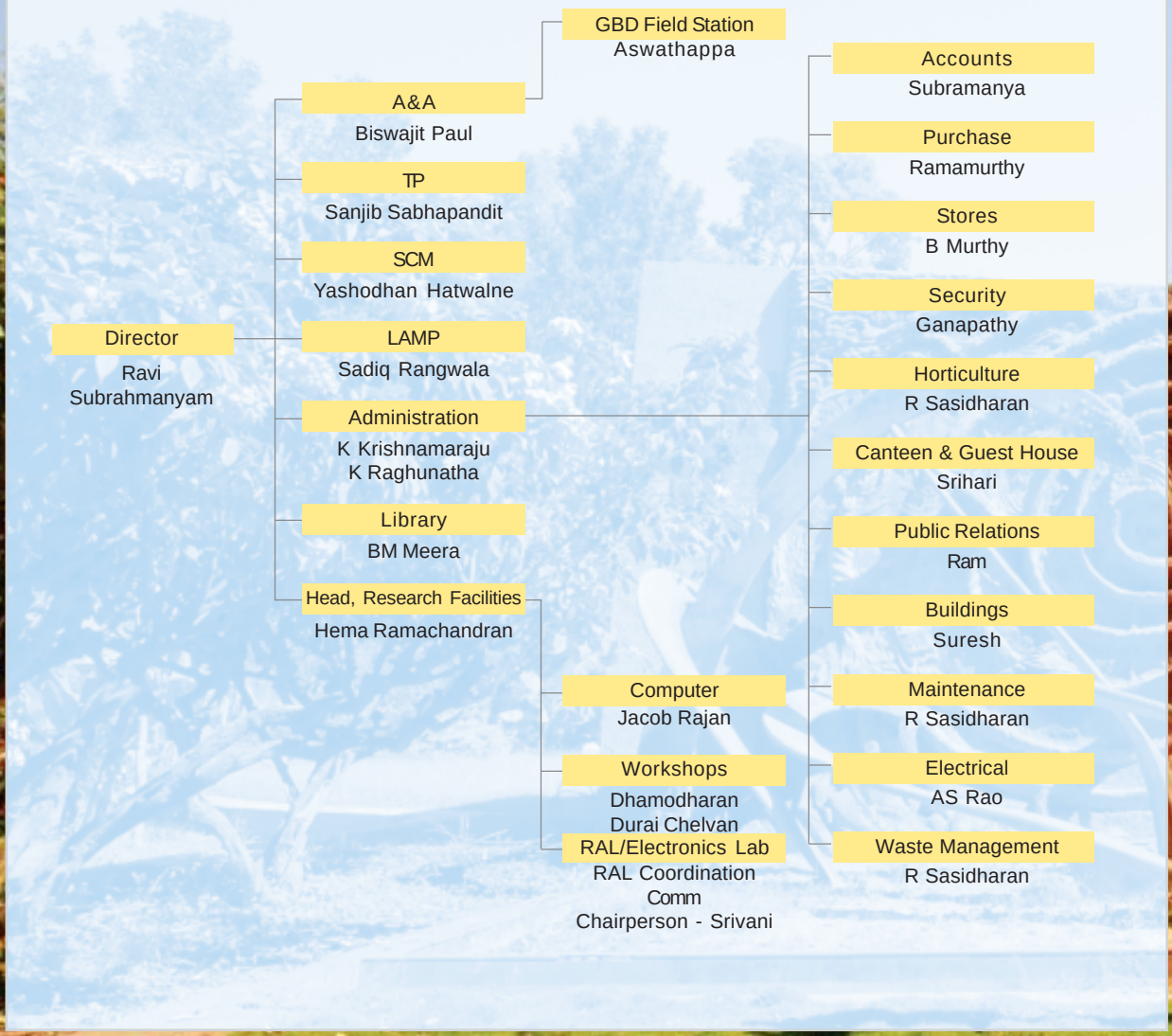
Funding

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

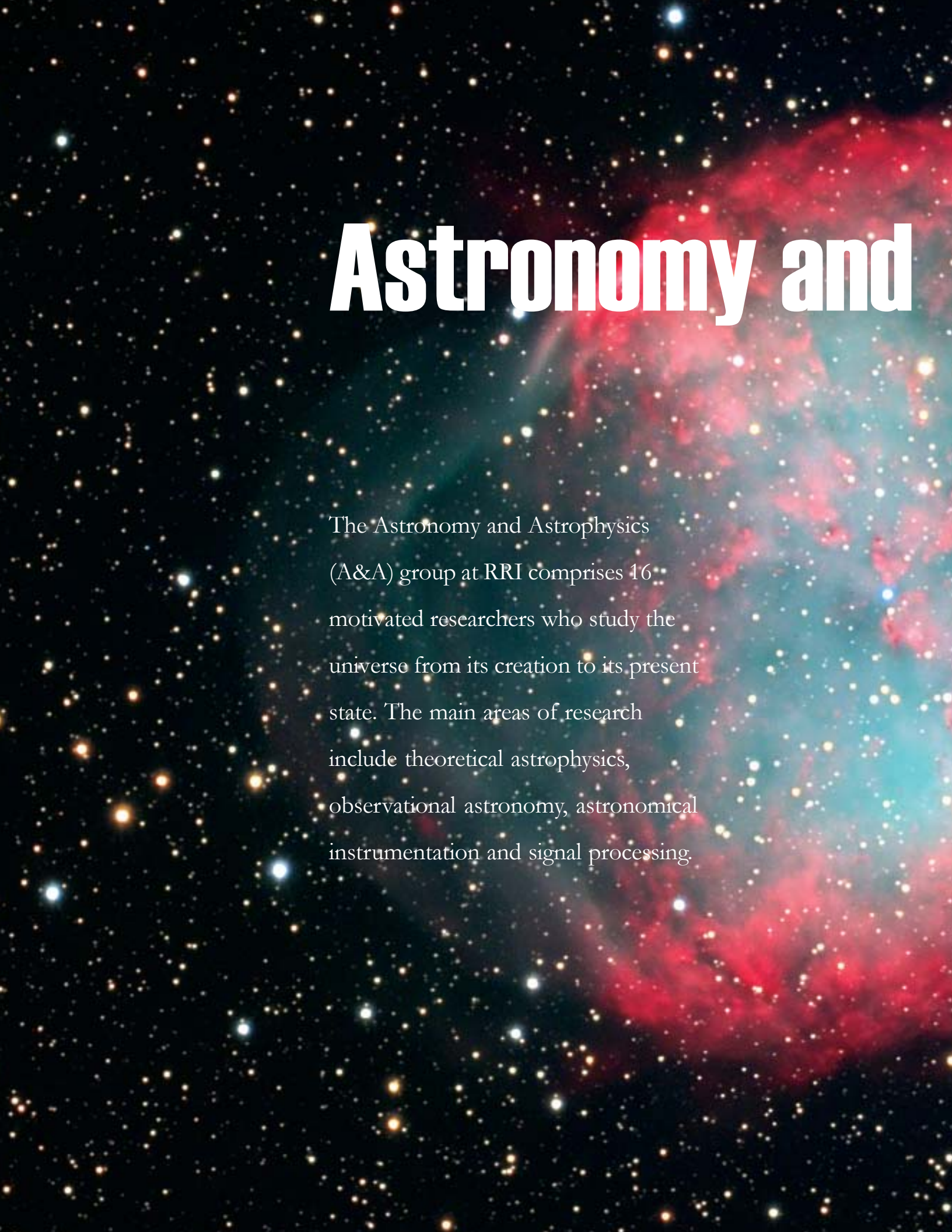
Faculty, Staff & Students

Research Faculty	48
Scientific/Technical	46
Administrative	27
PhD Students	64

Organisation



Journal Club	Arnab Pal, Suman G Das
Colloquia	Joseph Samuel, Pramod Pullarkat, Sadiq Rangwala
Hostel Warden	Reji Philip, Arun Roy, Srihari
Admissions Coordinator	Arun Roy
SAAC	Madan Rao
In-House Meeting	PhD students
JAP Rep of RRI	Shiv Sethi
Complaints Committee	Srivani (Chairperson), Vrinda, K Raghunatha, Madan Rao
Chairpersons of PhD Interview Committees	Biswajit Paul, Ranjini Bandypadhyay
Overseas Travel Committee	Udaya Shankar (Chairman), Lakshminarayanan, Madan Rao
Evaluation Committee	Lakshminarayanan (Chairman), Joseph Samuel, Biman Nath, V A Raghunathan, Sadiq Rangwala
Senior Management Team	Ravi Subrahmanyan (Chairman), Ruckmongathan, Udayashankar, Joseph Samuel, Lakshminarayanan, K Krishnamaraju, K. Raghunatha
Coordinator of Visiting Students Programme	Arun Roy



Astronomy and

The Astronomy and Astrophysics (A&A) group at RRI comprises 16 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.

Astrophysics

Overview

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.

Galaxies and surroundings: Galaxies do not evolve in isolation, and the interaction between galaxies and their surroundings play an important role in the evolution of galaxies, as well as the evolution of the intergalactic medium. RRI researchers use analytic methods and hydrodynamic simulations to study various aspects of these interactions. In particular, they have been studying the various mechanisms responsible for violent gaseous outflows from galaxies, and the effect of these outflows in the hot gas in galaxy clusters.

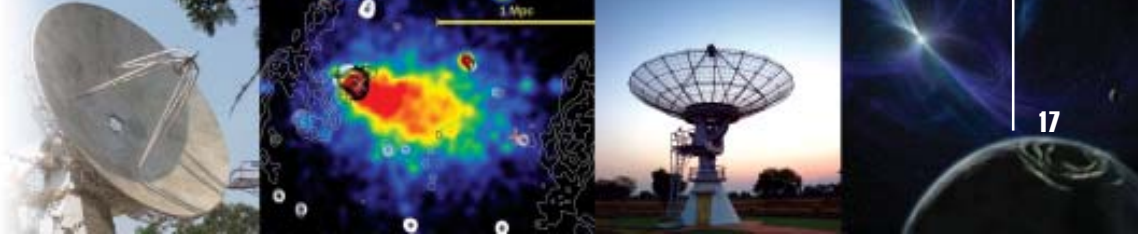
Magnetohydrodynamic (MHD) Turbulence: Turbulence in electrically conducting fluids is a rarely observed phenomenon here on Earth. However, in galaxies, clusters of galaxies and the interstellar medium, where matter is ionised, it is a widespread phenomenon. Researchers at RRI are actively working towards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

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 areas of research interest include neutron stars, pulsars andtransients, the galaxy and interstellar medium, instrumentation and signal processing.

During the past academic year, Deshpande continued his study into OH Maser sources in W49N, which included probing spatial scales associated with variations in scattering and magnetic fields.The sight-lines to the 200 or so sources spread across the W49N region potentially sample variations on a range of transverse scales within the region, as well as the intervening scattering medium. The estimated parameters for this set of scatter-broadened maser sources, observed with the VLBA, provide an excellent opportunity for probing the spatial scales associated with the variation in these parameters.

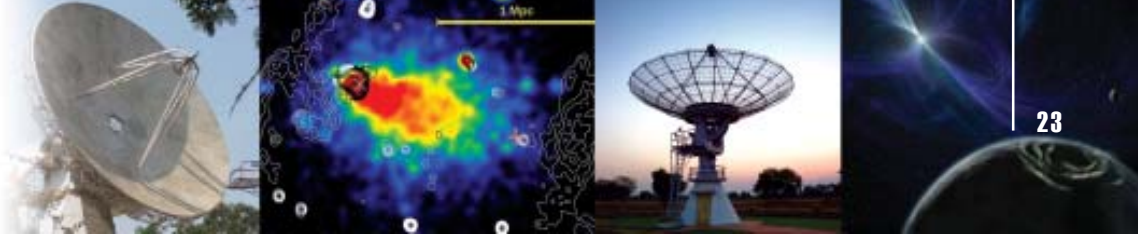
The structure function of the (line-of-sight) velocity associated with the sources reveals a trend consistent with the underlying velocity gradient across the region, manifesting the possible bipolar outflow morphology. The structure functions for the scatter-broadened size of the sources, as well as those for the source position angle and aspect ratio, suggest significant variations in the scattering property of the ISM on an angular scale of about 200-300 mas (or a spatial scale of 1000-15000 AU). The spatial structure function computed for the magnetic field using estimates available for a few dozen Zeeman pairs shows no significant monotonic trend. Although structure function is relatively poorly sampled, the scale on which the magnetic field appears to be decorrelated is about 150 mas

(or 1500 AU spatial scale at the source distance of 11.4 kpc). This study was done 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.

Recent studies of the drifting-subpulse phenomenon in radio pulsars suggest that the emission region may be organised as a system of emission columns seeded by a rotating spark pattern in the acceleration zone (Ruderman & Sutherland, 1975). In collaboration with Yogesh Maan, Deshpande conducted sub-pulse fluctuation studies of one of the bright pulsars B1237+25(with a multi-component profile), to establish its sub-beam circulation period and to look for any correlation between its various conal emission rings using existing observational data (courtesy Joanna Rankin of the University of Vermont). The analysis indicated that conal emission at different radii has significant correlation, implying a common underlying pattern may be responsible for emission associated with different conal rings. Further studies are underway, based on certain characteristics of the modulation in this pulsar being inconsistent with those expected from the rotating spark model.

Deshpande, in collaboration with Sneha Honnappa, W Lewandowski and J Kijak from the Kepler Institute of Astronomy, Poland, as well as A. Jessner from the Max-Planck-Institut fur Radioastronomie, Germany, conducted single pulse analysis from radio pulsars at high observing frequencies. A successful attempt was made to analyse about 40,000 individual pulses from seven of the strongest pulsars. The observations were conducted from 100-metre Effelsberg radio–telescope. High resolution (100 micro-seconds) data was taken at frequency of 2.63 GHz for one of the pulsars, while the rest were observed with low-time resolution at a high frequency of 8.35 GHz. In order to examine the pulse-to-pulse intensity and phase modulations, both the longitude-resolved and the harmonic-resolved fluctuation spectral analysis were performed. The modulation features associated with the subpulse drifting in several of the pulsars were identified and found to be consistent with the results of drifting studies at low-observing frequencies. Drift related features were only detected over certain time intervals of observation, during which the behaviour confirms the Ruderman & Sutherland model. The non-detection of the drift-related features in the remaining time intervals might be due to possible changes in some of the physical parameters (such as the number of evenly spaced subbeams), in which case the detection of the drift-related spectral features would indeed be difficult or even impossible.

Mutually uncorrelated random discrete events, manifesting a common basic process, are examined often in terms of their occurrence rate as a function of one or more of their distinguishing attributes, such as measurements of photon spectrum as a function of energy. Such rate distributions obtained from the observed attribute values for an ensemble of events will correspond to the "true" distribution only if the event occurrences were mutually exclusive. However, due to finite resolution in such measurements, the problem of event pile-up is not only unavoidable, but also increases with



event rate. Although extensive simulations to estimate the distortion due to pile-up in the observed rate distribution, as well as modelling incorporating computation of pile-up effects, are available, no direct restoration or inversion procedure has yet been suggested. Deshpande, along with Harsha Raichur, presented an elegant analytical solution to recover the underlying true distribution. The method, based on Poisson statistics and Fourier transforms, was shown to perform as desired even when applied to distributions that are significantly distorted by pile-up. This method is expected to find application in fields ranging from high-energy physics to medical clinical diagnostics, as well as in measurements of count-rates and/or spectra of incident radiation using Charge Coupled Devices or similar devices.

Deshpande and Nishant Singh studied binary systems and their implications for outflows and periodicities relevant to masers. As per recent observations of methanol masers, the evolution of symmetric wind in binary systems,with specific attention to the bipolar flows and the variability in the maser intensity, is monitored now through 3D simulation (using PLUTO code). Density maps together with the velocity structure, at different orbital phases and z-planes of the binary, are being obtained and studied further. The key question of the study is whether the velocity structure remains independent of the orbital phase, and only density variation is responsible for the observed variability.

Deshpande and N Kumar reported the results of the numerical simulation of classical-dissipative dynamics of a charged particle subjected to a non-markovian stochastic forcing. It was found that the system developed a steady-state orbital magnetic moment in the presence of a static magnetic field. Very significantly, the sign of the orbital magnetic moment turned out to be paramagnetic based on the choice of parameters, variedover a wide range. This was shown specifically for the case ofclassical dynamics driven by a Kubo-Anderson type non-markovian noise. Natural spatial boundary condition was imposed through (1) a soft (harmonic) confining potential, and (2) a hard potential, approximating a reflecting wall. There was no noticeable qualitative difference. The non-markovian property of the driving noise chosen appeared to be crucial to the noticed orbital magnetic effect. Implications of these results were also looked at.

Linear polarisation, weak but significant, from Supernova Remnant Cassiopeia A at low radio frequencies(319.5 MHz) was detected by Deshpande and Wasim Raja using the Giant Meter-wave Radio Telescope (GMRT). The spectro-polarimetric data was analysed using the new technique of RM-synthesis, first proposed by Burns (1966). The problems of disentangling weak sky polarisation from any remnant instrumental polarisation leakage were addressed. A novel technique using X-ray data to establish association of the apparent polarisation to the source, even in the presence of instrumental

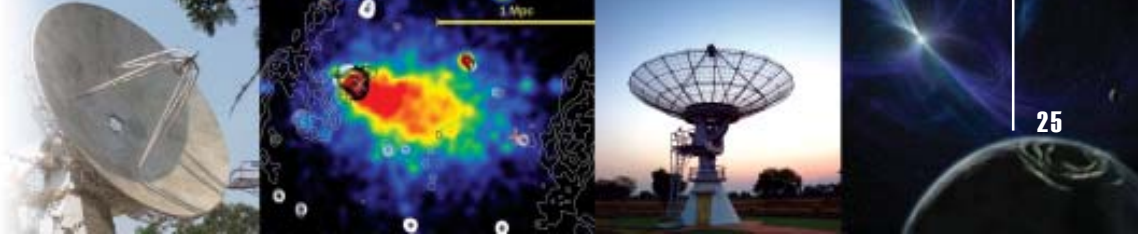
leakage, was demonstrated. Despite the expected severe depolarisation, and any remnant contamination due to polarisation leakage from Stokes I, the analysis of low frequency GMRT data revealed detectable (though weak) polarised emission, with a clear anti-correlation with soft x-ray emission, as would be expected. Given the angular and RM-resolution in the data, the observed amount of depolarisation relative to that at higher frequencies implies that the mixing of thermal and non-thermal plasma within the source might be occurring on spatial scales of the order of 1000 AU, assuming random superposition of polarisation states. Evidence of polarised emission at several other RM-planes is being assessed.

A mode that will allow targeted observations over full 300 MHz bandwidth of MWA, as against the present 30 MHz bandwidth used in its prime imaging mode, was suggested by Deshpande and his collaborators, T Prabu, Srivani, Kamini and Madhavi. This involves phasing of the eight tiles within each of the stations and recording data from 16 such stations in the form of raw complex voltages corresponding to the entire spectral span. The necessary firmware to enable this mode has been developed and is now ready for field tests.

Along with Steve Ord, Ramesh Bhat and Steven Trembly of Curtin University and T Prabu of RRI, observations were made over a limited bandwidth to test the high-time-resolution mode of the MWA.

Yogesh Maan, HA Aswathappa and Deshpande reported their search for and a possible detection of periodic radio pulses at 34.5 MHz from the Fermi Large Area Telescope pulsar J1732-3131. The candidate detection has been possible in only one of the many sessions of observations made with the low-frequency array at Gauribidanur, when the otherwise radio weak pulsar may have apparently brightened many folds. The candidate dispersion measure along the sight line, based on the broad periodic profiles from ~20 min of data, is estimated to be 15.44 +/- 0.32 pc/cc. A few bright single pulses, detected through single-pulse search, were found to occur at the edges of the average profile, coinciding with pulse-phases associated with high-energy emission. These results have interesting implications for both the pulsar and the intervening medium. In the case of J1732, the average profile obtained by connecting data over several epochs showed consistency with that obtained from the bright spell during the detection epoch.

Deshpande's work in radio astronomy during the year included implementation of second phase firmware for FPGA-backend to enable on-line spectral and Stokes parameter computation; the design and testing of a log-periodic array element with significantly reduced boom-length; interesting ways of incorporating RFI rejection ability through antenna responses; exploring unconventional ways of measuring zero-spatial-frequency component of the sky brightness distribution; using a 16-bit digitisation to assess if the increased dynamic range adequately ensures immunity to RFI, in tandem with analogue chains having limited dynamic range. These studies were in collaboration with C Vinutha, R Duraichelvan, P Sandhya, TS Mamatha and Nivedita (VSP).



Biman B Nath's areas of current professional research interests include cosmology and structure formation and extragalactic astronomy. During the year gone by, Nath's research covered supernovae and AGN driven wind; MgII lines in QSO sightlines and signature of outflows; superbubble breakout and galactic winds from spiral galaxies; entropy profile of intracluster gas; and gamma rays from galactic wind and Fermi Bubble.

Nath and his student Mahavir Sharma carried out detailed analytical work on the dynamics of galactic winds driven by supernovae and AGN. Earlier work had confined itself to supersonic winds without any gravity and without any momentum injection from AGN radiation, and which formed the basis of all previous comparisons with observations. The new formalism revealed a more general result, of which the earlier results were shown to be a subset, and which yielded some new results. The most significant result is that the speed of supernovae driven wind cannot exceed 1000 km/s and can be used as a diagnostic of winds driven by supernovae or AGN. This result is supported by recent observations. Also, it was found that winds from quiescent star forming and intermediate mass galaxies such as the Milky Way cannot escape the halo and in these galaxies there would be a large reservoir of gas in the halo, as supported by recent observations. Further, the new formalism, in conjunction with chemical evolution models, can correctly explain the observed ratio of stellar to halo mass ratio for different galaxies.

Using SDSS-DR7 data for QSOs with strong MgII absorption lines a correlation between the velocity offset of these lines and the bolometric luminosity of background quasars has been discovered. Nath, Mahavir Sharma and Hum Chand of ARIES showed that the velocity offset scales with the luminosity in a power-law with a slope of 1/4, which is consistent with radiation driven winds from quasars. The results of their research showed that a significant fraction of strong MgII lines are associated with the quasars themselves and not with the intergalactic medium.

In order to understand the initiation of galactic winds from spiral galaxies, Nath has undertaken a detailed, both analytical and numerical, study of superbubbles triggered by multiple supernovae and how they break out of the spiral galaxy and seed galactic winds. The analytical and numerical work shows that a minimum star formation rate of 0.1 solar mass per year per square kpc is needed to seed a galactic wind, consistent with observational results. It was also found that thermal instability is more important than Rayleigh-Taylor instability in breaking the superbubble shell, as previously thought. This has important implications for the escape of ionising radiation from galaxies and in the reionisation of the universe. This work was done in collaboration with JAP student Arpita Roy and Prateek Sharma of IISc.

Following last year's work on the entropy profile of 30 nearby galaxy clusters (REXCESS sample), work has been extended to the inner radii of the clusters, and the total energy deposited in the intracluster medium (ICM) of these clusters has been calculated. Nath and his collaborators also estimated the radio luminosities of central sources in these clusters and compared with the total energy deposited. It was found that radio galaxies can account for up to a third of the total energy deposited. Further, it was found that significant differences exist in the energy deposition profiles in non-cool core and cool core clusters, and a better diagnostic for cool core clusters, not in terms of density profile, as it is usually done, but in terms of the entropy profile was discovered. This work was done in collaboration with Chaudhuri and S Majumdar of TIFR.

Recent observations show a gamma ray feature near 130 GeV from the Galactic centre region. Most of the interpretations so far has focused on the line arising from dark matter annihilation. Nath, along with N Gupta (RRI), P Biermann (MPIfR), Eun Suk-Seo (University of Maryland), Todor Stanev (University of Delaware) and Julia Becker Tjus (Ruhr University, Germany) studied the possibility that this feature may arise from Galactic cosmic rays. They argued that the cosmic ray electrons steepen near 1 TeV, and the observed feature at 130 GeV would then arise from inverse Compton scattering of interstellar photons at infrared by Galactic cosmic rays near 1 Tev.

Biswajit Paul's areas of current research interests include X-ray binaries, transients and X-ray instrumentation. His research activities during the year cover developmental work for an X-ray polarimeter and ASTROSAT and investigation of various aspects of compact X-ray sources.

Under developmental work, he is involved in the development of 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. Specific developments during the year were:

- Fabrication of an engineering model of the X-ray polarimeter is almost completed. Two

detector units have been fabricated, wired, assembled, and tested successfully. Fabrication has been completed for two more detectors.

- A major work that has been accomplished is the development of a collimator that was designed in-house and fabricated by CNC machining and wire cutting. It has tapered slots leading to a flat topped response that can neutralise any small pointing offset of the satellite.
- Development of the event processing electronics is nearly completed and detailed tests have been carried out successfully. Significant developments and tests have been carried out on the common electronics unit.
- Significant development work has been carried out on the housekeeping electronics of the X-ray polarimeter.
- Space qualified layouts have been created for the front end electronics of the X-ray detectors and same have been tested in the laboratory.

PV Rishin, MR Golapakrishna, R Duraichelvan, CM Ateequlla and many members of RAL and MES have made major contributions to these projects.

Paul has, for some time, worked with two teams at ISAC, Bangalore, and SAC, Ahmedabad, in development of the ASTROSAT-LAXPC data reduction software. In this period, he also served as LAXPC representative in the ASTROSAT Ground Segment Committee that will take care of all ASTROSAT activities other than the hardware development. He has been a member of the ASTROSAT Science Working Group identifying the base line science to be done with this mission in its early days after launch. Paul also developed data reduction packages and carried out analysis of the LAXPC timing data, results from which have necessitated

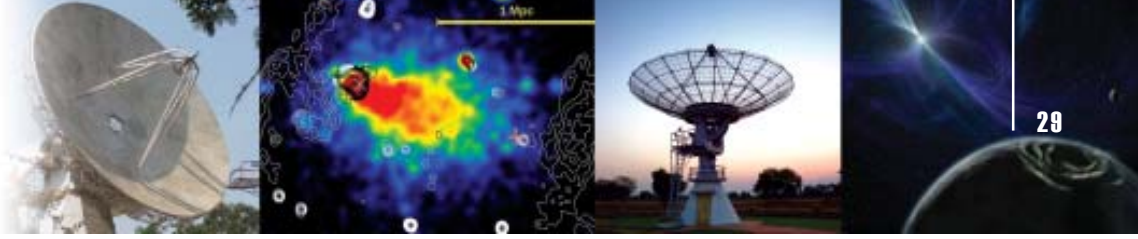
hardware corrections on the processing electronics.

During the year, several significant contributions were made in the studies of X-ray binaries.

Chandreyee Maitra and Paul performed a detailed pulse phase resolved spectral analysis of the cyclotron resonant scattering features (CRSF) of two Be/X-ray pulsars A0535+26XTEJ1946+274 and a wind accreting High Mass X-ray Binary (HMXB) pulsar 4U 1907+09 using Suzaku observations. The CRSF parameters were found to vary strongly over the pulse phase and can be used to map the magnetic field and a possible deviation from the dipole geometry in these sources. It also reflects the conditions at the accretion column and the local environment over the changing viewing angles. The pattern of variation with pulse phase was obtained with more than one continuum spectral models for each source, all of which gave consistent results. Care was also taken to perform the analysis over a stretch of data having constant spectral characteristics and luminosity to ensure that the results reflect the variations due to the changing viewing angle alone. For the two Be/X-ray pulsars, which showed energy dependent dips in their pulse profiles, a partial covering absorber was added in the continuum spectral models to take into account an additional absorption at those phases by the accretion stream/column blocking the line of sight.

Paul, Maitra, Sachin Naik and Gaurava K Jaisawal of PRL studied the broadband timing and spectral properties of a high mass X-ray binary (HMXB) pulsar EXO 2030+375using a Suzaku observation. Pulsations with a period of 41.41s and strong energy-dependent pulse profiles were clearly detected up to 100 keV. Narrow dips were seen in the profiles up to ~70 keV. The presence of prominent dips at several phases in the profiles up to such high energy ranges was not seen before. At higher energies, these dips gradually disappeared and the profile appeared to be single-peaked. The 1.0-200.0 keV broadband spectrum was well described by a partial covering high-energy cut-off power-law model. Several low-energy emission lines were also detected in the pulsar spectrum. They fitted the spectrum using neutral as well as partially ionised absorbers along with the above continuum model yielding similar parameter values. The partial covering with a partially ionised absorber resulted in a marginally better fit. The spectral fitting did not require any cyclotron feature in the best-fit model. To investigate the changes in spectral parameters at dips, the team also carried out pulse-phase-resolved spectroscopy. During the dips, the value of the additional column density was estimated to be high compared to other pulse phases. While using a partially ionised absorber, the value of the ionisation parameter was also higher at the dips. This was interpreted as the reason for the presence of dips up to higher energies. No other spectral parameters showed any systematic variation with pulse phases of the pulsar.

Paul and Naik investigated the variability of iron emission lines in the high mass X-ray binary (HMXB) pulsar Centaurus X-3 during the eclipse, eclipse-egress and out-of-eclipse phases using XMM-Newton observations. Three iron emission lines at 6.4 keV, 6.7 keV, and 6.97 keV were clearly detected in the spectrum of the pulsar



during the entire observations, irrespective of different binary phases. The properties of these emission lines were investigated at different intensity levels. The flux level and equivalent width of the emission lines changed during the three orbital phases. Based on the results obtained from the time resolved spectral analysis, it is understood that the most probable emitting region of 6.4 keV fluorescent line is very close to the neutron star whereas the other two lines are produced in a region that is far from the neutron star, probably in the highly photo-ionised wind of the companion star or in the accretion disk corona.

Maitra, Paul, Pragati Pradhan and Bikash C Paul of the North Bengal University carried out a detailed timing and spectral analysis of a Be/X-ray binary SWJ2000.6+3210 discovered in the BAT Galactic plane survey. Suzaku observations of the source made at six months intervals revealed pulsations at ~890s for both the observations with a much weaker pulse fraction in the second one. Pulsations were clearly seen at energies <1 keV for both observations and at high energies upto 40 keV for the second observation. The broadband X-ray spectrum was consistent with a powerlaw and high energy cutoff model along with a hot blackbody component. No change in spectral parameters was detected between the observations. They also analysed several short observations of the source with Swift/XRT and detected only a few percent variation in flux. The results indicate that the Be/X-ray binary is a member of persistent such Be/X-ray binaries that have the same broad characteristics as this source.

High rates of the orbital period change observed in certain HMXBs suggests that tidal interaction is strongly operative in close HMXBs. Extreme power-law dependence of the rate of tidal evolution on the companion-radius – semi major-axis ratio makes this effect dominant only in systems with very short orbital periods < 10 d. Since most of these systems are nearly circular, tidal interaction proceeds through the spin-orbit synchronisation. Paul and Harshal Bhadkamkar investigated the possible role of the tidal interaction in the evolution of HMXBs. Using standard framework of the tidal interaction via dynamic tide, they explored the parameter range over which this process is effective. Future evolution was calculated for three HMXBs Cen X-3, LMC X-4 and SMC X-1and it was shown that the active timescale reduces considerably. HMXBs are typically considered as progenitors of double neutron star systems, which in turn lead to gamma ray bursts. Double neutron stars are also considered as emitters of gravitational waves. Reduction in the active timescale at HMXB phase can have considerable effect on the calculation of the birth rate of these systems. The researchers also brought out possible directions in which these birth rates can be altered due to the tidal interaction at HMXB phase. They also provided quantitative estimates of the number

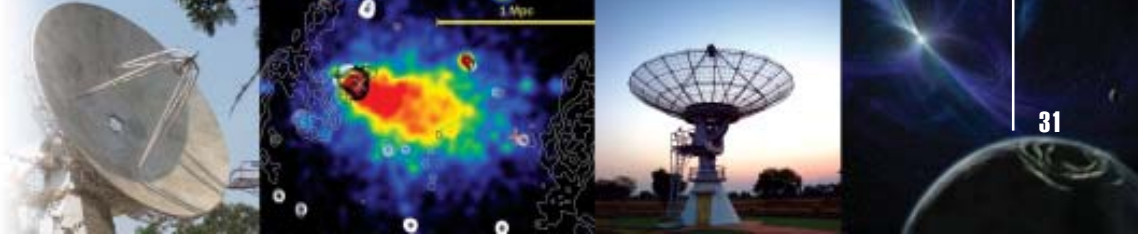
of HMXBs in which this effect will be dominant and detectable.

Paul, Naik and Jaisawal and Naik carried out detailed timing and broad-band spectral studies of a high mass X-ray binary (HXMB) pulsar 4U 1909+07 using data from Suzaku observation. The pulse profile was found to be strongly energy dependent. Presence of several absorption features at various pulse phases makes the soft X-ray pulse profiles complex. At high energies, however, the pulse profile was found to be single peaked. They tried to fit 1-70 keV phase averaged spectrum of the pulsar with various continuum models such as cut-off power-law, high energy cut-off power-law, Negative and Positive law with EXponential cut-off (NPEX) etc. with a simple absorption component and also with a partial covering absorption. However, it was found that the partial covering NPEX continuum model with blackbody component fitted data better. A weak iron fluorescence emission line at 6.4 keV was detected in the spectrum. The presence of an absorption like feature at ~44keV in residue of the spectral fitting required us to add a cyclotron resonance scattering feature (CRSF) at above energy that improved the spectral fitting further. They also estimated the corresponding surface magnetic field of the pulsar to be 3.8×10^{12} Gauss.

Paul and Nazma Islam used the long term light-curves of X ray binaries in our galaxy obtained with the All Sky X-ray Monitors to construct X ray luminosity functions (XLFs), taking into account the variability effect of galactic X ray binaries. Since XFLs of X-ray binaires in different types of galaxies are found to be indicators of galaxy parameters like star formation rate and stellar mass of a galaxy and the X ray binaries are highly variable in nature on wide range of time-scales, it is important to understand the effect of variability of X-ray binaries on the snapshot measurements of the XLF. Paul constructed multiple realisations of the X ray luminosity functions of our Galaxy, using the long term light-curves of sources obtained in the 2-12 KeV energy band with the RXTE All Sky Monitor. XLF constructed for galactic HMXBs in luminosity range $10^{35\text{-}39}$ erg/sec has a power-law index of -0.5 and a variance of 0.05 whereas galactic LMXB XLF constructed in luminosity range $10^{35\text{-}39}$ erg/sec has a power-law index of -0.2 and a variance of 0.02. These luminosity functions and their variances constructed for galactic X-ray binaries are used to compare with the snapshot Chandra and XMM-Newton measurements of X-ray luminosity functions in nearby galaxies available in literature.

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

During the year gone by, Dwarakanath's research included the probable detection of HI at $z \simeq 1.3$ from DEEP2 galaxies using the GMRT. The DEEP2 galaxies have been observed using the Giant Meterwave Radio Telescope in the frequency band of 610 MHz. There are around 400 galaxies in the redshift range $1.24 < z < 1.36$ and within the field of view $\simeq$ 44 arcmin of the GMRT dishes. Dwarakanath and his collaborators Sethi and Murugesan coded the HI 21 cm-line emissions at the locations of these DEEP2



galaxies. They applied stacking on three different data cubes – primary beam uncorrected, primary beam corrected, and primary beam corrected (optimal weighing). They obtained a peak signal strength in the range 8-23 μJy/beam for a velocity width in the range 270-810 km/sec). The error on the signal, computed by bootstrapping, lies in the range 2.5-6 μJy/beam, implying a 2.5-4.7-ó detection of the signal at $z \simeq 1.3$. These results are compared with existing simulations of the signal at $z \simeq 1$ and find reasonable agreement. The impact of residual continuum and systematics was also looked at.

With a view to image low-surface brightness radio emissions (halos and relics) that would have gone undetected in galaxy clusters so far, there are ongoing efforts to image galaxy clusters with the Murchison Widefield Array. The MWA, with its excellent sensitivity to extended low surface brightness features, is expected to detect many halos and relics in galaxy clusters. This study is expected to shed new light on some basic questions concerning the origin and evolution of these, rather rare, halos and relics in galaxy clusters. Currently, data from the commissioning phase of MWA is being analysed to produce continuum images and continuum-free cubes for further analysis and interpretation. Data analysis procedures are being developed by Dwarakanath, Lijo George, Sourabh Paul, Shiv Sethi and Udaya Shankar.

Lakshmi Saripalli's areas of current professional research interests include using giant radio galaxies (GRGs) to probe the intergalactic medium, understanding the origin of radio galaxy types, environments in which giant radio galaxies originate and evolve and radio and optical observations of radio galaxies.

In the year 2012-2013, Saripalli's work included characterization of 119 extended radio sources mapped in the sensitive, 1.4 GHz radio survey, Australia Telescope Low Brightness Survey (ATLBS). Evolution in radio source morphology with flux density was a major theme in the work, enabled by the unique high surface brightness sensitivity of the survey. Radio source morphologies were examined and used to recognise and compile samples of radio galaxies as active, dead and restarted stages of evolution. This was used to suggest a model for radio galaxies 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. Massive ellipticals may undergo a few such activity cycles where adjacent events may blend and constitute the lifetime of a radio source. The work also presents the discovery of several giant radio galaxies at high redshifts as well as, for the first time, a large sample of low power FR-I radio galaxies at redshifts $z > 0.5$. This work was carried out in collaboration with R Subrahmanyan (RRI), K Thorat (IISc and RRI), RD Ekers (CASS, Australia), and RW Hunstead, HM Johnston and

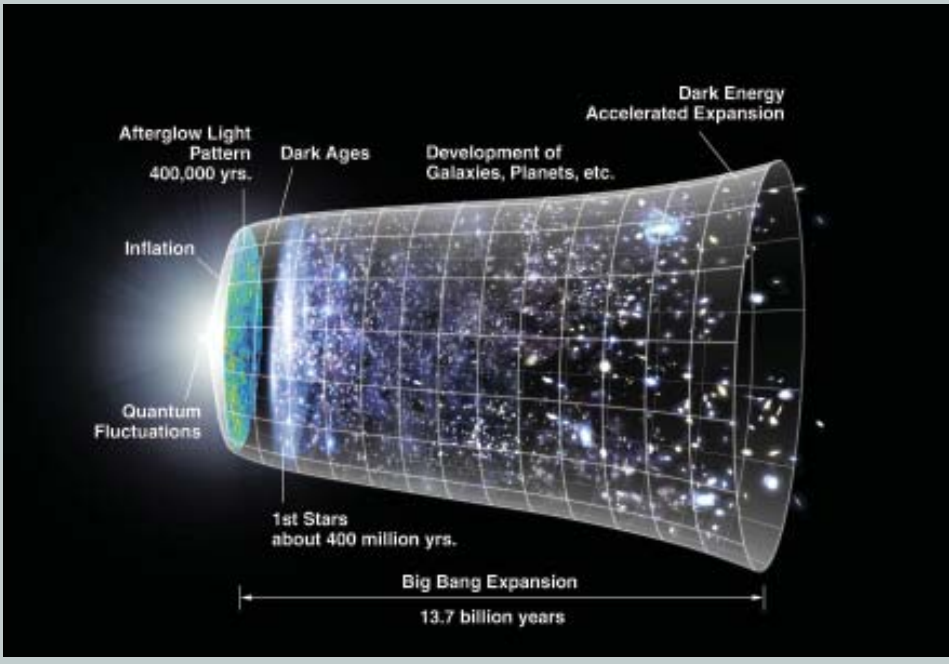
EM Sadler (Sydney Institute for Astronomy, School of Physics, University of Sydney, Australia).

The ATLBS radio survey was also the subject of two other projects both carried out in collaboration with R Subrahmanyan (RRI) and K Thorat (IISc and RRI). In one, the high-resolution imaging of the ATLBS regions was used to study radio source counts and in another, galaxy environments of a select sample of radio galaxies were examined in relation to the extended source structures using a new method of dipole and quadrupole Fourier components.

Saripalli also worked on the problem of the well known FRI-FRII morphological divide in the radio galaxy population. She presented a framework for understanding the dichotomy resting, mainly, on the radio-power-absolute-magnitude relation and including for the first time the dust properties of the hosts of the two FR classes together with the relative orientations of dust, host major axis, and the radio axis.

In collaboration with Jurek Malarecki (ICRAR, UWA, Perth, Australia), Ravi Subrahmanyan (RRI), Lister Staveley-Smith (ICRAR, UWA, Perth, Australia) and Heath Jones (Monash University, Australia) she was involved in a project where Giant radio galaxies were used as probes of the Warm-Hot Intergalactic Medium (WHIM). Using radio observations and estimates of lobe pressures as well as the latest simulations of the WHIM gas they were able to characterize the WHIM environment (temperature and density) of GRGs.

One of the GRGs constituting the sample being studied was separately imaged and studied by Saripalli in collaboration with Jurek Malarecki (ICRAR, UWA, Perth, Australia), Ravi Subrahmanyan (RRI), Lister Staveley-Smith (ICRAR, UWA, Perth, Australia) and Heath Jones (Monash University, Australia). The GRG B0707-359, with its two lobe pairs separated by an angle was the subject of a case study to understand the formation of the peculiar radio structure. Various models were explored and one model, that of an AGN with a changed black hole spin axis was found most suitable. The 1-megaparsec radio morphology was found to be consistent with a model where the beams from the central engine stopped, creating a relic double radio source.

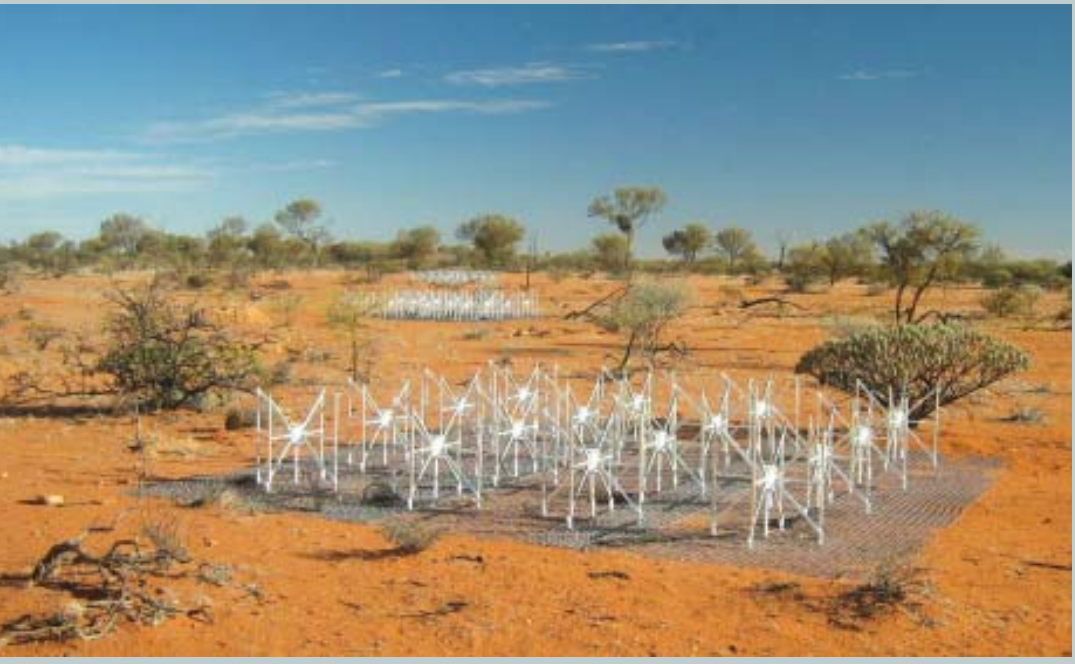


This interruption was then accompanied by triggering of a movement of the axis of the central engine at a rate of a few degrees Myr-1.

She also worked on simultaneous X-ray and optical observations of thermonuclear bursts in the LMXB EXO 0748-676, in collaboration with Biswajit Paul and M Archana of RRI.

N Udaya Shankar's current areas of research interest include galactic and extragalactic radio astronomy, radio surveys, instrumentation and signal processing.

During the academic year, he continued his work on the Murchison Widefield Array (MWA), a low frequency demonstrator operating in the frequency range 80 MHz to 300 MHz to detect signals from the Epoch of Reionisation (EoR). He and his collaborators, Nithyanandan Thaygarajan and Ravi Subrahmanyan, had initiated work on extending the framework developed earlier on minimising foreground contamination in EoR window. This included estimating the relative magnitudes of four fundamental sources of uncertainties – classical source confusion, sidelobe confusion, thermal noise, and sample variance in detecting the HI power spectrum from the EoR. They showed that a statistical representation of residual images and the interferometer array configuration could be used to derive fundamental limits on an instrument's sensitivity. They derived an expression for the region dominated by foregrounds in the power spectrum, which was a natural consequence of the new framework. They also found that bandpass shaping is important when confusion from sources and their sidelobes dominate over thermal noise in the power spectrum. Udaya Shankar and his collaborators quantitatively explored for the first time the idea of an optimal EoR window to collapse

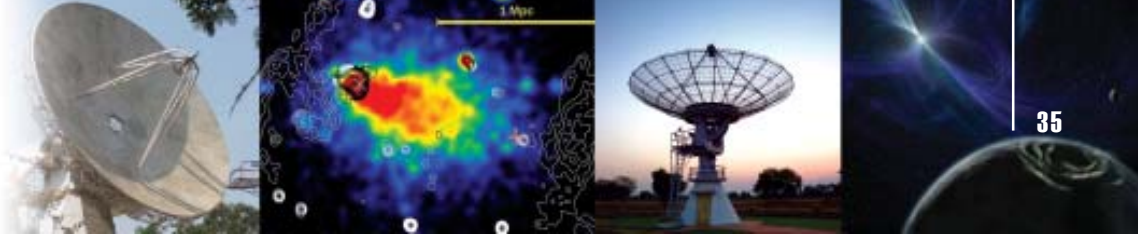


the three-dimensional power spectrum to a one-dimensional power spectrum. The sensitivity of the 128-tile MWA to detect EoR power spectrum was estimated and it was found that detection is possible with 1,000 hours of integration. Sample variance and thermal noise limit sensitivity on large and small scales, respectively, thereby necessitating exploration of optimal observing strategies (drift scan versus targeted observations) to maximise sensitivity on the spatial scales of interest. They proposed that a compact array with a higher collecting area would improve the chances of EoR detection with future instruments.

RRI has been working on an experiment to measure the 21 cm global all sky signal. Significant progress was made during the year in terms of building a system capable of useful measurements of spectral signatures of the EoR in the cosmic radio background. This work is the Ph.D. thesis project of Nipanjana Patra and is being worked on in collaboration with VA Raghunathan and Udaya Shankar. As part of a system design, they evolved a design for a correlation spectrometer for the measurement of the absolute spectrum of the cosmic radio background in the frequency range 87.5–175 MHz. The system is called Shaped Antenna measurement of the background Radio Spectrum, or SARAS. This has been deployed in the Gauribidanur Observatory about 80 km north of Bangalore. This design, with a focus on design strategies and calibration methods, is novel and relevant for wideband measurements of background spectra. This work uses a complex correlation approach to solve for the total power spectra, the framework was developed in different stages, beginning with a simplified treatment of an ideal system and then going on to develop the understanding considering non-ideal behaviour of increasing complexity and ending with a hierarchical approach to modelling of SARAS data.

They also deigned a wide-band fat-dipole antenna with a sinusoidal profile having a frequency independent performance over the octave band 87.5-175 MHz. This has allowed a return loss higher than 15 dB, and the radiation power pattern is frequency invariant and close to Cosine Square over the desired octave bandwidth.

Udaya Shankar has also been involved with RRI's flagship programme build an Array of Precision Spectrometers (APSERa) to detect recombination lines from the Epoch of Cosmological Recombination. The Very Early Universe was completely ionised. As it expanded and cooled down it went through several stages of recombination. The associated release of photons during this epoch manifest as "ripples" in wideband spectra of the cosmic radio background leading to interesting and unique deviations of the Cosmic Microwave Background spectrum from a perfect blackbody spectrum. The spectral features are expected to be isotropic over the whole sky. The APSERa project will comprise an array of 128 small telescopes that are purpose built to detect a set of adjacent lines from cosmological recombination in the spectrum of the radio sky in the 2-6 GHz range. State-of-the-art low-noise high-dynamic range interference tolerant radio receivers are being designed and built at RRI, tested in nearby radio-quiet locations



and relocated to a remote site for long duration exposures to detect the subtle features in the cosmic radio background arising from recombination. As a first step, the APSERa team has designed a state-of-the-art FPGA-based (field- programmable gate array) precision digital spectrometer board (pSPEC) capable of digitising analogue signals at rates higher than 1 GHz, breaching the Giga Hertz barrier in digitising signals. The figure, first light from the spectrometer, shows the characteristics in frequency domain of a single tone with a frequency of 156.25 MHz digitised at 1.25 GHz, 4096 output points grabbed by a computer and Fourier transformed. The value of the noise floor and the harmonics of the tone digitised are at expected levels in the spectrum. At present, evaluation of the dynamic parameters of the pSPEC board is under progress. This project is in collaboration with Srivani & BS Girish, as team leads, A Raghunathan, R Somashekar, Mayuri, and Ravi Subrahmanayan.

S Sridhar's areas of current professional research interests are magnetohydrodynamics, turbulence, dynamo theory, accretion disks and gravitational dynamics.

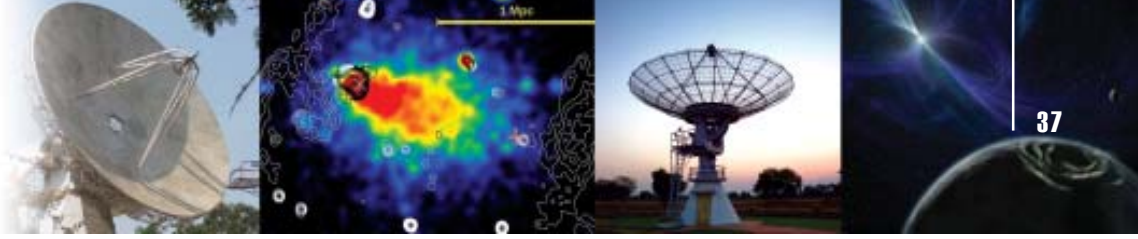
His research work during the year includes the global description of light beams and their geometric phase, done along with Rajaram Nityananda of the National Centre for Radio Astrophysics. They constructed the manifold describing the family of plane monochromatic light waves with all directions, polarisations, phases and intensities. A smooth description of polarisation, valid over the entire sphere S^2 of directions, is given through the construction of an orthogonal basis pair of complex polarisation vectors for each direction; any light beam is then uniquely and smoothly specified by giving its direction and two complex amplitudes. This implies that the space of all light beams is the six-dimensional manifold S^2 X C^2, the (untwisted) Cartesian product of a sphere and a two-dimensional complex vector space. A Hopf map (i.e., mapping the two complex amplitudes to the Stokes parameters) then leads to the four-dimensional manifold S^2 X S^2, which describes beams with all directions and polarisation states. This product of two spheres can be viewed as an ordered pair of two points on a single sphere, in contrast to earlier work in which the same system was represented using Majorana's mapping of the states of a spin one quantum system to an unordered pair of points on a sphere. This is a different manifold, CP^2, two-dimensional complex projective space, which does not faithfully represent the full space of all directions and polarisations. Following the now-standard framework, Sridhar exhibited the fibre bundle whose total space is the set of all light beams of non-zero intensity, and base space S^2 X S^2. They gave the U(1) connection which determines the geometric phase as the line integral of a one-form along a closed curve in the total space. Bases are classified as globally smooth, global but

singular, and local, with the last type of basis being defined only when the curve traversed by the system is given. Existing as well as new formulae for the geometric phase are presented in this overall framework.

Sridhar's other research projects during the year included dynamo action due to turbulence in shear flows along with Nishant K Singh of the Inter-University Centre for Astronomy and Astrophysics; stellar dynamics in galactic nuclei with collaborators Mamta Gulati of RRI and Tarun Deep Saini of the Indian Institute of Science; and exoplanetary dynamics, stellar dynamics in galactic nuclei along with Jihad Touma of the American University of Beirut (Lebanon).

Nayantara Gupta's areas of current professional research interests are cosmic rays, neutrinos, gamma rays and gamma ray bursts.

During the year gone by, Gupta worked on testing hadronic models of gamma ray production at the core of Cen A along with Jagdish C Joshi. The Pierre Auger experiment has observed a few cosmic ray events above 55EeV from the direction of the core of Cen A which might have originated from the core of Cen A. High energy gamma ray emission has been observed by HESS from the radio core and inner kpc jets of Cen A. Gupta and Joshi are testing whether pure hadronic interactions of protons or heavy nuclei with the matter in the core region or photo-disintegration of heavy nuclei can explain the cosmic ray and high energy gamma ray observations from the core. The scenario of p-γ interactions followed by photo-pion decay has been tested earlier and found to be consistent with the observational results. Some other possibilities have been considered: (i) the primary cosmic rays at the core of Cen A are protons and the high energy gamma rays are produced in pp interactions, (ii) the primary cosmic rays are Fe nuclei and the high energy gamma rays are produced in Fep interactions and (iii) the primary cosmic rays are Fe nuclei and they are photo-disintegrated at the core. The daughter nuclei de-excite and high energy gamma rays are produced. The high energy gamma ray fluxes expected in each of these cases are compared with the flux observed by HESS experiment to normalise the spectrum of the primary cosmic rays at the core. The expected number of cosmic ray nucleon events between 55 EeV and 150 EeV was calculated in each of these cases to verify the consistencies of the different scenarios with the observations by the Pierre Auger experiment. It was found that in the case of pure pp and Fep interactions, the expected event rates are not consistent with the Pierre Auger observations. In the scenario of photo-Fe nuclei required to explain the observational results of HESS and Pierre Auger is higher than the luminosity of the cosmic ray protons in the p-γ interaction model and also exceeds the Eddingtons luminosity by a factor of ten. However, there are several uncertainties in determining the photon density at the source. A higher photon density at the source would enhance the rate of photo-disintegration and explain the results of Pierre Auger and HESS without exceeding the luminosity budget of cosmic rays.



Gupta also studied the galactic wind haze and its γ-spectrum along with Biman B Nath, Peter L Biermann, Eun-Suk Seo, Todor Stanev and Julia Becker Tjus. The spectrum observed by Fermi-LAT from the Galactic Centre region shows a gamma ray feature near 130 GeV, that in some analyses appears as a possible line. The possibility that this gamma ray feature has a cosmic ray origin was looked at in this study. It is argued that the cosmic ray electrons steepen near 1TeV from E-3 to about E-4.2, and are all secondary derived from the knee- feature of normal cosmic rays. It is also suggested that the observed feature at ~130GeV could essentially be a noise feature on top of a sharp turn-off in the ray spectrum at ~130GeV. This match suggests that the knee of normal cosmic rays is the same everywhere in the galaxy. It is believed to follow that all supernovae contributing give the same cosmic ray spectrum, with the knee feature given by common stellar properties; in fact, this is consistent with the supernova theory proposed by Bisnovatyi-Kogan (1970), that massive stars converge to common properties in terms of rotation and magnetic fields just before they explode.

Galactic PeV neutrinos were another area of research for Gupta during the year. The IceCube experiment detected two neutrinos with energies between 1-10 PeV. In this work, hadronic interactions of the diffuse very high energy cosmic rays with the interstellar matter within our galaxy are considered to explain the PeV neutrino events detected in IceCube. PeV gamma ray events are expected along with the PeV neutrino events if the observed PeV neutrinos were produced within our galaxy in hadronic interactions. PeV gamma rays are unlikely to reach us from sources outside the Milky Way. In future, with simultaneous detections of PeV gamma rays and neutrinos, it would be possible to distinguish between galactic and extragalactic origins of very high energy neutrinos.

S Mayuri worked with Ravi Subrahmanyan to design an experiment to detect spectral signatures of the Epoch of Cosmological Recombination between 2 and 6 GHz. The Cosmic Microwave Background, the relic thermal radiation that fills the universe, is thought to be the earliest light in the universe, tracing its origins back to the Big Bang in accordance with the Standard Cosmological Model. The Epoch of Recombination refers to that period in cosmological evolution when the hot plasma content of the early universe gradually transitioned to the atomic state as the universe expands and cools. Understood to have occurred close to redshift z = 1100 for hydrogen, z = 2500 for HeII —> HeI and z = 6000 for HeIII —> HeII, the recombination of Hydrogen and Helium is via capture of free electrons by the nuclei. The electrons trickle down the bound quantum states of the atom proceeding over multiple quasi-stationary states. As the captured electrons in the atoms make bound-bound transitions, the atoms exchange energy with the radiation content of

the universe in the recombination-line transition frequencies. The atoms also undergo multiple dissociations and recaptures until finally the atom arrives at the ground state from the first excited state via either the 2s two photon decay or because of emission of Lyman-alpha photons along with their removal from the background radiation via Hubble expansion. All of the bound-bound transitions result in spectral features in the spectrum of the relict radiation and these redshift by a factor 1100 to be observable at cm and mm wavelengths today. Physical processes which occurred during the major epochs of cosmological evolution leave "imprints" in the Cosmic Background Radiation and understanding these imprints hold the key to understanding the early evolution of the universe. Mayuri is working on developing a pipeline to simulate the output of an antenna receiver chain recording sky noise temperature to obtain all sky spectra and to determine a suitable form of the spectrum recorded to recover the buried recombination lines.

During the year, Mayuri also looked at receiver designs for the detection of spectral signatures from the Epoch of Recombination, a project undertaken with Ravi Subrahmanyan and N Udaya Shankar. They are exploring various receiver configurations to identify the configuration of system which would be most suited to detect extremely weak spectral signatures from the Epoch of Recombination. Choice of a suitable receiver configuration would then lead the way in other aspects of sub-system design.

In conjunction with Biswajit Paul, Mayuri investigated Power Density Spectra (PDS) and kHz Quasi Periodic Oscillations (KQPOs) of some LMXBs in different broad band spectral states. They have chosen sources which 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. They are studying the correlation between the presence of KQPOs, their frequencies, rms, quality factor, energy dependence of the QPOs etc. with their broad band spectral behaviour. Any dependence of the power spectra on the broad band spectral state would give important clues towards the origin of the temporal behaviour. As of now, the sources have been identified by looking into the long term light curves in the

medium energy band (RXTE-ASM) and hard X-ray band (SWIFT-BAT) and have extracted the power spectra of two sources, 4U 1608-52 and 4U 1636-54, from time period February 12, 2005, to April 18, 2010. They looked for all observations which have the required time resolution to be able to look for KQPOs as well as the flexibility to extract power spectra over the required energy band. This exercise has resulted in about 1000 observations for which power spectra have been successfully extracted. Care has been taken not to include data coming from the time interval containing a type I burst, if present in the light curve. It has been found that KQPOs are observed in certain preferred windows of hardness ratios and count rates. This has serious implications in better understanding the spectral origin of KQPOs. Another interesting application of the study is to use these preferred windows of KQPO presence to optimise observations in future missions whose scientific goals require detection of KQPOs.

During the year gone by, **Nithyanandan Thyagarajan**'s work included studying the Epoch of Reionisation with the Murchison Widefield Array in collaboration with N Udaya Shankar, Ravi Subrahmanyan and the MWA project team.

Direct observation of redshifted 21 cm spin transition of neutral hydrogen has been identified to be a useful method for detecting structures in cosmological gas at high redshifts. Tomography of redshifted 21 cm line promises to be a key probe of reionisation history. Observing images of the three-dimensional distribution of neutral hydrogen temperature fluctuations in excess relative to the CMB temperature is expected to reveal the epoch as well as the process of reionisation in detail; however, it has been previously pointed out that such imaging requires the sensitivity of the Square Kilometer Array (SKA).

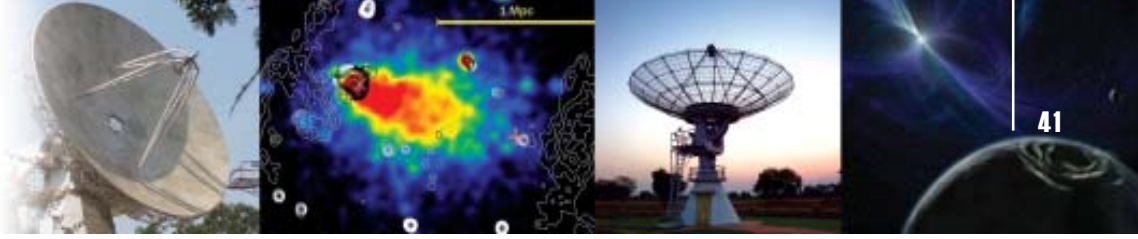
Nevertheless, numerous first-generation radio telescopes such as the Murchison Widefield Array, the Low Frequency Array (LOFAR), and the Precision Array for Probing the Epoch of Reionisation (PAPER) are being designed with enough sensitivity for a statistical detection of the EoR Hi power spectrum. Measuring the Hi power spectrum and its cosmological evolution is a first step to understanding structure formation and astrophysics in the EoR.

Power spectrum measurements of the redshifted 21 cm from EoR are difficult. The EoR signal is extremely weak relative 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. It has been 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 but warn that such symmetry considerations provide only an additional space for attempting separation of foreground contamination from the signal and does not guarantee that foreground contamination will become negligible. It has also been pointed out that an inherent mechanism for foreground contamination via the frequency dependent structure (chromaticity) of the primary and synthesised beams, which becomes significant owing to the relatively large bandwidths (~8 MHz) associated with EoR observations. The chromatic nature of the primary and synthesised beams carries the transverse structure of contamination due to the residuals of continuum foreground subtraction into the frequency domain. This has been termed as "mode-mixing". Previous research has shown a framework to understand the localisation of this foreground contamination from residuals in spatial scales in the line-of-sight direction. They have also shown that appropriate choices of bandpass window functions and imaging algorithms can significantly minimise levels of such contamination in specific regions of k-space, which is termed as the "EoR window". An earlier work simulated instances of sky models consisting of bright radio sources and showed that residuals left over after source subtraction due to source position errors and calibration errors are localised to a wedge-like region in the k-space.

Thyagarajan, in this work, makes use of the one-dimensional framework provided by Vedantham et al. (2012). Detailed statistical estimates have been presented of the distribution of four sources of uncertainty, namely, classical source confusion, sidelobe confusion, thermal noise, and sample variance, in two-dimensional k- space. The 128-tile (128T) array configuration proposed for the MWA has been used in the estimates. The relative magnitudes of these different sources of uncertainties have been compared and a more complete view of the estimates of the EoR power spectrum sensitivity characteristics of the measuring instrument have been obtained.

Some of the most recent results of this study includes the following:

- In detecting the Hi power spectrum from the EoR, the relative magnitudes of four fundamental sources of uncertainties (classical



source confusion, sidelobe confusion, thermal noise and sample variance) were estimated for the first time.

- A statistical representation of residual images and the interferometer array con- figuration can be used to derive fundamental limits on the instruments sensitivity.
- A novel technique was presented (synthesised beam decomposition) that acts as a comprehensive framework for estimating, in any region of k-space, contamination in the power spectrum caused due to sidelobes and frequency dependent effects.
- The expression for the region dominated by foregrounds in k-space follows as a natural consequence of this framework.
- Bandpass shaping was inferred to be important when confusion from sources and their sidelobes dominate over thermal noise in k-space. A framework was provided and the idea of an optimal EoR window was explored for the first time.
- Sensitivity for EoR Hi power spectrum detection was estimated for different integration times.

Thyagarajan also worked on a study of radio transients and variables in collaboration with KS Dwarakanath and Shri Kulkarni of Caltech University.

Studying the dynamic radio sky has been identified as one of the most promising frontiers of exploring new and yet to be understood astrophysical phenomena. Until recently, only a few dedicated searches for variables and transients have been undertaken. Indeed, one of the key scientific aims of the next generation radio telescopes such as LOFAR, ASKAP, MWA and eventually, the SKA is a study of radio transients.

Research on dynamic faint radio sources has so far yielded small samples as a consequence of the small areas searched and the long integration times required. In the galaxy, single radio bursts detected from the Parkes Multibeam Pulsar Survey revealed a new population of neutron stars: Rotating Radio Anomalous Transients. Galactic Center Radio Transients have diverse light curves with outburst periods and burst durations varying from minutes to months. Lacking counterparts at other wavelengths, their hosts, and the physical mechanisms involved, remain a mystery. Recently, archival VLA calibrator observations spanning 22 years with 944 independent epochs were used to search for radio transients. They detected eight transients in single epochs and two transients in two-month averages of the data. Two of the transients were identified as RSNe, while the absence of optical counterparts for the remainder offers a wide variety of possibilities including Orphaned GRB Afterglows (OGRBA), stellar sources, propagation effects, microlensing events, or perhaps mechanisms heretofore unknown. It has been argued that these transients lacking optical counterparts must be of galactic origin, possibly

neutron stars. Furthermore, it also implied that the areal density of radio transients on the sky is ~1.5 deg-2 for a source detection threshold at 370 μJy (at 5 and 8.4GHz) at any given time, which exceeds that of all other known radio transient source populations by an order of magnitude (or more).

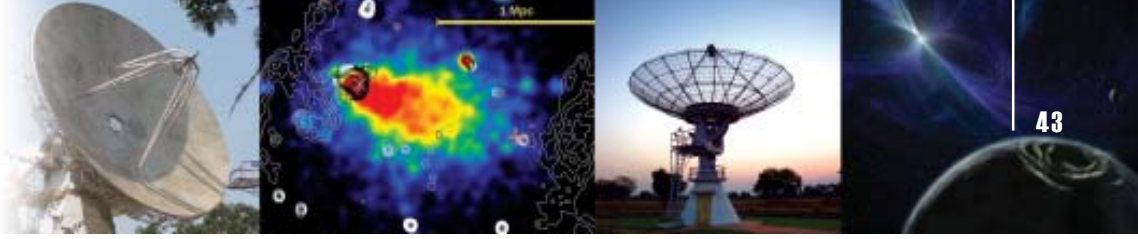
Two large, sensitive, wide-field surveys exist at radio wavelengths – the NRAO VLA Sky Survey and the Faint Images of the Radio Sky at Twenty-cm survey (FIRST). These two surveys in their overlap region have been used to search for radio transients.These studies have been complicated by the mismatched resolutions and flux density sensitivities of the NVSS and the FIRST surveys.

A prior analysis conducted by Thyagarajan of the FIRST survey consists of ~55,000 snapshot images to create the largest, unbiased sample of variable radio sources to date. This sample consists of sources with flux densities down to a few mJy and with variability over timescales of minutes to years. 1,627 sources have been found to be significantly variable based on various criteria such as the variations observed in the light curve, deviation between the maximum and minimum data points in the light curve, and single most deviant data points. They were subsequently matched with multi-wavelength catalogues to identify counterparts.

During the previous year, Thyagarajan focused on obtaining optical counterpart information using the Palomar Transient Factory (PTF) in collaboration with a team at Caltech University. In parallel, they put in a proposal with the GMRT to observe 20 transient candidates. High sensitivity (~ 50 μJy) is essential to identify any faint and possibly extended structures in the host galaxies and hence two hours on each source at each epoch was required. With 20 sources, it amounts to a total of 80 hours. During the year gone by, Thyagarajan completed the data analysis on these observations and found that 13 out of 20 sources were detected in both epochs. One source exhibited transient-like behaviour above the 5σ level wherein it was detected in one epoch and not in the other. A couple of sources exhibited variability above the 3σ level. Refining the data analysis for possible calibration errors is in progress.

Shiv Sethi's areas of research interest are cosmology and structure formation, Reionisation era and cosmological magnetic fields.

During the year gone by, Sethi's research covered Lyman-alpha clouds and primordial magnetic fields and detecting HI at high redshifts. Lyman-alpha clouds are known to be a mildly non-linear manifestation of density perturbations. And therefore they have been shown to be a very good probe of these perturbations at high redshifts ($z>2$) on scales in range from a few hundred kiloparsec toa few Mpc. It is known that primordial magnetic fields can generate density perturbations at such scales. Sethi and Kanhaiya Lal Pandey simulated Lyman-alpha clouds including the effect of magnetic fields induced perturbations and compared the results with existing observations of Lyman-alpha clouds. They showed that these considerations allowed putting very stringent bounds on the strength of primordial magnetic fields



Using GMRT 610 MHz band, Sethi, Dwarakanath and Chandrashekar Murugesan observed two DEEP2 fields at a redshift z ' 1:3. By stacking the spectra of nearly 500 DEEP2 sources in one such field, they reported a tentative detection (between 2 and 4.5) of the HI signal at this redshift. More data is currently being analysed.

B Ramesh has research interests in the field of molecular astronomy using the light from celestial sources in the radio-submillimeter window covering the frequency range 1 to 1000 GHz. This light carries information about the cold and diffuse universe and helps us to understand the process of star formation and its regulation, in our galaxy as well as in others, besides tracing the structures in the cosmic microwave background. Ramesh's work also includes constructing better telescopes.

During the year, his research revolved around Efficient Linear-array Imager (ELI) being a suitable antenna element for SKA-high. Large scale surveys are an essential means to leapfrog astronomical understanding, and are undertaken by both space and ground telescopes. Instantaneous field of view plays a vital role in determining survey speeds. Optical telescopes achieve this via large CCD cameras and low frequency radio telescopes via synthesis imaging, which necessarily requires multiple receivers. Yet, galaxy-wide surveys at millimeter wavelengths are rare and have not benefitted much from multiple receivers that provide large instantaneous field-of-view. If one were to have a large number of millimeter wave receivers, the question arises of how best to deploy them to maximise survey speed to attain desired sensitivity. This was investigated and the result was a new cross telescope configuration, Efficient Linear-array Imager, which was demonstrated to provide an optimal solution.

The ALMA has recently started its science operations and the focus on constructing the Square Kilometer Array (SKA) has gained momentum. In this context, Ramesh and his team also had a first look at using ELI as an antenna element for SKA-high. It was found that, as an interferometer element, ELI lends itself for close packing and can blend short and long spacing visibilities naturally to provide low-pass spatial filtering performance, necessary for high frequency arrays such as Square Kilometer Array (high). Future studies will include the use of ELI as a SKA-high element and suitable UV configurations.

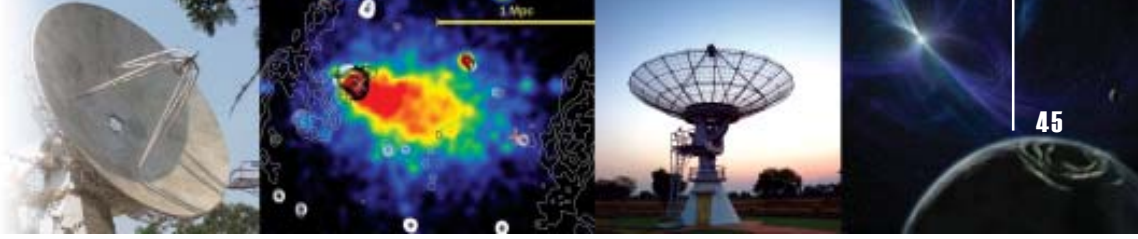
Ramesh also conducted off-axis performance simulations on the Fan-beam Telescope (FBT). Typical radio telescopes made of dish antennas often form circular pencil beams on the sky. Deviation from circularity is considered an aberration. Such antennas are also used as elements of synthesis array and their beam circularities are important. At lower frequencies non-circular beams are often encountered, such

as fan-beams created in low frequency arrays such as Mills' cross telescopes. At higher radio frequencies one seldom creates and uses fan-beams. This is largely because wavelengths being small, high frequencies necessitate the use of dishes as single telescopes or as an array element. Inevitably, they make circular pencil beams.

However, in recent times, two high frequency applications of FBTs have been proposed: (a) to retro-fit an FBT to an afocal beam expander that circularises the beam again; then, by rotating the FBT about its focal line, one can steer the final circular beam in elevation without moving the primary (and secondary); this allows building large millimeter wave telescopes economically; (b) to use two FBTs in a cross-configuration to realise a focal-plane Mills' cross high frequency telescope that promises to offer great advantages. In this background, studying the off-axis performance of the FBT has become important. Ramesh has carried out such an investigation for a Cassegrain FBT and found that, in a 15 feed linear array operating at 3 cm, even the end beams suffer negligible distortion. At higher frequencies, the distortions should be even smaller. They are currently carrying out the investigations for a Gregorian secondary and also at 3 mm wavelength.

As part of Ramesh's interests in telescope development, he has been involved with the construction of prototype equipment and over the years has developed two key ideas for a radio telescope. Both use FBTs as a part in their optical scheme. He initially focused on a prototype FBT for a sub-millimeter instrument, work done with K Aruna, an M Tech student, in 2010-11. The back-up structure and elevation rail support have been built and making and setting of the panels and making the secondary are the only elements left. However, working at high frequencies requires precision manufacture and measurement which is not easily available and accessible. Therefore, towards the end of 2011, he started making a low-frequency FBT prototype. The CAD model and laser cutting of profiles on aluminium plates were completed by June 2012, with the help of BE project students from BMSCE. Later, the link components and assembly were carried out with help from Paul and Mohammed Ibrahim from MES and VSP student Abhijit Venkatesh. Current work includes setting of the surface, for which an automatic surface measurement system accurate to 1 mm is required. Ramesh worked with VSP student Shyam Nambiar to use a structured lighting technique to solve for 3D point cloud. But an accuracy better than 6 mm at several meter distances was not achieved. He is now working on a simple computer controlled laser distance meter that uses trigonometry to obtain the distances to the desired accuracy.

Once the surface is set and measured, the secondary will be milled with a CNC machine and mounted; the two mirror assembly will be equipped with a DTH LNBC, ready to measure the beam over several days as the sun (and moon) transits across the beam. Later, a rotation of about one axis will be added. Construction of the axial motion system will be given to an external agency. A prototype Ku-band receiver chain is also being built with the help of VSP students and members of RAL, to pursue Ku-band science. This includes developing a USB 3 digitiser that can

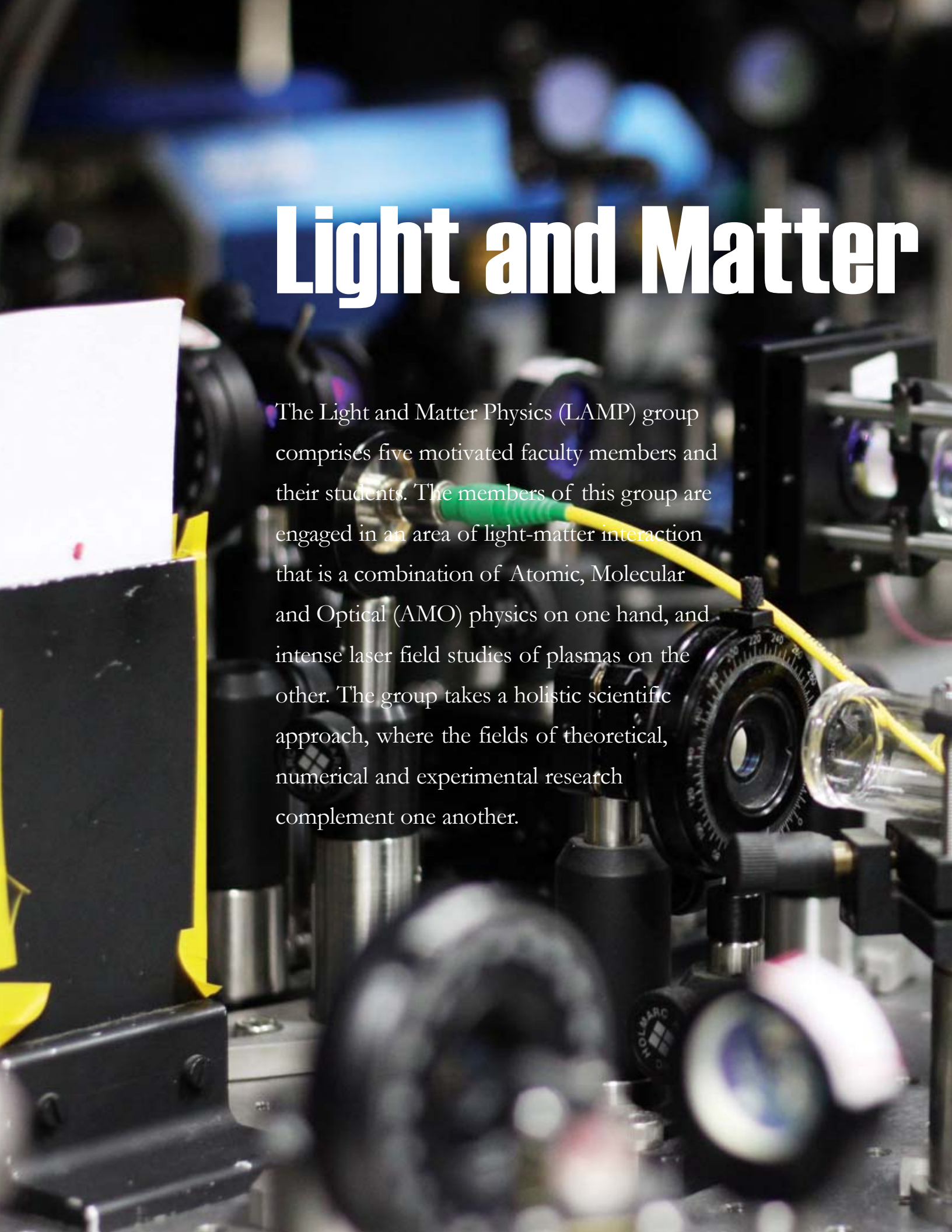


sample multiple channels and dump the data in the memory of a desktop that can process the data and construct the image. Future work will include constructing an ELI to operate at Ku-band (a) to demonstrate its working; (b) to undertake such Ku-band line surveys of the Galactic plane.

Another instrument that Ramesh is working on is the development of a Brain-Computer Interface, along with Hema Ramachandran, to develop patient assistant systems that help people with limb-immobility.

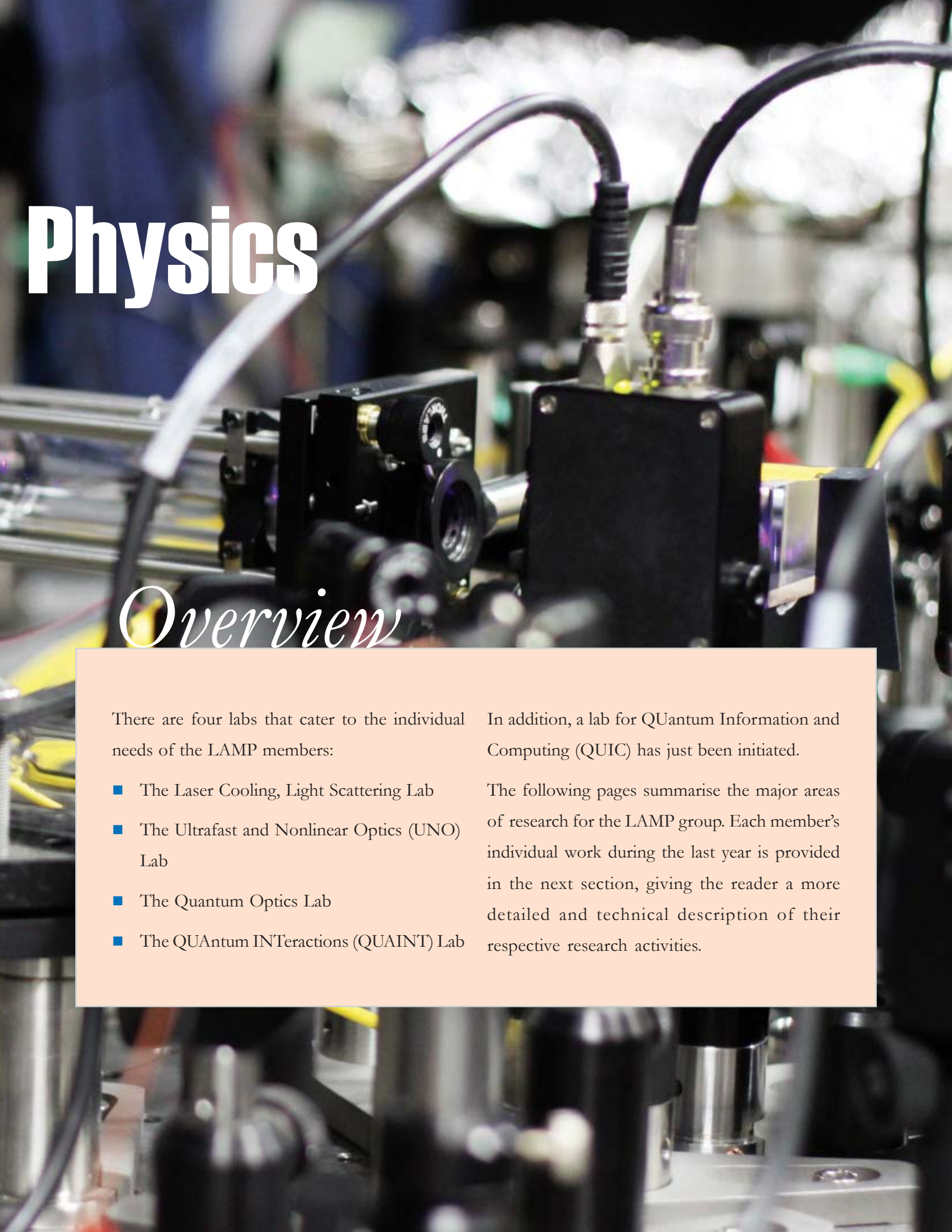
Harsha Raichur's work during the year gone by included multi-wavelength observations of the giant X-ray flare galaxy NGC 5905, in collaboration with M Das and P Shastri (IIA, Bangalore), A Alonso Herrero (CSIC-UC, Santander) and NG Kantharia (NCRA, Pune). NGC 5905 is one of the few galaxies in which an X-ray flare was discovered by the ROSAT All Sky Survey (RASS). This flare was supposed to have occurred due to tidal disruption of a star by the central black hole. In this work we present analysis of multi-wavelength follow-up observations made in X-ray, mid-infrared and radio using data obtained from the Chandra X-ray observatory, Spitzer and Giant Meterwave Radio Telescope, respectively. The archival Chandra 2007 observations show that the X-ray luminosity in the energy band of 0.5-2.0 keV has decreased by a factor of 200 since the peak of the X-ray flare observed in 1990. The X-ray image reveals no centrally bright core expected in the presence of an AGN. Diffuse X-ray emission lying close to the circum-nuclear star forming ring is observed.

The radio flux density observed with the GMRT data is similar to the flux density derived using the VLA FIRST observation in 1997 which indicates that the radio emission is probably unaffected by the 1990 X-ray flare. The archival Spitzer 2006 mid-infrared spectrum shows strong evidence of nuclear star formation but does not show any clear signatures of AGN activity. Therefore, it was concluded that there is no central AGN in NGC 5905 and reaffirm that the 1990 X-ray flare observed in this galaxy was a tidal disruption event and not due to AGN variability. NGC 5905 represents one of the few direct evidences that non-accreting black holes exist and hence provides an opportunity to study the post-outburst evolution of a tidal disruption event in the nucleus of a giant low surface brightness galaxy.



Light and Matter

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.



Physics

Overview

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 (UNO) 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.

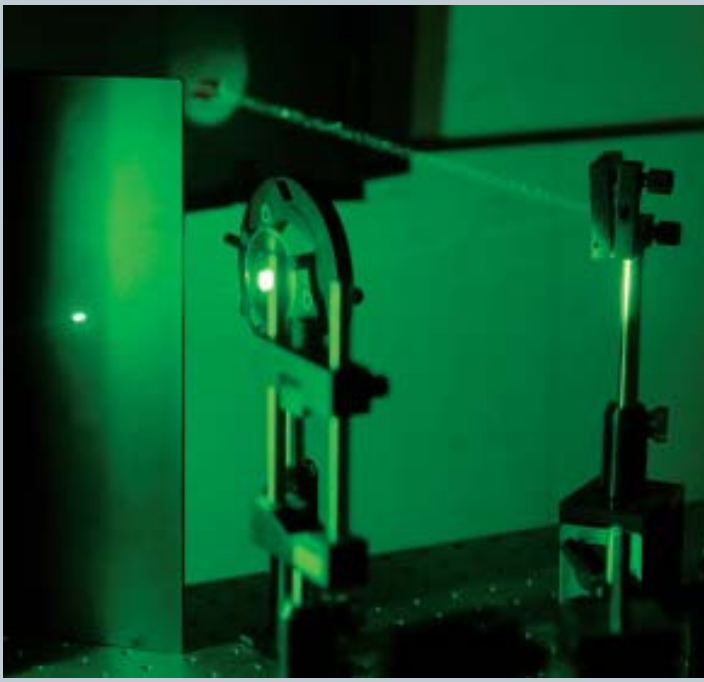
QUANTUM OPTICS

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. Quantum Coherence transfer between atoms and light and creation of new quantum states of light and matter are some of the questions which 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

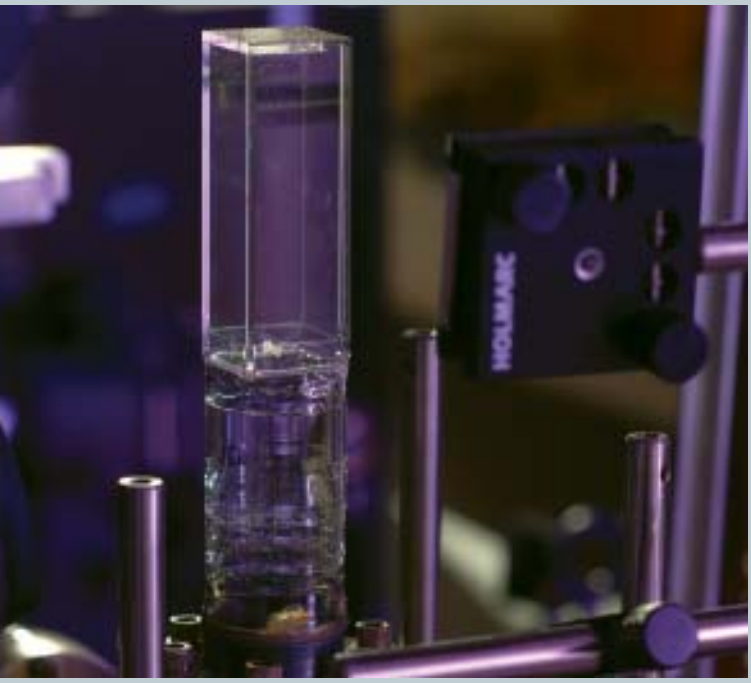
Laser cooling and trapping is an area of physics that has largely expanded over the last decade. Presently, atoms can be cooled to extremely low kinetic temperatures (as low as 150 microK) and trapped for a time period of the order of seconds. Such control over the motion of atoms allows researchers 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.



HYBRID TRAPPING OF ATOMS AND IONS

Hybrid trap experiment, which combine cold atoms, ions and molecules have given rise to a new class of experiments in physics. In such an experiment, interactions between these can be studied with maximal control and accuracy. Very crucial studies done at RRI have overturned long held views on the nature of energy transfer in the interaction of trapped ions with trapped atoms. Collision rates between atoms and ions have been accurately measured. In another first, ion molecule processes have been measured which show a variety of very interesting phenomena. The possibilities on this experiment are very rich and virtually inexhaustible.



CAVITY PHYSICS AND CAVITY QED

A major leap in the hybrid trap experiments is the accessible quantum electro-dynamic regime for atom-electromagnetic field interactions. Several measurements have now been made which demonstrate the non-classical nature of atom field interactions. The system has been constructed so that cold ions, atoms, molecules are simultaneously cooled and trapped along with photons in a high quality optical cavity. This is the first experiment of its kind anywhere in the world and a complete system for the study of cold dilute classical and quantum gases. Several promising lines of study are being investigated.

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

Nonlinear optical transmission of material systems finds applications in optical switches, optical limiters and saturable absorbers. RRI researchers have investigated the nonlinear optical properties of various types of materials including nanoparticles and nanocomposites. Materials in the nanophase show tunable properties which are quite different from those in the bulk form. Evolution of the nonlinear optical response in these media in picosecond timescales has been investigated using ultrafast (100 fs) laser pulses. The experimental techniques used are pulsed laser Z-scan, white light Z-scan, degenerate four wave mixing (DFWM), and femtosecond pump-probe spectroscopy.

LASER INDUCED PLASMAS

Plasma, the fourth state of matter, can be produced in the lab by irradiating suitable targets using powerful pulsed lasers. Such plasmas which exist for a few microseconds may be considered as short-lived stars, and their study is aptly named "Laboratory Astrophysics". LAMP researchers have studied ultrafast laser produced plasmas from metal targets kept in vacuum environments. The emission is found to contain electrons, ions, visible radiation, and high energy photons in the soft and hard X-ray regimes. While plasma emission spectral lines can be used to identify constituent elements present in an unknown target, analysis of their temporal evolution will give information on the velocity and recombination rate of ions and electrons present in the plasma.

Ongoing Research

Andal Narayanan's areas of research interests are quantum optics and laser cooling and trapping of atoms.

During the past year, the following research activity which comes under the broad purview of Electromagnetically Induced Transparency and related effects in atomic systems was pursued.

Slowing down a pulse of light with a room temperature collection of atoms in a double lambda configuration of its internal levels with laser fields: An electromagnetic pulse of light can have its group velocity changed when it travels in a highly dispersive medium. A resonant absorption phenomenon creates anomalous dispersion (with negative slopes) of their refractive index profiles. However, atoms that undergo the electromagnetically induced transparency (EIT) effect have steep dispersion profiles with positive slopes. This enables a pulse of light to undergo reduction in its group velocity. The reduction in the velocity is directly proportional to the steepness of the refractive index profile and hence to the narrowness of the EIT transmission window.

After successfully slowing down a pulse of light travelling inside a Rubidium atomic vapour, questions relating to transient response of the atomic medium on the pulse of light were undertaken. This study will answer the question as to how much time a control pulse will need to establish the ground state coherence necessary to observe effects such as slowing down of light. Transient studies of systems which show complex internal level structures with a view to establish ground state coherence time scales are also being pursued. This will eventually tells us the effect of other additional levels on the establishment of an EIT dark state in these systems. This work was experimental in nature and was done in collaboration with VSP students Vineetha and Asha.

Cavity opto-mechanics is a field where a high quality optical cavity is coupled to a high quality mechanical spring. Usually this is done by attaching one of the cavity mirrors to a mechanical resonator. The radiation pressure of light inside the cavity makes the cavity resonances to depend on both mechanical and optical parameters. Thus a coupling is established. Narayanan and VSP student S Sainadh studied the opto-mechanically induced transparency (OMIT) effect. During the past year, a theoretical proposal was put forth, where, using an additional mechanical mode in a dual cavity optomechanical architecture, it was shown to be possible to enable or inhibit quantum state transfer of light between two cavities. This study was published in the Journal Physical Review A.

Measurement of an observable to yield its eigen values is at the heart of quantum mechanics. Recently, a new kind of measurement that does not necessarily yield one of the eigen values is gaining momentum. This is called weak measurement. In the context of cavity optomechanics we are exploring the theory weak measurements in specific scenarios to amplify small signals.

Hema Ramachandran's research involves the study the influence of light on matter and of matter on light, on different scales.

On the nanoscopic scale, she is interested in the scattering of light by random active and passive suspensions of particles. She is currently involved investigating the role of externally applied fields in altering the optical properties of ferrofluids. These materials are known to display very puzzling optical properties. The aim of the research is to unravel the underlying mechanisms that bring about the observed changes in the optical properties.

On the mesoscopic scale, she is interested in separating out image bearing near-ballistic photons from a multitude of diffusive photons that emerge from a suspension of mesoscopic scatterers. Such a requirement for imaging in the presence of strong multiple scattering is encountered in a variety of diverse situations, like in medical imaging, navigating under fog, under-water exploration, amongst others. Dr. Fade, Prof. Alouini and Prof. F Bretenaker (France), and Ramachandran have jointly devised a polarisation-based imaging technique for real-time imaging through fog, for which a patent has been applied for. The technique is now being implemented in the laboratory, in a collaborative programme financed by the Indo-French Center for Promotion and Advancement of Research (IFCPAR).

On the sub-microscopic scale, she is interested in the interaction of few quanta of matter and few quanta of light. The ultimate aim is the manipulation of single atoms and single photons. To this end, Ramachandran and her collaborators B Girish, D Pandey and B Suryabrahmam are developing tools creating light sources with novel photon number distributions and for photon counting and correlation measurements. During the previous year, they had built a photon coincidence counter using NI-DAQ card under a LabVIEW environment. While its timing precision of 30ms was adequate for tailored light sources that were being studied at that time, the

present object of study (collection of atoms in thermal equilibrium) required nanosecond timing accuracy. They have developed and tested a time-tagged single-photon counting module that is capable of storing on a PC, in realtime, the data on arrival of single photons at four different detectors, for correlation studies. This has been used to measure the second-order intensity correlations from thermal sources at room temperature and at ~100microkelvin. Coherence times have been obtained that are in good agreement with theoretical predictions, ratifying the performance of the APODAS system.

Using the technique of imparting phase and intensity fluctuations to light by acousto-optic interactions, Hema Ramachandran, Deepak Pandey, Nandan Satapathy, B Suryabrahmam demonstrated a way of creating classical light sources with arbitrary photon number distributions, both Gaussian and non-Gaussian. Along with Solomon Ivan, they have theoretically investigated the properties of such states, and states obtained by adding single photons to classical Gaussian and non-Gaussian states.

Hema Ramachandran has initiated the activity of "Brain Computer Interfaces."

Reji Philip's research interests include nonlinear optical materials and laser produced plasmas. Nonlinear optical transmission finds applications in optical switches, optical limiters and saturable absorbers. Philip and his team consisting of doctoral students and visiting students investigate the nature, magnitude and ultrafast temporal evolution of nonlinearity in various materials, particularly nanoparticles and nanocomposites. On the plasma front, laser produced plasmas from solid targets irradiated by intense ultrafast laser pulses are being investigated. Plasma emission contains visible radiation, high energy photons in the soft and hard X-ray regions, electrons, and ions. The workhorse of the lab is a CPA Ti:Sapphire laser system that produces 100 fs laser pulses at a maximum energy of 10 mJ.

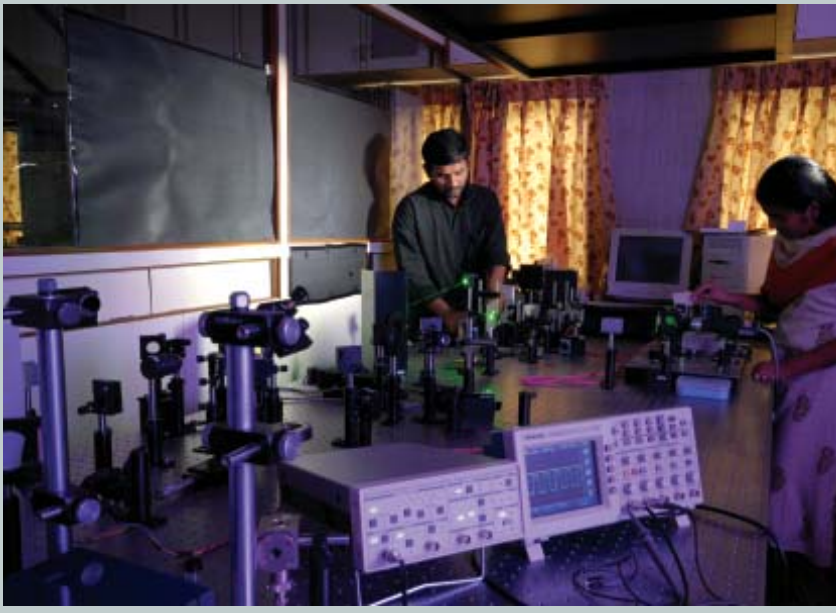
During the year gone by, Philip and colleagues carried out optical nonlinearity measurements in nanostructured materials with a focus on applications. They found interesting features in the size-dependent evolution of optical nonlinearity in atomically precise clusters of gold containing less than 150 atoms. They also investigated fluorinated graphene oxide, functionalised hydrogen exfoliated graphene and its metal hybrids, ZnO modified MoO_3 nanostructures, nanosized mixed Zinc ferrites, ZnO nanotetrapods, and $AgVO_3$ nanobelts. The studies include (i) the role of defects in the optical nonlinearity of hydrogen exfoliated graphene and its metal hybrids; (ii) enhanced optical power limiting in fluorinated graphene oxide and nanosized mixed zinc ferrites; and (iii) photophysical properties of ZnO modified MoO_3 nanostructures. The nanomaterials were mostly synthesized by collaborators: AM Rao of Clemson University (USA); Jayan Thomas of the University of Central Florida (USA); Tae Joo Park of Hanyang University (South Korea); C Vijayan

of the Indian Institute of Technology Madras (India); and VPM Pillai of the University of Kerala, Trivandrum (India). Using a broadband, ultrafast white light supercontinuum as light source, the two-photon absorption spectrum of the laser dye Coumarin 120 in the wavelength range of 650-850 nm could be measured in a single Z-scan. In addition, a novel technique for the simultaneous optical and photoacoustic measurement of nonlinear absorption called "OPAZ-scan" was devised and successfully implemented for saturable absorber, reverse saturable absorber and light scatterer materials. Some of the above studies were carried out when Philip was on a sabbatical to the University of Central Florida, USA.

Philip and his team also conducted spectroscopy and time of flight studies of ultrafast laser-produced plasmas from solid targets. For instance, he carried out extensive time and space resolved measurements of neutral Zn present in the plasma plume produced by the irradiation of a Zn target with 100 femtosecond laser pulses. Fast and slow peaks were observed in the time of flight data due to recombination and atomic contributions occurring at different time scales. The rate of ionisation and recombination becomes stronger and faster in a double pulse excitation configuration. Average velocities of the fast atomic species are independent of background pressure, ensuring the presence of strong forward directed particles, which is unaffected by double pulse excitation. The plasma parameters have been evaluated from the recorded optical emission spectra in each case and a prominent characteristic triplet emission is found. Similarly, the influence of excitation laser pulse width on the expansion dynamics of laser produced Zn and Ni plasmas has been investigated using time-resolved spectroscopy over a broad ambient pressure range of 10^{-6} to 10^{2}Torr. An experiment for interferometric detection and diagnostics of laser plasmas is now being set up.

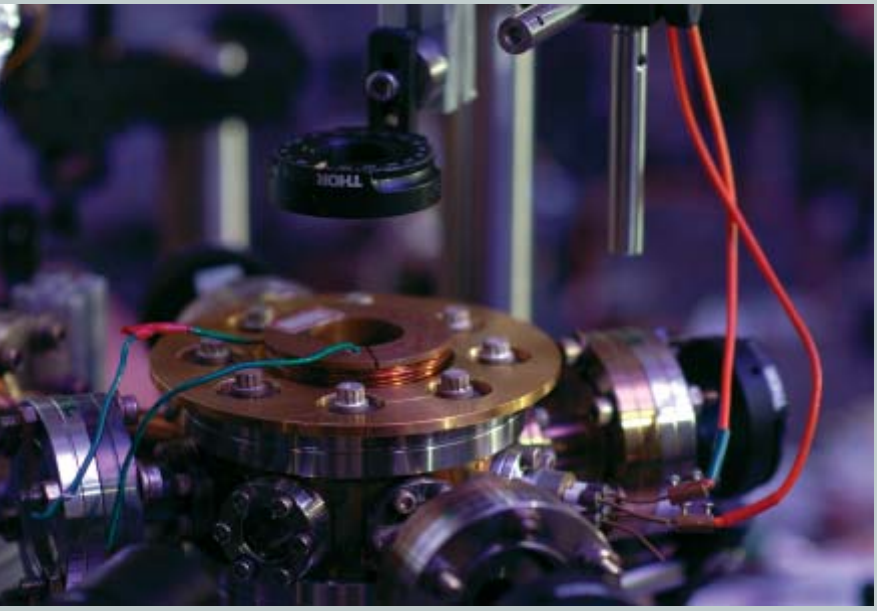
Sadiq Rangwala's areas of current research interest include ultra-cold molecules and quantum interactions.

During the year gone by, his work included the reporting of an experimental apparatus and technique which simultaneously traps ions and cold atoms with spatial overlap. Such an apparatus is motivated by the study of ion-atom processes at temperatures ranging from hot to ultra-cold. This area is a largely unexplored domain of physics with cold trapped atoms. The article discusses the general design considerations



for combining these two traps and presents the experimental setup. The ion trap and atom traps are characterised independently of each other. The simultaneous operation of both is then described and experimental signatures of the effect of the ions and cold-atoms on each other are presented. The use of such an instrument for several problems in physics and chemistry is also briefly discussed. Published in Applied Physics B Online October 2011, and in print August 2012. Collaborators on this work included K Ravi, Seunghyun Lee and Arijit Sharma of RRI and G Werth from the Institut für Physik, Johannes Gutenberg-Universität Mainz, Germany.

Using the above apparatus a very important set of results have been obeyed, which shed light on the nature of cooling of trapped ions by cold atoms. The accepted notions of when ions would cool in collisions with atoms, which have stood the test of time for decades, was comprehensively revised and reinterpreted, by specific demonstrations with ion-atom system, accompanied by theoretical and numerical work. This has opened up several new possibilities with these systems, which include the clever exploitation of symmetry of the colliding, ion atom system. A new cooling mechanism exploiting this symmetry, which is "swap cooling", has been discussed in detail. The remarkable fact of this cooling is that it exploits the very likely glancing collisions between the energetic ion and cold atoms, which results in the ion at rest as a result of a single collision. Normally hundreds of collisions are required to cool the ion. Published in Nature Communications in October 2012. Collaborators on this work included K Ravi, Seunghyun Lee and Arijit Sharma of RRI and G Werth from the Institut für Physik, Johannes Gutenberg-Universität Mainz, Germany.



In this study, the collision-rate coefficient between laser-cooled rubidium (Rb) atoms in a magneto-optical trap (MOT) and optically dark Rb^+ ions in an overlapping Paul trap were measured. In such a mixture, the ions are created from the MOT atoms and allowed to accumulate in the ion trap, which results in a significant reduction in the number of steady-state MOT atoms. A theoretical rate-equation model is developed to describe the evolution of the MOT atom number due to ionisation and ion-atom collisions, and an

expression derived for the ion-atom collision-rate coefficient. The loss of MOT atoms is studied systematically by sequentially switching on the various mechanisms in the experiment. Combining the measurements with the model allows the direct determination of the ion-atom collision-rate coefficient. The scope of the experimental technique is discussed. Published in Physical Review A in May 2013. Collaborators include Lee and Ravi.

Rangwala and collaborators Tridib Ray, Arijit Sharma and S Jyothi studied temperature measurement of laser-cooled atoms using vacuum Rabi splitting. Rubidium atoms were laser cooled to form a magneto-optical trap, within a Fabry-Perot cavity, and strong coupling of the cold atoms to the cavity was demonstrated. The coupling strength is measured using the vacuum Rabi frequency splitting (VRS) of transmitted, cavity-coupled light on atomic resonance. The VRS is measured for two- and three-level atomic systems and the atom-cavity-coupling strength for each system is determined. By allowing the laser-cooled atoms to expand for different times and measuring the corresponding VRS, the number of atoms overlapped with the cavity mode as a function of time was determined. This time-of-flight of atoms from the cavity permits the measurement of the temperature of the laser-cooled atoms. The study also discussed the need for this technique and its utility. Published in Physical Review A in March 2013.

Trapped dilute gas systems at ultra-cold temperatures allows specific state preparation for sizeable populations and the possibility to track the consequent evolution of the system. Traps ensure that even relatively weak and infrequent interactions (collisions) exhibit experimentally observable signatures due to long hold times. Such mixtures of ions and atoms, which have been realised in recent times, can potentially probe chemical processes and interactions in ways that have not been accessible before. This is because the presence of ions provides an attractive force (1/r^5), that is far stronger than the van der Waals' interaction between neutral species and induces interactions in the dilute gas system. Very recently, some investigations of inelastic and three particle processes have been reported. In the present work, Rangawala and his collaborators first manufactured highly vibrationally excited ultra-cold rubidium (Rb) molecules by photoassociation (PA) and then studied their interaction with trapped ions. The experiments were carried out in the combined trap for ions and atoms. The molecules are associated from the magneto optically trapped (MOT) atoms, overlap with the trapped Rb ions created from the MOT. It was demonstrated that the associated molecules dissociate when overlapped with ions, and the "product" free atoms are recaptured by the MOT, resulting in enhancement of the MOT fluorescence. The mechanism for the dissociation of a vibrationally highly excited molecule in collision with an ion was also discussed. The experiment studies molecule photoassociation, a three particle process, which was enabled by another three particle process (PA). The results illustrate the richness of the combined trap system by the creation of systems which have not been experimentally realised so far. The manuscript is under revision post-review. Such experiments create the collision conditions encountered in

upper atmosphere and space. Lee, Jyothi and K Rai Dastidar, a visiting scientist from Indian Association for the Cultivation of Science, also worked on this study.

A number of other experimental numerical and theoretical studies are underway in the context of the physics discussed above by Sadiq Rangwala and RRI students working with him. Several manuscripts are in preparation.

Urbasi Sinha's research interests include Quantum Information and Computation, Fundamental tests of Quantum Mechanical postulates, Quantum Optics, Nanotechnology and Superconductivity.

The research carried out by her during the year gone by included the completion of two major pieces of work in quantum optics and nanotechnology.

The quantum optics study was the demonstration of a triple slit based qutrit system with collaborators at the Institute for Quantum Computing, Waterloo, Canada. The system was used to provide an experimental demonstration of the Aharon Vaidman quantum game for the first time. This work was done in collaboration with P Kolenderski, L Youning, T Zhao, M Volpini, R Laflamme and T Jennewein at IQC and A Cabello at Universidad de Sevilla, Spain. The work was published in Physical Review A.

For the other research project, temperature dependent electron mobility was measured in InAs nanowires with collaborators at IQC. Sinha's major contribution to this was the fabrication of devices for the nanowire based measurements using clean room facilities. This work was done in collaboration with N Gupta, Y Song, GW Holloway and J Baugh at IQC and C Haapamaki and R LaPierre at McMaster University. This work was published in Nanotechnology.

During the past one year at RRI, her major accomplishment has been the setting up of a Quantum Optics laboratory which will specialise in the production and application of single photon sources to problems in Quantum Information and Computation. The lab is a class 10000 clean room and is a highly modulated environment with precise control on temperature, humidity and level of dust particles. This will provide the desired conditions necessary for the performance of precision experiments.

Bhargava Ram's research during the year gone by has been on studying and characterising collisions in trapped atom and ion mixtures along with Sadiq Rangwala, Seunghyun Lee, Tridib Ray and Jyothi S. Work is also in progress on characterising and experiments using the new ion trap, Magneto-Optical Trap (MOT) and Fabry perot cavity with Ray, Jyothi and Rangwala.

Soft Condensed

Over the past few decades, the science of soft condensed matter has emerged as an important area of cross-disciplinary research.

Soft Matter

Overview

The principal areas of interest to the members of the soft condensed matter (SCM) group are summarised in the following pages. 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 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.

The laboratory 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 (LCDs).

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 aging 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 crystallites. The crystallisation of high molecular weight polyethylene from melt or solution leads to the formation of chiral sperulites, as well as tent-like structures. The stability of these structures has been probed using a free-energy expression based on elasticity theory of thin plates with in-plane order.

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 areas of research interest include phase transitions and electro-optic properties of liquid crystals, mean field phenomenological modelling, physics of nano-materials and nano-composites.

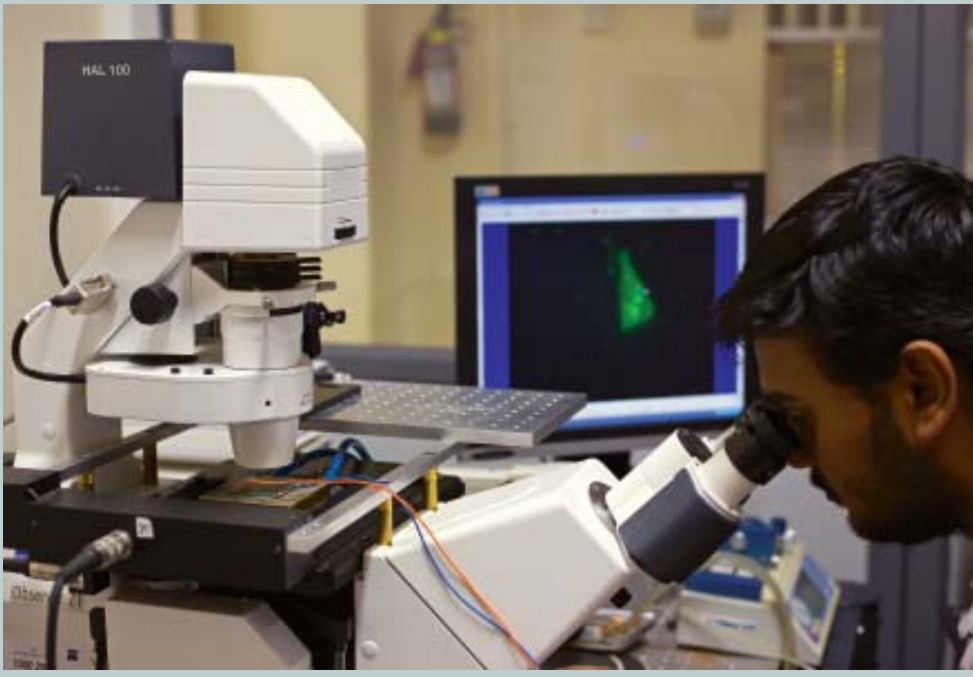
During the year gone by, Roy worked on two experimental studies on achiral triclinic lamellar phase exhibited by bent-core hockey stick shaped molecules in conjunction with R Pratibha, Meenal Gupta, BK Sadashiva and S Radhika. The higher temperature lamellar phase is characterised as an anticlinic and apolar phase. The experimental observations in the lower temperature phase indicate a new fluid lamellar phase having triclinic point symmetry of the layers as first predicted by de Gennes. This is perhaps the first report of the lowest symmetry achiral fluid lamellar phase. The packing of these bent-core hockey stick shaped molecules in the layers gives rise to apolar intercalated strongly biaxial layers in these tilted smectic phases.

Along with M Vijay Srinivasan and P Kannan of the Department of Chemistry, Anna University (Chennai, India), Roy reported a new class of photo and electrically switchable azobenzene containing pendant bent-core liquid crystalline monomers (AZBM 1, 2, and 3) and their polymers (AZBP 1, 2, and 3). The synthesised precursors, monomers, and polymers were characterised by FT-IR, 1H, and 13C NMR spectroscopy. Thermal stability of polymers was examined by thermogravimetric analysis and revealed stable up to 260C. The mesophase transition of monomers and polymers are observed through

polarised optical microscopy (POM) and further confirmed by differential scanning calorimetry (DSC). The electrically switching property of monomers and their polymers were studied by electro-optical method. Among the three monomers AZBM 1 and 2 exhibit antiferroelectric (AF) switching and AZBM 3 exhibits ferroelectric (F) switching behaviour. On the other hand, low molecular weight polymers (AZMP 1, 2, and 3) show weak AF and F switching behaviour. The photo-switching properties of bent-core azo polymers are investigated using UV-vis spectroscopy, trans to cis isomerisation occurs around 25s for AZBP-1 and 30 s for AZBP-2 and 3 in chloroform, whereas reverse processes take place around 80 and 90s.

Roy also investigated photo and electrically switchable asymmetric bent-core liquid crystals with Srinivasan and Kannan. The homologous series of liquid crystals was constructed with a five-ring system using structurally non-symmetrical rod-like mesogens connected with 1, 3-phenylene unit. The synthesised precursor and bent-core liquid crystals were characterised by FT-IR, 1H-NMR, and 13C-NMR spectroscopy. The mesophase characterisation of the asymmetric bent-core liquid crystals was carried out using polarised optical microscopy, differential scanning calorimetry, and X-ray diffraction studies. The significance of tail length (alkyl chain) and nature of mesogen was explored; shorter alkyl chains bent-core compounds exhibited non-switchable rectangular columnar B1 phase. Whereas longer alkyl chain induces switchable lamellar B2 phase, which was further confirmed by electro-optical methods. This lamellar B2 phase exhibits antiferroelectric–anticlinic organisation (SmCAPA) of the molecules in the layers. The photo-switching properties of bent-core azo molecules were investigated using UV–Vis spectroscopy, the trans to cisphotoisomerization was observed at 30s, whereas reverse processes take place in 40s in chloroform.

In another study, a new series of asymmetric bent-core compounds were synthesised using azo linkages with equal as well as unequal terminal alkyl chains and their photo and electrical switching properties investigated. The



mesomorphic properties were characterised using polarised optical microscopy, X-ray diffraction and differential scanning calorimetry. The lower homologues of the series of compounds show a B1 phase whereas higher homologues exhibit a B2 phase. The B2 phase shows an anticlinic-antiferroelectric switching behaviour during electro-optic measurements. The photo-switching properties of the azobenzene containing bent-core molecules were investigated using ultraviolet-visible spectroscopy. The trans to cis photo isomerisation was observed at 25s whereas reverse processes took 14h in chloroform.

D Vijayaraghavan's areas of current professional research interests include nanoparticle-liquid crystal composites, magnetic properties and physical studies of soft condensed matter.

During the year gone by, Vijayaraghavan conducted magnetic susceptibility studies on ferrofluid (FF) doped lyotropic liquid crystal (LLC) systems consisting of a) rod-like and b) disc-like micelles and also on a ternary lyotropic liquid crystal system consisting of rod- like micelles as a function temperature using a Faraday balance. In the case of FF doped discotic LLC, the magnetic susceptibility is positive and found to increase more than one order of magnitude with respect to that of the undoped one indicating a strong coupling between the magnetic nanoparticles and the discotic micelles. However, for LLC system consisting of rod-like micelles, only a marginal increase in susceptibility is seen on doping which can be attributed to the changes in the micellarsizes.

He conducted optical birefringence studies on pure and single-wall carbon nanotubes (0.01 wt%) dispersed lyotropic liquid crystal (LLC) consisting of 25 wt% cetyltrimethyl-ammonium bromide (CTAB) in water as a function of temperature. The pure LLC exhibits

crystal (crystalline surfactant + water), nematic, isotropic and hexagonal phases as function of temperature. The temperature dependence of birefringence is found to exhibit discontinuous changes and peaks at the phase transition temperatures of pure and SWCNTs dispersed LLC respectively. Temperature dependence of mass magnetic susceptibility and electrical conductivity of this system also showed similar behaviour. It is inferred that the observed birefringence peaks may be related to some structural ordering of SWCNTS in the host LLC matrix. Application of 2 Tesla magnetic field to the pure sample shifts the temperatures at which discontinuous changes in birefringence occurs and in the case of composite, the applied field shifts the peaks to the new positions.

Vijayaraghavan conducted a ^{1}H NMR study of an aqueous surfactant solution containing single-walled carbon nanotubes and the role of water associated with the self-assembled structures of carbon nanotubes. This involved dispersing 0.1 wt% single-wall carbon nanotubes (SWCNTs) in 10 mM CTAB aqueous (D_2O) solution which led to interesting self-assembled structures of carbon nanotubes. This system exhibits anisotropic nanotubes bundle, linear chains, loops of CNT fibers, small and large aggregates of nanotubes on increasing the temperature. DSC thermogram of this system also showed peaks at these transition temperatures. He used ^{1}H NMR chemical shift to probe the association of water molecules with these self assembled nanotube structures. It is inferred that in the case of the anisotropic bundle and linear chains of nanotubes, the water molecules are adsorbed at the outer surface of the nanotubes and in the case of CNT loops, the water molecules are trapped inside the loops. For small aggregates of nanotubes, there is no association of water molecules with the nanotubes as the small aggregates break the CNT loops as evidenced from polarised optical microscopy images.

In collaboration with Sandeep Kumar of RRI, Vijayaraghavan carried out physical studies on a nematic liquid crystal doped with different concentrations of single walled carbon nanotubes as a function of temperature. They found an

enhancement in the optical birefringence, magnetic susceptibility and electrical conductivity of the composite very close to the nematic-isotropic transition temperature. They believe that the enhancement may be related to some anomalous structural ordering of carbon nanotubes in the LC matrix.

Pramod Pullarkat's is interested in exploring mechanical responses and shape dynamics of axons—long tubular extensions produced by neuronal cells. The group is also investigating stem-cell mechanics and dynamics. Cell shape and related dynamics are controlled by the cell membrane and the cell cytoskeleton—a biopolymer gel composed of polymer filaments and motor proteins, which can utilize chemical energy to generate active stresses and flow.

The biophysics laboratory has developed an optical fiber based force apparatus with pico-Newton sensitivity and feedback control and can perform simultaneous fluorescence or Phase contrast imaging (Seshagiri Rao and Chirag Kalelkar). The setup is now complete and was used to explore the viscoelastic properties of axons under stretch (Jagruti Pattadkal). Experiments during the last year have shown a non-linear viscoelastic response which depends on the applied force. Theoretical modeling and computer simulations are being developed to investigate the role of force dependent detachment of protein crosslinks in the cytoskeleton which can contribute to the energy dissipation. This work is in collaboration with the group of Aurnab Ghose at IISER-Pune, Andrew Callan Jones of University of Paris, Diderot and Andrea Parmeggeani from University of Montpellier.

Anagha Datar and Roli Srivastava have performed a series of experiments to understand induced axonal shape instabilities, similar to those seen during neurodegeneration. Extensive fluorescence microscopy studies have been performed by genetically modifying neuronal cells to express Green Fluorescence Protein (GFP) on specific cytoskeletal components.

Another set of experiments to study the role of membrane tension in deciding axonal shape has been completed by Anagha using Laser Tweezers in collaboration with Patricia Bassereau of Institut Curie, Paris. She has also completed laser-ablation experiments using a nano-second laser to cut axons to study their cytoskeletal response and axonal stability after "injury".

Renu Vishvakarma (in collaboration with the group of Jyotsna Dhawan, INSTEM, NCBS) has investigated stem-cell mechanics with the aim of understanding cell response to external conditions like stiffness of the extra-cellular matrix. It has been shown that changes in cell spreading due to external factors lead to very systematic nuclear deformations. A quantitative relation has been obtained by performing a variety of experiments and a simple model has been proposed to account for the cell spreading dependent nuclear deformation.

R Pratibha's research interests include phase transitions of liquid crystals and some investigations on liquid crystal-nanocomposites.

Her recent work is concerned with experimental investigations on novel phase transitions resulting from the interplay of chirality and polarity in achiral bent-core liquid crystals (BCLCs).

Pratibha recently carried out detailed studies involving techniques like optical microscopy, x-ray diffraction and dielectric spectroscopy on the bent-core (BC) compound 2,7-naphthylene bis[4-(3-methyl-4-n-tetradecyloxybenzoyloxy)] benzoate (NMTBB) exhibiting two columnar phases. Her studies showed evidence for a new type of phase transition from the switchable orthogonal reverse columnar phase (B_{1rev}) to another switchable reverse columnar phase, with a structure which had hitherto not been observed. The special feature in this novel phase ($B_{1revtiltM}$), is that the layer fragments in the columnar structure modulate in order to relieve the steric hindrance caused by an anticlinic tilting in the adjacent blocks.

She also observed electric field induced transitions into dark conglomerate (DC) phases which were designated as DC-B_{1rev} and DC-$B_{1revtiltM}$, by applying ac electric fields in the B_{1rev} and $B_{1revtiltM}$ phases respectively. While the chiral domains in the DC-B_{1rev} phase appear similar to those observed in other DC phases, the domains in the DC-$B_{1revtiltM}$ phase preserve the typical features of the columnar texture, suggesting that the detailed structure in this DC phase may be different. The experimental studies also showed that, unlike most of the DC phases which are non-switchable and transform into the chiral B_2 phase on application of a high electric field, the DC phases in the present system are electro-optically switchable. Another interesting feature is that the switching behaviour which is ferroelectric in the higher temperature range changes to antiferroelectric, at the same temperature at which the B_{1rev} to $B_{1revtiltM}$ phase transition occurs in the absence of the electric field. This implies that the tendency for anticlinic tilting is retained even in the field induced DC phases. Switchable dark conglomerate phases are very rare and are of interest because of their potential in electro-optic applications. These studies were done in

collaboration with G B Deepa, S Radhika and B K Sadashiva.

Discotic liquid crystals are promising materials for photovoltaic applications as they can provide a means for one-dimensional charge transport along the column axis. Device performance can be enhanced by having separate electron and hole transport channels by combining electron donating disc-like molecules and an electron acceptor like TNF. In relation to this it is important to know whether the TNF molecules lie between the disc-like molecules within a column or between the columns. Pratibha and her collaborators therefore undertook a study of mixtures of a non-mesomorphic compound made of disc-like molecules and TNF. Interestingly they found evidence for the formation of a smectic phase exhibiting focal conic textures very similar to calamitic smectics and XRD studies also showed evidence for reflections corresponding to lamellar order. In addition, a second sharp reflection in the wide angle region corresponding to the distance between two adjacent discotic moieties was also observed. Based on their studies they have proposed that the TNF molecules are present perpendicular to the core regions of the disc-like molecules in the region occupied by the alkyl chains, causing a special type of nanophase segregation which results in the organisation of the disc-like molecules into a lamellar structure. This is believed to be the first observation of a well ordered lamellar phase formed by disc-like molecules induced by nanophase segregation. These studies were done in collaboration with Supreet of Thapar University, Patiala, and Sandeep Kumar.

Ranjini Bandyopadhyay's research interests lie in the structure, dynamics and rheology of complex fluids.

During the year gone by, she studied the rise of an intruder in a vertically and sinusoidally vibrated quasi-two dimensional rectangular cell packed with mustard seeds. For a range of relative density ratios, it was shown that intruder sizes and bed heights, the intruder rise time τ, measured at several angular frequencies ω and peak-to-peak amplitudes a, varies as $\sim (v-v_c)^2$, where $v=a\omega$ and v_c is identified as the critical vibration velocity for the onset of convective motion of the mustard seeds. These experiments, performed in collaboration with with Prakhyat Hejmady, Sanjib Sabhapandit and Abhishek Dhar, show that boundary-driven granular convection is responsible for the intruder rise and that the peak-to-peak velocity of shaking, rather than the peak to peak acceleration, is the relevant parameter for describing the results.

The effects of temperature and drug hydrophobicity on the uptake and release of the drugs Ibuprofen, Erythromycin and Aspirin in the hydrophobic core of Pluronic F127 micelles were studied along with PhD student Rajib Basak. The shapes and the size distributions of the micelles

in dilute, aqueous solutions, with and without drugs, are ascertained using cryo-Scanning Electron Microscopy and Dynamic Light Scattering experiments, respectively. The hydration of the micellar core at lower temperatures is verified using fluorescence measurements. Increasing solution pH is shown to leads to micellar rupture and the subsequent release of the drugs into the solution.

The primary (α) and secondary (β) relaxation processes of aging colloidal glasses of Laponite are extracted from intensity autocorrelation functions obtained in Dynamic Light Scattering (DLS) experiments. A mapping is proposed between the inverse of the thermodynamic temperature ($1/T$) of a supercooled liquid and the waiting time (t_w) of an aging Laponite suspension. In this framework, a coupling between the α and β-relaxation processes and the self-similar nature of these dynamics upon changing the Laponite concentration are reported. Addition of salt to Laponite suspension results in the formation of gel. The microscopic aging dynamics at various clay concentrations, sample waiting times, salt concentrations, sample *pH* and temperatures are studied. A comprehensive overlap of the data is obtained with clay concentration, salt, temperature. The data at different *pH* values cannot be superposed, indicating structural changes in Laponite suspensions. This study was in collaboration with PhD student Debasish Saha and Yogesh Joshi of the Department of Chemical Engineering, IIT Kanpur.

Bandopadhyay, in collaboration with Debasish Saha and Prakhyat Hejmady studied the instabilities at the quasi 2D interface between an aging non-Newtonian fluid and a Newtonian fluid. The fractal dimensions of the patterns are seen to be extremely sensitive to Laponite age, with the fingers showing ballistic propagation in the viscous fingering regime and showing a transition to a crack propagation regime thereafter.

Along with Samim Ali, Bandopadhyay looked at the particle size distributions of Laponite platelets using ultrasound spectroscopy. Ultrasound attenuation increases with suspension age due to the increase of particle-particle correlations and the platelet clusters (tactoids) are believed to eventually break up into single platelets.

This is accompanied by an increase in the viscoelasticity of the medium due to a gradual evolution of electrostatic charges in the system.

Sandeep Kumar's areas of research interests are the design, synthesis and applications of various liquid crystalline materials. He is interested in understanding the structure-property relationship in these intriguing self-assembling supra-molecular architectures.

During the year gone by, Kumar's work has been on liquid crystal nanoscience:

(a) It was shown that gold nanorods (GNRs) can be easily inserted into the supramolecular order of discotic liquid crystals (DLCs) along the director without disturbing their mesomorphism. This work was done in collaboration with V Lakshminarayanan and JK Vij,

(b) Cadmium selenide quantum dot (CdSe QD) has been used as a dopant in ferroelectric liquid crystal (FLC) 2-methylbutyl 4-(4-decyloxybenzylideneamino) cinnamate (DOBAMBC). The effect of CdSe QD in DOBAMBC on its different electro-optical (E-O) properties has been studied in the SmC* phase. This was done in collaboration with R Manohar, SK Gupta, DP Singh, P Tripathi, M Varia,

(c) An experimental characterisation of dispersions of ZnO nanoparticles (NPs) in the columnar matrix of a discotic liquid crystal was carried out along with R Pratibha, R Supreet and KK Raina,

(d) The effect of octadecylamine functionalised

carbon nanotube (ODACNT) on the electro-optic response and dielectric measurements of a liquid crystal were investigated. The threshold electric field of ODACNT doped LC is less as compared to that of pure LC whereas the dielectric anisotropy is enhanced. Collaborators on this were V Manjuladevi and Raj Kumar Gupta,

(e) The photoconductivity of undoped as well as nanostructures of gold chloride doped hexa-alkoxytriphenylene series (HAT4, HAT5 and HAT6) has been studied. After doping with gold chloride, the photoconductivity of HAT4 and HAT5 increased by more than ten times. This study was in collaboration with C Kavitha and V Lakshminarayanan.

Under design and synthesis of novel liquid crystalline materials, Kumar's work included the following:

(a) Microwave-assisted synthesis of novel alkoxycyanobiphenyl-substituted rufigallols is reported by systematically replacing one, two, four, five or six cyanobiphenyl-tethered alkoxy chains. This work was done with Santanu Kumar Pal,

(b) Two novel triphenylene-ammonium-ammonium-triphenylenediads were synthesised. The effect of the peripheral chain length around triphenylene and the length of the linker connecting triphenylene with an ammonium moiety on the liquid crystalline behaviour was studied,

(c) New unconventional T-shaped non-symmetrical dimeric liquid crystalline compounds have been synthesised and their thermotropic properties studied,

(d) Two mesogenic homologous series of H-shaped symmetrical dimers were synthesised and their thermotropic properties studied.

Physical studies on liquid crystalline materials included the following:

(a) Along with Raj Kumar Gupta, Kumar studied the monolayer of the tricycloquinazoline based disk-shaped (TCQCB) molecules at air-water and air-solid interfaces. The TCQCB molecules form a stable Langmuir monolayer at the air-water interface. The monolayer exhibits gas, low density liquid (L1), and high density liquid (L2) phases.

(b) A technique that combines image analysis and polarising optical microscope (POM) was used for the physical investigation of DLCs. This work was done with SS Sastry.

TN Ruckmongathan's areas of current professional research interests include display devices and application of signal processing to driving LCDs. During the year gone by, Ruckmongathan's research themes include exploring the potentials of micro-pulse width modulation that was proposed recently (in SID'2012) to drive displays. He also explored the application of compressive sensing to driving displays.

V Lakshminarayanan's areas of research interest 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 year gone by he started working on a new class of ionic liquids called Deep Eutectic Solvents (DES) which are hydrogen bonded complexes of quaternary ammonium salt (QAS) and a hydrogen bond donor (HBD). These compounds have very interesting properties, such as good stability, wide electrochemical potential window and biomolecular compatibility. He and research scholar Anu Renjith studied the electron transfer processes of some standard redox species in this medium and found that the redox potentials of these systems are shifted with respect to aqueous medium which can be correlated with the thermodynamics of hydration of the redox species in the aqueous medium compared to ionic liquid medium. They also found that the DES medium is ideal for the growth of Pd and Ag nanoparticles which can be directly electrodeposited on a substrate at much lower current densities than in normal conventional electrolytes. The Pd and Ag nanoparticles have been characterised using Raman, DSC, FTIR, SEM, TEM and XRD. Pd nanoparticles have been shown to act as a catalyst in the Suzuki-Miyaura coupling reaction. The electrodeposited mesoporous Pd film was also found to be a good catalyst for the electro-oxidation of methanol and ethanol in addition to hydrogen evolution reaction (HER).

Electron transfer studies through self-assembled phospholipid membranes are quite important in understanding the electron transfer and ion transfer phenomena in biological medium in general and across cell membrane in particular. For this purpose, a method of forming solid surface (ITO) supported lipid bilayer membrane was developed. This lipid immobilised planar surface was used as a working electrode and the electron transfer process is studied using the standard redox species by means of electrochemical techniques such as Cyclic Voltammetry and Impedance Spectroscopy. The results show that the redox species are incorporated in the film and electron transfer processes are controlled by the diffusion of the species through the bilayer lipid membrane. This work is being carried out with the research scholar RV Jagadeesh.

VA Raghunathan's areas of research interest include amphiphilic systems, membranes, and surfactant - polyelectrolyte complexes.

During the year gone by, Raghunathan worked on controlling the thermodynamic stability of intermediate phases in a cationic amphiphile-water system with strongly binding counterions along with PhD student Santosh Prasad Gupta. The influence of two structurally isomeric organic salts, namely, 2-sodium-3-hydroxy naphthoate

(SHN) and 1-sodium-2-hydroxy naphthoate (SHN1), on the phase behaviour of concentrated aqueous solutions of the cationic surfactant cetylpyridinium chloride (CPC) has been studied. Partial phase diagrams of the two systems have been constructed using polarising optical microscopy and X-ray diffraction techniques. A variety of intermediate phases are seen in both the systems for a range of salt concentration. The CPC-SHN-water system exhibits the rhombohedral and tetragonal mesh phases in addition to the random mesh phase, whereas the CPC-SHN1-water systems shows only the tetragonal and random mesh phases. The CPC-SHN-water system also exhibits two nematic phases consisting of cylindrical and disc-like micelles at relatively low and high salt concentrations, respectively. These results show that the concentration of the strongly bound counterion provided by the organic salt can be used as a control parameter to tune the stability of different intermediate phases in amphiphile-water systems.

In collaboration with PhD student Antara Pal, Raghunathan also studied hexatic phases of achiral and chiral self-assembled polymers. A thermodynamically stable line hexatic phase formed by self-assembled polymer-like micelles of amphiphilic molecules has been observed. In agreement with theoretical predictions, this phase occurs in between a nematic phase and a two-dimensional hexagonal phase. Structure of the chiral line hexatic phase, obtained by doping with a chiral molecule, is found to be consistent with the theoretically envisaged Moire state consisting of polymer bundles, with bond-orientational order within each bundle twisted about an axis parallel to the average polymer direction. In addition to confirming the predictions of fundamental theories of two-dimensional melting, these results are relevant in a variety of situations in physics and biology, where parallel packing of polymer-like objects is encountered.

Yashodhan Hatwalne's areas of research interest include phenomenological theory of liquid crystals, membranes, and polymer crystallisation.

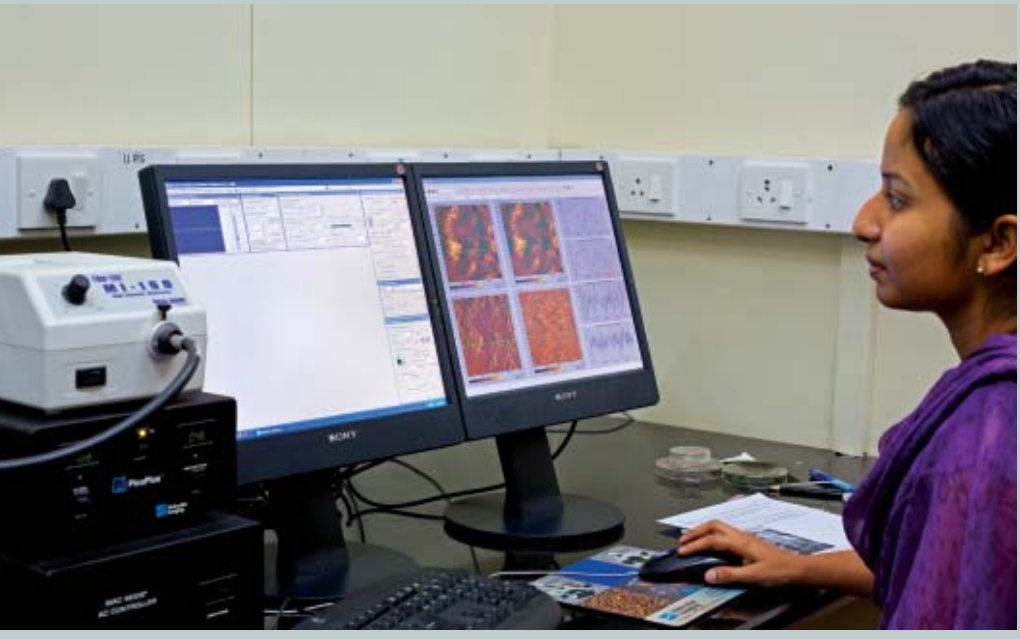
During the year gone by, he studied the structure and energetics of dislocation arrays, grain boundaries in smectics, and the twist grain boundary- A phase (with PR Venkatramanan and

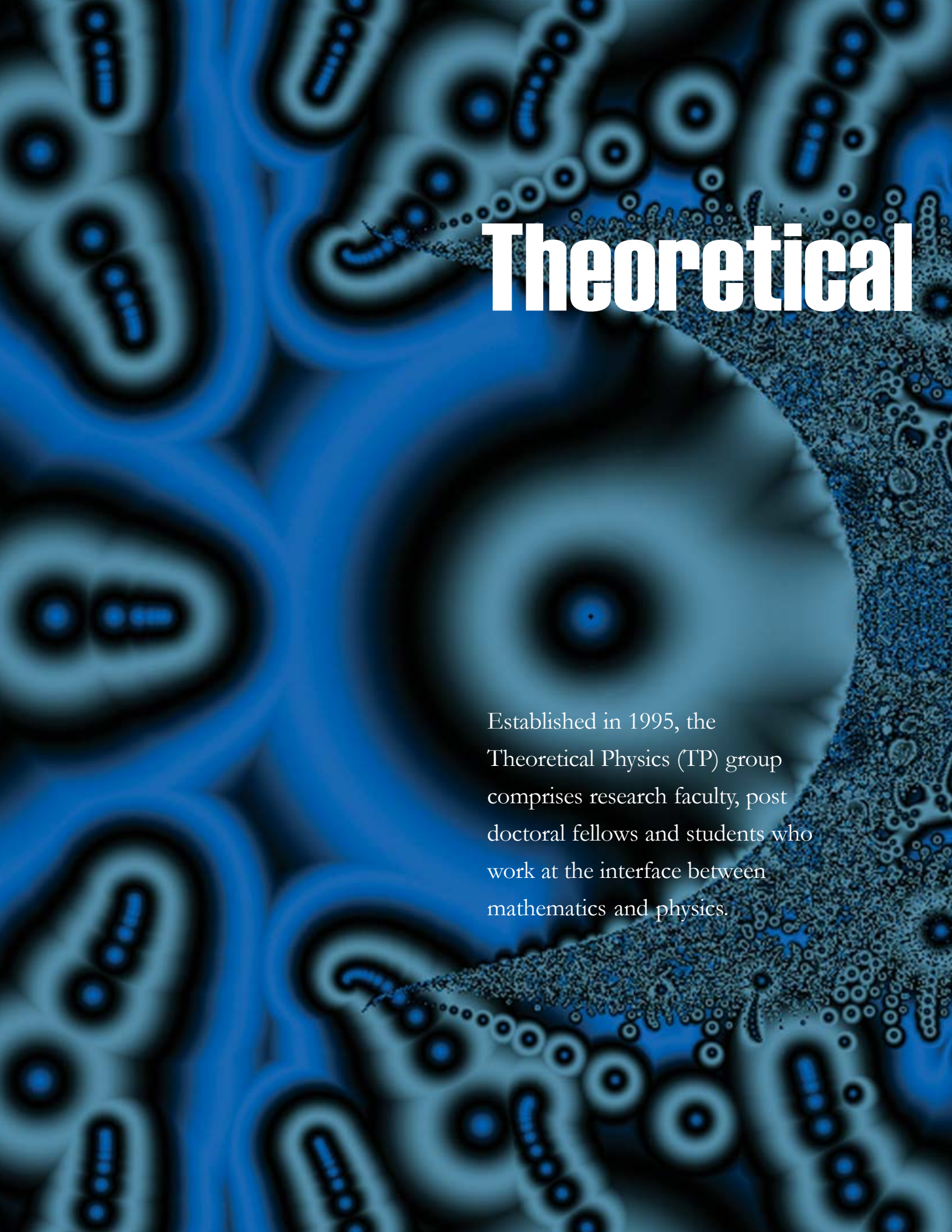
TC Lubensky). Extensive analysis of the geometry, topology and energetics of all possible linear dislocation arrays in smectic-A liquid crystals, and that of the twist grain boundary-A phase was completed. Structure of the twist grain boundary-C phase was also investigated. The lower critical chirality (analogous to the lower critical field for the Abrikosov phase of superconductors) for the twist grain boundary-C phase was calculated. He also predicted a novel modulated phase of smectic-C liquid crystals (with PR Venkatramanan and NV Madhusudana). This modulated phase is a manifestation of covariant elasticity in the unusual context of *achiral* smectics.

Hatwalne also examined chiral symmetry breaking in polymer spherulites (with Jaya Kumar A and M Muthukumar). Work on detailed comparison between the proposed theory and experiments is in progress. Analysis of the structure and energetics of tent- and scroll structures of polymer crystallites continues, with the aim of formulating a unified theory for the diverse morphologies of polymer crystallites.

Mahesh Kumar Varia's research interests include blue phase forming materials, peri-dodeca substituted hexabenzenecoronene, truxene, etc. liquid crystalline PAHs and new core for liquid crystalline materials.

During the year gone by Varia's research covered the synthesis of various discotic liquid crystals with Sandeep Kumar; the synthesis of cholesterol benzoate derivatives and lithocholic acid derivatives with HT Srinivasa; the synthesis of calamitic and bent-core LCs with Prajapati of the University of Baroda; various physical studies of LCs and their nanocomposites with Rajiv Manohar of the University of Lucknow; and the study of Langmuir-Blodgett film of azo-based molecule with Rajkumar Gupta of BITS Pilani.





Theoretical

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.

Physics

Overview

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.

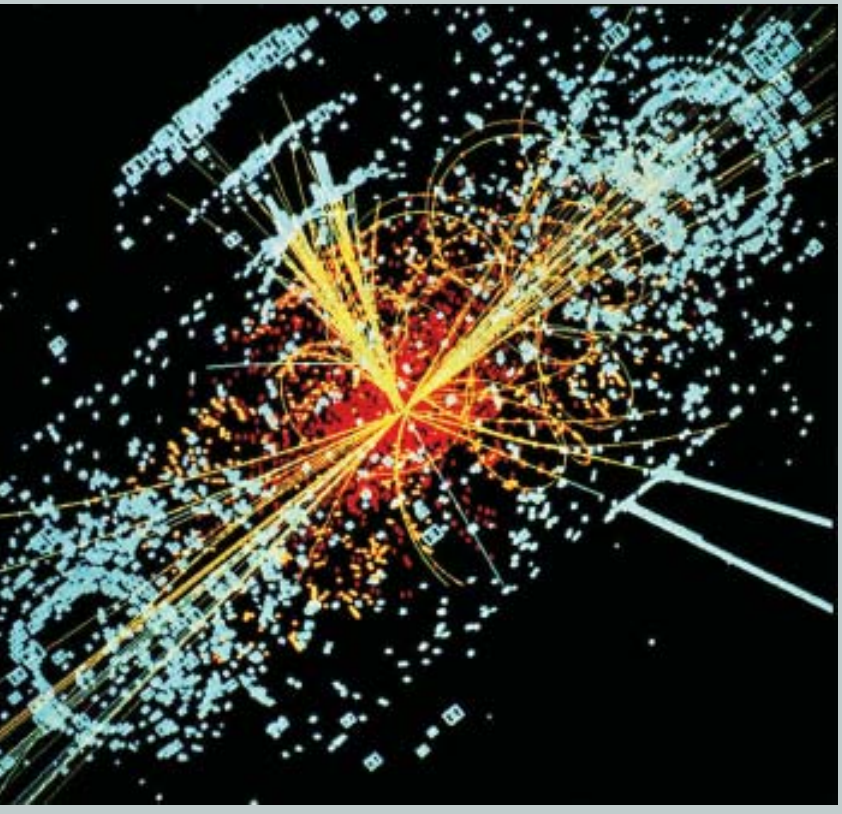
Theoretical and experimental research in heat and electron transport in mesoscopic scale systems is important for the advancement of the fundamental understanding of the transport properties of materials, which in turn would lay the foundation needed to improve the performance of nanodevice applications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

Bala R Iyer's areas of current professional research interests include general relativity and gravitational waves.

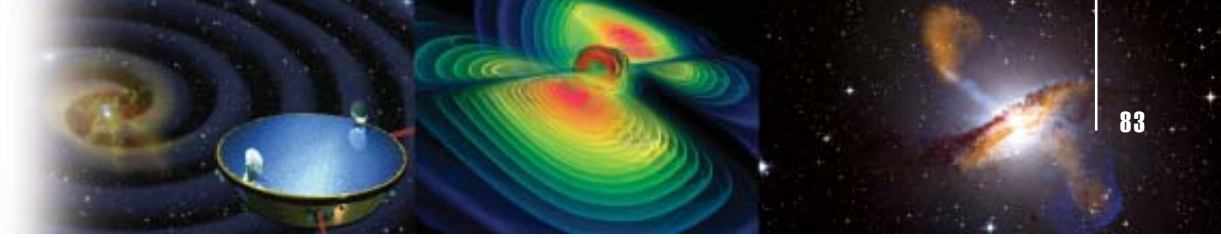
During the year gone by, Iyer studied instantaneous terms of spherical harmonic modes of the third post-Newtonian gravitational waveform for inspiralling compact binaries in general orbits with CK Mishra and Arun KG (of CMI, Chennai). Though most of the prototypical inspiralling compact binaries in their final stages are expected to have circularised, there are other classes of sources where the binaries do possess significant eccentricities when they enter the sensitive bandwidths of the terrestrial GW detectors. This work computes the spherical harmonic modes of the gravitational waveform at 3PN accuracy for such eccentric systems. It deals with all the terms in the waveform propagating on the light cone and referred to as the "instantaneous" terms. Using the multipolar post Minkowskian (MPM) formalism, all the instantaneous terms in the radiative moments are obtained going via the two cannonical moments and their relation to the six source moments. The STF radiative moment then allows one to compute the spherical harmonic decomposition of the gravitational waveform. The modes are then re-expressed using the 3PN generalised quasi-Keplerian representation for the elliptical orbit case.

Iyer also looked at hereditary contribution to spherical harmonic modes of the third post-Newtonian gravitational waveform for inspiralling compact binaries in quasi-elliptical orbits in terms of small eccentricity approximation. The complete spherical harmonic modes include "hereditary" terms arising from backscatter of the radiation from the static field of the source as it

propagates to infinity. These computations of these terms are more involved since they depend on an integration involving the complete past history of the source. Unlike in the circular orbit case, closed form expressions for the hereditary contributions are not feasible in the general orbit case. However, the use of the quasi-Keplerian representation makes possible an analytical treatment as an expansion in the time-eccentricity. The expansion can be carried out to any order in powers of eccentricity and hence supplementing the results for the "instantaneous terms" with the present one, the complete expression for the 3PN accurate spherical mode decomposition for binaries in elliptical orbits has been obtained. The modes would be useful for comparison with results of numerical relativity simulations for eccentric binaries. Further, these results are equivalent to the computation of GW polarisations and hence useful for applications in GW data analysis for eccentric binaries. This study was done in conjunction with CK Mishra and G Faye (Institut d'Astrophysique de Paris, France).

Comparison of post-Newtonian templates for extreme mass ratio inspirals was also undertaken during the year. Extreme mass ratio inspirals (EMRIs), the inspirals of compact objects into supermassive black holes, are important gravitational wave sources for the Laser Interferometer Space Antenna (LISA). The performance of various post-Newtonian (PN) template families relative to the high precision numerical waveforms is investigated in the context of EMRI parameter estimation with LISA. Expressions for the time domain waveforms TaylorT1, TaylorT2, TaylorT3, TaylorT4 and TaylorEt are derived up to 22PN order beyond the Newtonian term, for a test particle in a circular orbit around a Schwarzschild black hole. The phase difference between the above 22PN waveform families and numerical waveforms are evaluated during two-year inspirals for two prototypical EMRI systems with mass ratios 0.0001 and 0.00001. It is found that the dephases (in radians) for TaylorT1 and TaylorT2, respectively, are about 10^{-9} (10^{-2}) and 10^{-9} (10^{-3}) for mass ratio 0.0001 (0.00001). This suggests that using 22PN TaylorT1 or TaylorT2 waveforms for parameter estimation of EMRIs will result in accuracies comparable to numerical waveform accuracy for most of the LISA parameter space. On the other hand, from the dephase results, it was found that TaylorT3, TaylorT4 and TaylorEt fare relatively poorly as one approaches the last stable orbit. This implies that, as for comparable mass binaries using the3.5PN phase of waveforms, the 22PN TaylorT3 and TaylorEt approximants do not perform well enough for the EMRIs. The reason underlying the poor performance of TaylorT3, TaylorT4 and TaylorEt relative to TaylorT1 and TaylorT2 is also examined. This work was done in collaboration with V Varma of BITS, Pilani; R Fujita of the Univ. de les Illes, Balears (Spain), and A Choudhary of Indian Institutes of Science Education and Research, Pune.

Joseph Samuel's research interests are in the use of geometry and topology in physics. He has been interested in the geometric phase in quantum mechanics and optics, general relativity and more



recently, in DNA elasticity. 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 year gone by, Samuel studied the mechanics and thermal fluctuations of biopolymer elasticityin collaboration with Supurna Sinha. They used methods from semiclassical mechanics to address the problem of thermal fluctuations in semiflexible polymers. Their approach interpolates between mechanics and statistical mechanics and they were able to determine the elastic properties of DNA using this method.

He worked on a "Gaussian" for diffusion on the sphere in collaboration with Abhijit Ghosh of the Department of Chemical and Biomolecular Engineering, South Korea, and Supurna Sinha.

They derived an analytical closed form expression,which 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 work suggests a new and efficient algorithm for numerical integration of the diffusion equation on a sphere. They performed Monte Carlo simulations to compare the numerical efficiency of the new algorithm with the older Gaussian one.

In collaboration with Anirban Polley and Supurna Sinha, Samuel also studied bending elasticity of macromolecules. They studied the bend angle distribution of semiflexible polymers of short and intermediate lengths within the wormlike chain model. This enabled them to calculate the elastic response of a stiff molecule to a bending moment. The results go beyond the Hookean regime and explore the nonlinear elastic behaviour of a single molecule. This work offers analytical formulae for the bend angle distribution and for the moment-angle relation. The analytical study is compared against numerical Monte Carlo simulations. The functional forms derived here can be applied to fluorescence microscopic studies on actin and DNA. The results are relevant to recent studies in "kinks" and cyclisation in short and intermediate length DNA strands.

Samuel and Sinha also studied the statistical mechanics of bent twisted ribbons. They presented an analytical study of bent twisted ribbons, first having described the elastic response of a ribbon within a purely mechanical framework. They then studied the role of thermal fluctuations in modifying its elastic response. They predicted the moment angle relation of bent and twisted ribbons. Such a study is expected to shed light on the role of twist in DNA looping "J factor" and on bending elasticity of twisted grapheme ribbons.

In collaboration with Rahul Sawant, Urbasi Sinha and Supurna Sinha of RRI and Aninda Sinha of

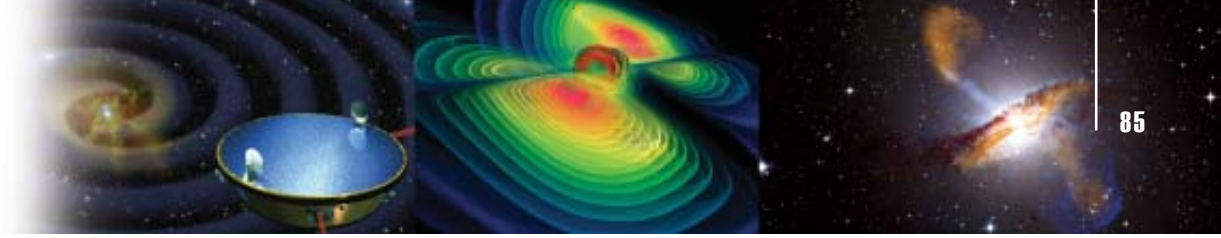
the Center for High Energy Physics, IISc, Samuel worked on three-slit experiments based on a path integral perspective. In an n-slit experiment where each slit may be open or closed there are(2^n)-1 configurations possible. From the Schrodinger point of view there is no connection between the outcomes of these experiments since they correspond to different boundary conditions. However, the Feynman path integral form suggests that in an approximate sense these outcomes may be related. This study looked at the extent to which this approximation holds in a three-slit experiment.

Madhavan Varadarajan's areas of professional research interest include classical and quantum gravity.

During the year gone by, he worked towards an anomaly-free quantum dynamics for a weak coupling limit of Euclidean gravity and its diffeomorphism covariance with C Tomlin of Penn State University. The G-->0 limit of Euclidean gravity introduced by Smolin is described by a generally covariant U(1)xU(1)xU(1) gauge theory. In an earlier paper, Tomlin and Varadarajan had constructed the quantum Hamiltonian constraint of density weight 4/3 for this U(1)xU(1)xU(1)theory so as to produce a non-trivial anomaly free LQG-type representation of the Poisson bracket between a pair of Hamiltonian constraints. These constructions involved a choice of regulating coordinate patches. The use of these coordinate patches is in apparent conflict with spatial diffeomorphism covariance. In this current work, they showed how an appropriate choice of coordinate patches together with suitable modifications of these constructions results in the diffeomorphism covariance of the continuum limit action of the Hamiltonian constraint operator,while preserving the anomaly free property of the continuum limit action of its commutator.

Work continued on the Koslowski- Sahlmann Representation I. A generalisation of the representation underlying the discrete spatial geometry of Loop Quantum Gravity, to accommodate states labelled by smooth spatial geometries, was discovered by Koslowski and further studied by Sahlmann. Varadarajan's work shows how to construct the diffeomorphism constraint operator in this representation from suitable connection and triad dependent operators. It was shown that the KS representation supports the action of hitherto unnoticed "background exponential" operators which, in contrast to the holonomy-flux operators, change the smooth spatial geometry label of the states. These operators are shown to be quantisations of certain connection dependent functions and play a key role in the construction of the diffeomorphism constraint operator.

Varadarajan also studied the Koslowski-Sahlmann Representation II, imposition of SU(2) and diffeomorphism invariance, along with Miguel Campiglia of RRI.The background exponentials discovered in the previous work play a key role in the imposition of the SU(2) Gauss Law and the spatial diffeomorphism constraints in the KS representation. Their use corrects certain errors in prior work by Sahlmann by virtue of additional phases which arise when the group



averaging techniques used to impose the constraintsare correctly employed. This is work in progress, about to be completed soon.

The Koslowski-Sahlmann Representation III was with regard to realising the KS Representation as that of square integrable functions on a spaceof generalised connections. Augmenting the holonomy-flux algebra underlying Loop Quantum Gravity with the background exponentials discovered above, leads to a larger algebra. Restricting attention to its holonomy-ackground exponential commutative subalgebra allows an application of Gel'fand theory, which obtains a configuration space of generalised connections. Varadarajan, Campiglia and Alok Laddha of CMI Chennai are investigating whether the Koslowski-Sahlmann Hilbert space can be realised as a space of square integrable functions of these generalised connections.

Narendra Kumar's research interests are in randomness, dissipation and decoherence in condensed matter – quantum as well as classical.

During the year gone by, he studied first-passage time of lattice of lattice versus continuum along with Kamal Sharma. The well-known approach, based on Schrödinger's integral equation, to the problem of calculating the first passage probability density in time for classical diffusion on a continuum is re-visited for the case of diffusion by hopping on a discrete lattice. It turns out that a certain boundary condition central to solving the integral equation, invoked first by Schrödinger and then by others on the basis of a physical argument, needs to be modified for the discrete case. In fact, the required boundary condition turns out to be determined entirely by the normalisation condition for the first passage probability density. Explicit analytical expression is derived for the first passage density for a three-site problem modelling escape over a barrier. The related quantum first passage problem is also commented upon briefly.

Sharma and Kumar also worked on getting acquainted with gears and wheels – quantum mechanically. For a pair of wheels or gears with positive coupling, i.e., without slip or play, there are rules of engagement that have some interesting consequences when their dynamics is treated quantum mechanically. They illustrated the principal ideas involved here with the help of an elementary, basically a textbook exercise whose solution, however, is not only interesting, but may also be re-interpreted rather creatively. Possible relevance of this simple exercise to the incredible, ever-shrinking world of the nano is pointed out.

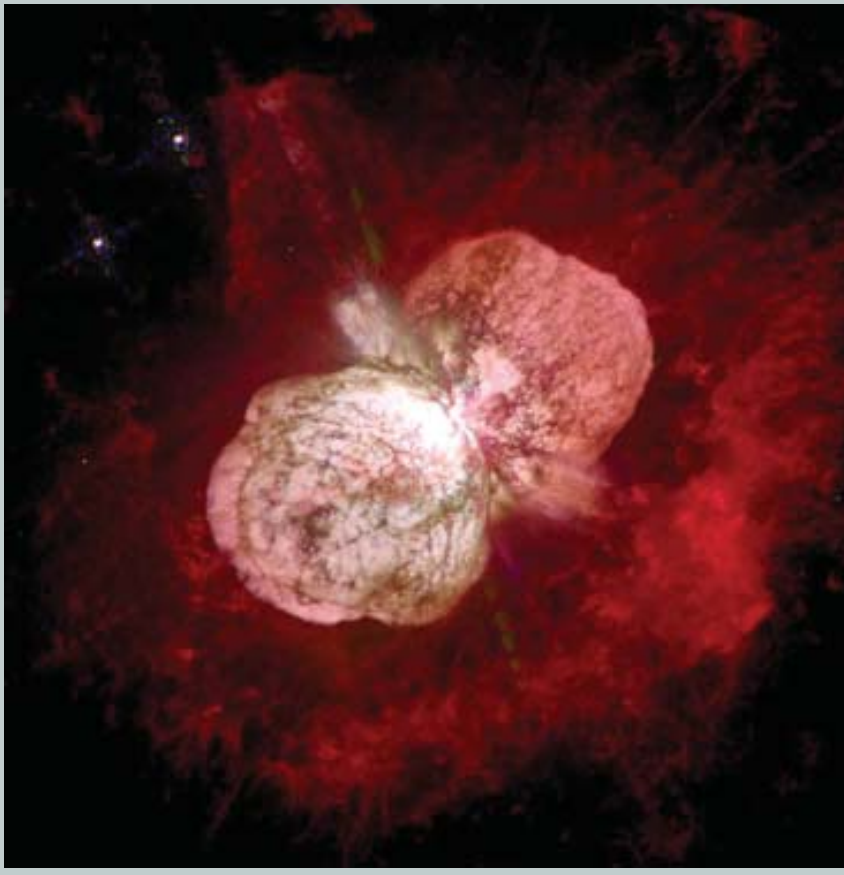
V Ranjith and Kumar offered exact solutions for a class of tight-binding Hamiltonian systems. The Schrodinger integral-equation approach for calculating the classical first-passage time (C-fpt) probability density is extended to the case of quantum first-passage time (Q-fpt). Using this extension, they calculated analytically the Q-fpt probability density for a class of few-site/state tight-binding Hamiltonian systems, e.g., a qubit,

as well as for an infinite 1D lattice. The defining feature of such a quantum system is that the passage across the boundary between a subspace (ω) and its complement (ω) is through a unique pair of door-way sites such that the first departure from (arrival at) ω corresponds to the first arrival at (departure from) ω. The Q-fpt probability density so derived remains positive over the time interval in which it also normalises to unity. These conditions of positivity and normalisation define the physical time domain for the Q-fpt problem. This time domain is found to remain finite for the few-site/state Hamiltonian systems considered here, which is quite unlike the case for the diffusive C-fpt problems. The door-way sites and the associated Q-fpt probability density derived here should be relevant to inter-biomolecular/ nanostructural electron transport phenomena.

Sanjib Sabhapandit's research interests are in the field of statistical physics.

During the year gone by, he studied work fluctuations for a Brownian particle in a harmonic trap with fluctuating locations along with Arnab Pal. They considered a Brownian particle in a harmonic trap, with the location of the trap being modulated according to an Ornstein-Uhlenbeck process. They investigated the fluctuation of the work done by the modulated trap on the Brownian particle in a given time interval in the steady state. The large deviation as well as the complete asymptotic form of the probability density function of the work done was calculated. The theoretical asymptotic forms of the probability density function are in very good agreement with the numerics. The validity of the fluctuation theorem for this system was discussed.

Sabhapandit looked at tagged particle diffusion in one-dimensional gas with Hamiltonian dynamics in collaboration with Anjan Roy of RRI, Onuttom Narayan of the University of California, Santa Cruz, and Abhishek Dhar of the International Centre for Theoretical Sciences, TIFR, Bangalore. They considered a one-dimensional gas of hard point particles in a finite box that are in thermal equilibrium and evolving



under Hamiltonian dynamics. Tagged particle correlation functions of the middle particle were studied. For the special case where all particles have the same mass, analytic results were obtained for the velocity auto-correlation function in the short time diffusive regime and the long-time approach to the saturation value when finite-size effects become relevant. In the case where the masses are unequal, numerical simulations indicate sub-diffusive behaviour with mean square displacement of the tagged particle growing as t/ln(t) with time t. Also various correlation functions, involving the velocity and position of the tagged particle, show damped oscillations at long times that are absent for the equal mass case.

The Brazil-nut effect is the phenomenon in which a large intruder particle immersed in a vertically shaken bed of smaller particles rises to the top, even when it is much denser. The usual practice, while describing these experiments, has been to use the dimensionless acceleration of shaking. Considering a vibrated quasi-two-dimensional bed of mustard seeds, it has been shown here that the peak-to-peak velocity of shaking, rather than the acceleration, is the relevant parameter in the regime where boundary-driven granular convection is the main driving mechanism. Sabhapandit and his collaborators P Hejmady, R Bandyopadhyay and A Dhar found that the rise-time of an intruder is described by a scaling law that holds over a wide range of the amplitude and the angular frequency of vibration, and the diameter and the density of the intruder.

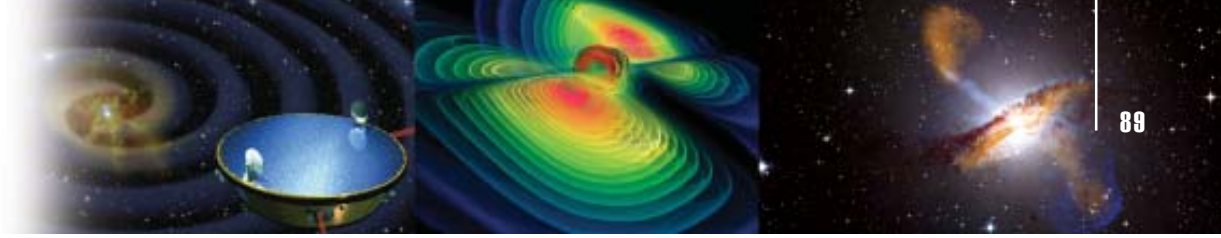
Sumati Surya works on both classical and quantum aspects of gravity. The main focus of her research is currently on the causal set approach to quantum gravity. In this approach the space-time continuum is replaced by a discrete substructure, the causal set which is a

locally finite poset. She is also interested in the related question of quantum interpretation in the context of quantum cosmology.

During the year, she studied the boundary term contribution to the volume of a small causal diamond along with Surbhi Khetrapal, a VSP student from RRI. The calculation of the space-time volume of a small Alexandrov interval in four-dimensional curved space-time was first formalised by Myrheim to leading order in the curvature. In his work, Myrheim introduced a term which he referred to as a surface integral, whose evaluation however remained opaque until the present work. This led subsequent authors to evaluate the volume using other, somewhat less rigorous techniques. In the present work, an unambiguous evaluation of this integral was performed, and it was shown that it arises from the difference in the flat space-time volumes of the curved and flat space-time intervals. An explicit evaluation was done using first order degenerate perturbation theory, and it was shown that the Myrheim term adds a dimension independent factor to the flat space-time volume as the lowest order correction. Surya's analysis admitted a simple extension to a more general class of integrals over the same domain. A combination of techniques then allowed her to show that the next order correction to the volume vanishes.

Surya, along with Mriganko Roy and Debdeep Sinha, also looked at the discrete geometry of a small causal diamond. An important question in causal set theory is how to recover continuum in formation from the underlying discrete substructure. While much progress has been made on this front, for causal sets that are approximated by flat space-time, the effects of curvature have not been easily included. In this work, it was shown that the discrete geometry of a small causal diamond in a curved space-time can be studied extensively using the average abundance of element chains or total orders in the underlying causal set C. The first order curvature corrections to the flat space-time expression for the abundance were first obtained using Riemann normal coordinates. For fixed space-time dimension, this allowed Surya and her team to find a new expression for the discrete scalar curvature of C as well as the time-time component of its Ricci tensor in terms of the abundances of k-chains. In addition, a new dimension estimator for C was obtained replacing the flat space-time Myrheim-Meyer estimator in generic curved space-times. This work takes a big step in finding a purely local definition of the discrete curvature scalar.

Another project during the year was phase space diffusion of particles in FRW space-time, whose main idea was to extend the flat space-time analysis of Lorentz invariant phase space diffusion to that of FRW space-times. This is important for causal set phenomenology and the question: does the discrete structure of space-time manifest itself in evolution over cosmological scales? In the project, the basic analytic equations for the model were set up and an analysis was begun on the stochastic equations. Initial attempts at numerical simulation did not yield useful results and hence new techniques are now being implemented. This work though challenging is nevertheless of considerable value for Lorentz



invariant phenomenology and is therefore being actively pursued. The study was done in conjunction with VSP student Masooma Ali.

Along with Lisa Glaser of the Neils Bohr Institute, Copenhagen, Surya worked towards a definition of locality in a manifold-like causal set. In preserving Lorentz invariance, causal set discretisation leads to a certain type of (causal) non-locality, which makes the reconstruction of manifold-like structures highly non-trivial. In earlier work in analysing the observables of 2d causal set quantum gravity, it was noticed numerically that the abundances A(k,N) of k-element inclusive intervals in a finite N(>k) causal set obey a certain distinctive and characteristic fall-off as k increases. In this work, an analytic calculation was done and it was shown that indeed A(k,N) is proportional to a generalised hypergeometric function in all space-time dimensions. This behaviour is thus a characterising "finger-print" for a manifold like causal set, since it means that there are local regions which are approximately like flat space-time. Extensive numerical analysis was done and it was demonstrated that this fingerprinting of a causal set is remarkably successful in determining a local neighbourhood of an element in a causal set. The work is currently being written up.

In tackling the question of full causal set quantum gravity in 4-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 4-d case, we 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 has been 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 4-d causal set quantum gravity. This work was done in collaboration with David Rideout of UC San Diego and Rafael Sorkin of the Perimeter Institute.

Supurna Sinha's areas of research interest are equilibrium and non-equilibrium statistical mechanics and soft condensed matter. In recent years, she has focused on semi-flexible polymer elasticity. In the area of non-equilibrium statistical mechanics, she has particular interest in finite wave-vector extension of hydrodynamics applied to granular matter and bacterial bath. She has also applied statistical mechanical methods to lipid membranes to understand some issues in analogue quantum gravity and cosmology.

During the year gone by, an analytical study of the role of thermal fluctuations in shaping molecular elastic properties of semiflexible polymers was carried out along with Joseph Samuel. The study interpolates between mechanics and statistical mechanics in a controlled way and showshow thermal fluctuations modify the elastic properties of biopolymers. The research involved the following.

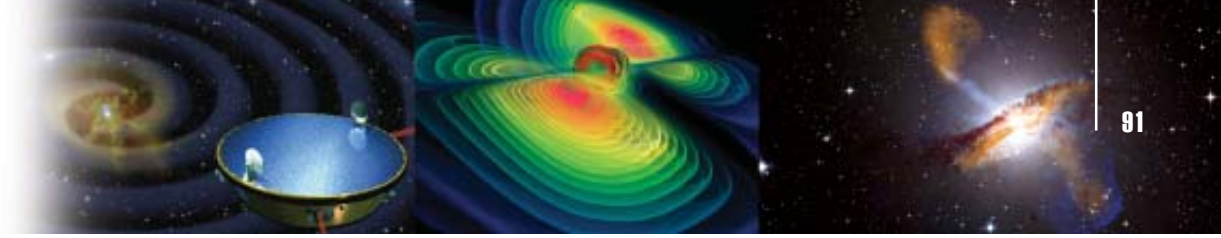
1) A study of the minimum energy configurations with approximate analytical formulae for the free energy of stretched twisted polymers. The central new result of the study is a closed form expression for the leading thermal fluctuation correction to the free energy around the nonperturbative writhing 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.

2) A "Gaussian" for diffusion on the sphere in collaboration with Abhijit Ghosh of the Department of Chemical and Biomolecular Engineering, South Korea, and Joseph Samuel. They derived an analytical closed form expression, which 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 is derived using saddle point methods for short times, it works well even for intermediate times. The work 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.

3) In collaboration with Anirban Polley and Joseph Samuel, Sinha studied the bend angle distribution of semi flexible polymers of short and intermediate lengths within the wormlike chain model. This enables the calculation of the elastic response of a stiff molecule to a bending moment. These results go beyond the Hookean regime andexplore the nonlinear elastic behaviour of a single molecule. They presented analytical formulae for the bend angle distribution and for the moment-angle relation. The functional forms derived here can be applied to fluorescence microscopic studies on actin and DNA. These results are relevant to recent studies in "kinks" and cyclisation in short and intermediate length DNA strands.

4) In collaboration with Samuel, Sinha presented an analytical study of bent twisted ribbons. They first describe the elastic response of a ribbon within a purely mechanical framework. The role of thermal fluctuations in modifying its elastic response was studied and the moment angle relation of bent and twisted ribbons was predicted. This study is expected to shed light on the role of twist in DNA looping "J factor" and on bending elasticity of twisted grapheme ribbons.

She was also part of the three-slit experiments conducted in collaboration with Rahul Sawant, Joseph Samuel, Urbasi Sinha of RRI and Aninda Sinha of IISc. In an n-slit experiment where each



slit may be open or closed there are(2^n)-1 configurations possible. From the Schrodinger point of view there is no connection between the outcomes of these experiments since they correspond to different boundary conditions. However, the Feynman path integral form suggests that in an approximate sense these outcomes may be related. The extent to which this approximation holds in a three-slit experiment was studied.

Sandipan Sengupta's area of current professional research interests include gravitational physics.

During the year gone by, he studied topological parameters in space times with boundaries. In four dimensional gravity theory, the Barbero-Immirzi parameter has a topological origin, and can be identified as the coefficient multiplying the Nieh-Yan topological density in the Lagrangian (density). Based on this fact, a first order action formulation for space times with boundariesis introduced. The bulk Lagrangian (density), containing the Nieh-Yantopological density, needs to be supplemented with suitable boundary terms so that it leads to a well-defined variational principle. Within this general framework, he analysed spacetimes with Dirichlet and locally Antide Sitter (or de Sitter) asymptotia.

For asymptotically locally de Sitter geometries, the action principle has non-trivial implications. It admits an extremum for all such solutions provided the SO(3,1) Pontryagin and Euler topological densities are added to it with fixed coefficients. The resulting Lagrangian, while containing all three topological densities, has only oneindependent topological coupling constant, namely, the Barbero-Immirzi parameter. In the final analysis, it emerges as a coefficient of the SO(3,2) (or SO(4,1)) Pontryagin density, and is present in the action only for manifolds for which the corresponding topological index is non-zero.

Along with Madhavan Varadarajan, Sengupta studied parametrised field theory and quantum gravity. The parametrised field theory, which is just the free scalar field theory in two spacetime dimensions written in a diffeomorphism invariant manner, is a good toy model for gravity which is also a diffeomorphism invariant theory. The topic of this project is to quantise this model with a background spacetime. The insights gained would be useful for dealing with the notion of a background structure in the loop quantisation of four dimensional gravity theory.

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.

Facilities

Millimeter Wave and RF Lab

The engineers from the RF lab are experienced professionals with diverse skill-sets in the design and development of millimetre 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 decametre to millimetre.

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 Quantum Information and Computing (QUIC) 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 the 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 with cryo facilities** and the other is a **Raman spectrograph**, both of which are functioning well.

The **Field Emission Scanning Electron Microscope (FESEM)** can image surfaces with a narrow focused electron beam produced by a Schotty type field emitter at a resolution of better than 0.8 nm and has many additional features for studies of soft matter. The instrument has an in-lens secondary electron detector in addition to a chamber mounted detector. There is also a Back Scattered Electron Detector for low voltage imaging studies to provide chemical contrast. The FESEM has a Scanning Transmission Electron Microscope that can be used for imaging nanomaterials as well as an Energy Dispersive X-ray Spectroscope to identify elements and their surface composition. A special feature of the FESEM is the local charge compensation mode to enable imaging of non-conducting surfaces and low voltage operation for organic thin film studies. A cryo microscopy attachment has the capability to image freeze fractured samples at liquid nitrogen temperature. The FESEM is being used for studies of nanomaterials, polymers, liquid crystal nanocomposites and soft matter.

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 RRI Library, founded by Sir CV Raman, started functioning with his personal collection of books and journals. The library has grown to be a hybrid library comprising both print and electronic information resources. It continues to be a constant source of both general and specialised information for its users. Its collection totals 67,689, consisting of 27,395 books and 40,294 Bound Volumes of journals. Besides these, it possesses 1,649 non-book materials consisting of scientific slides, CD-ROMs, DVDs and audio/video tapes. This year, 31 e-books were added to the collection. The RRI Library subscribes to 138 journals.

The library continued its partnership with the National Knowledge Resource Consortium, which provides access to the users to 15 publishers and their journals, a total of 4,594 publications. The library's web page has been continuously upgraded to provide single window access to these consortium online resources.

Digital Library Activities

Digitisation of archival materials, photographs and audio/video was continued during the year. These materials are uploaded on to the institutional repository, namely the RRI Digital Repository. Current research publications, theses submitted to RRI, photos and audio/video files are being added to this repository. The communities on this repository have grown from 10 to 17 and the number of uploads from 4,320 to 5,594 records. One hundred photos of Sir CV Raman were added, increasing the total number to 400.

Researcher Id Badge, a helpful tool offered by Web of Knowledge of Thomson Reuters to manage intellectual assets (the published works of a researcher), has been created for all the faculty of RRI.

The RRI library has trained 12 library students, from Bangalore University, Kuvempu University and Women's Polytechnic, Bangalore, as a part of their internship programme.

The RRI library has given a part of its Hindi books and multimedia resources like CDs and DVDs as a part of an outreach programme to five institutions in different parts of North India, thus enabling them to build their collection and reach out particularly to remote communities.

COMPUTER FACILITIES

The various computing needs of the different research and development groups and the library at the institute are handled by the computer division. The present campus network consists of a switched gigabit backbone on fibre and wired 10/100 Mbps ethernet to the desktops.

The campus is connected to the internet and the National Knowledge Network via a high speed 1Gbps link. It is also connected to the internet via a dedicated 10Mbps link. A 2Mbps leased line connects the institute to the observatory at Gauribidanur. Users are also provided with VPN access to the LAN. The campus network is expected to be upgraded and the process for the same has been initiated. Further mobility is assured by the secured wireless network available on the campus premises.

The computing power of multi-CPU multi-core systems is 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 computer of 16 nodes, 32 Intel Xeon X5570 processors, 256GB RAM and 32TB storage caters to the heavy computation needs of users. The storage was enhanced from 8TB to 32TB.

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 like email, web, printing, VPN, 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 employeesas well as those who work at the Indian Academy of Sciences. 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.

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

Academic Programmes

requirements and process can be found on the website.

Currently, there are nearly 62 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 five PhD degrees were awarded and six 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 8 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)

The Visiting Student Programme, aimed at offering research experience to highly motivated undergraduate or post-graduate students, continued during the year.

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

The total number of visiting students at a time was limited by available project/mentor and relevant resources. During this year, a total of 124 students from different parts of the country participated in the programme, with the duration ranging anywhere between 6 weeks and 6 months.

People at RRI

RESEARCH FACULTY

ASTRONOMY AND ASTROPHYSICS

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N Udaya Shankar
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Biman Nath
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Avinash A Deshpande
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B Ramesh
Research Interests: diffuse matter in our and other galaxies, analogue and digital signal processing, (sub) millimeterwave telescopes
Email: *ramesh@rri.res.in*

S Sridhar
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CR Subrahmanya (Visiting Professor)
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Biswajit Paul (Coordinator)
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Shiv Kumar Sethi
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KS Dwarakanath
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Lakshmi Saripalli
(RRI Trust funded position)
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Nayantara Gupta
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Mayuri S (Research Associate)
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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. 138 papers featuring RRI members as their authors and/or co-authors were published during the year. There were 20 publications in conference proceedings and 33 (31 in journals and 2 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.

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.

Other Activities

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 "Polymer translocation through active and patterned nano-pores", "Beltrami States in Plasmas", "A quantum dot close to Stoner instability: the role of Berry's phase", "How do insects fly?", "The discovery of the Higgs Boson and consequences"and "Coherent perfect absorption mediated bending of light the wrong way".

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.

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

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

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

Submitted

Nandan Satapathy: Investigations towards quantum walk in optical and cold atomic systems

Venkataraman PR: The structure of the TGB-A and TGB-C phases near the lower critical twist

Radhika S: Investigations on the synthesis and structure-property relationships of novel mesogenic bent-core compounds.

Arijit Sharma: Atom cavity interactions with hot and cold atomic vapors.

Ravi K: Trapping and cooling of ions and the study of ion atom interactions.

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.3,480.00
NON-PLAN (Recurring)	Rs.107.10
TOTAL	Rs.3,587.10

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. In addition, this year included a lecture on "The Three Great Rivers of Himalayas" as part of the Hindi Day Celebrations. 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 is a partner of this international initiative that also includes students of the Jawahar Navodaya Vidyalaya (JNV), a school in Dodaballapur, approximately an hour's drive away from Bangalore. Members of RRI have set up a 20-inch optical telescope. 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". The commissioning of this project is in the finishing stages and efforts on mode of participation by this projet, the Institute and the school are being worked out.

The International Science School

Professor Harry Messel International Science School: This is being conducted by the Science Foundation of Physics, University of Sydney, Australia.

RRI has been coordinating this event from India since 2007. Based on a selection procedure conducted by RRI in 2012 on a national level, five students of classes XI and XII were selected to attend the School to be held during June-July 2013.

APPENDIX 1

PUBLICATIONS

PAPERS IN JOURNALS

1 Neutrinos from decaying muons, pions, neutrons and kaons in gamma ray bursts
Moharana, Reetanjali*; Gupta, Nayantara
Astroparticle Physics, **36**, 195, 2012

2 Energy deposition profiles and entropy in galaxy clusters
Chaudhuri, Anya*; Nath, Biman B; Majumdar, Subhabrata*
Astrophysical Journal, **759**, 87, 2012

3 High-resolution imaging of the ATLBS regions: the radio source counts*
Thorat K*; Subrahmanyan, Ravi; Saripalli, Lakshmi; Ekers RD*
Astrophysical Journal, **762**, 16, 2013

4 Pulse phase resolved spectroscopy of Vela X-1 with Suzaku
Maitra, Chandreyee; Paul, Biswajit
Astrophysical Journal, **763**, 79, 2013

5 Timing and spectral properties of Be/X-ray pulsar EXO 2030+375 during a Type I outburst
Nair, Sachindra*; Maitra, Chandreyee; Jaisawal, Gaurava K*; Paul, Biswajit
Astrophysical Journal, **764**, 158, 2013

6 Roles of radiation and RAM pressure in driving galactic winds
Sharma, Mahavir; Nath, Biman B
Astrophysical Journal, **750**, 55, 2012

7 Fast holographic deconvolution: a new technique for precision radio interferometry
Sullivan IS*; Morales MF*; Hazelton BJ* ; Deshpande AA ; Prabu T; Roshi, Anish D; Udaya, Shankar N; Srivani KS; Subrahmanyan, Ravi; +40 Co-authors
Astrophysical Journal, **759**, 17, 2012

8 Probing primordial magnetic fields using Ly-alpha clouds
Pandey, Kanhaiya L; Sethi SK
Astrophysical Journal, **762**, 15, 2013

9 Understanding the Fanaroff-Riley radio galaxy classification
Saripalli, Lakshmi
Astronomical Journal, **144**, 85, 2012

10 Low-frequency observations of the moon with the Murchison wide field array
McKinley B*; Briggs F*; Deshpande AA; Prabu T; Roshi D Anish; Udaya Shankar N; Srivani KS; Subrahmanyan, Ravi ; +45 Co-authors
Astrophysical Journal, **145**, 23, 2013

11 Low-frequency imaging of fields at high galactic latitude with the Murchison Wide Field array 32 element prototype
Williams, Christopher L*; Subrahmanyan, Ravi; Sethi SK; Deshpande AA; Prabu T; Udaya Shankar N; Srivani KS; and 45 co-authors
Astrophysical Journal, **755**, 47, 2012

12 Supernovae and AGN driven galactic outflows
Sharma, Mahavir; Nath, Biman B
Astrophysical Journal, **763**, 17, 2013

13 The impact of thermodynamics on gravitational collapse: lament formation and magnetic field amplification
Peters, Thomas*; Schleicher RG*; Klessen, Ralf S*; Banerjee, Robi*; Federrath, Christoph*; Smith, Rowan J*; Sur, Sharanya
Astrophysical Journal Letters, **760**, L28, 2012

14 Simultaneous X-ray and optical observations of thermonuclear bursts in the LMXB EXO 0748-676
Paul, Biswajit; Archana M; Saripalli, Lakshmi
Bulletin of the Astronomical Society of India, **40**, 93, 2012

15 Investigation of variability of iron emission lines in Centaurus X-3
Naik, Sachindra*; Paul, Biswajit
Bulletin of the Astronomical Society of India, **40**, 503, 2012

16 Astrosat: some key science prospects
Paul, Biswajit
International Journal of Modern Physics D, **22**, 1341009, 2013

17 Measurements of a cryogenic linear polarization modulator form m-wavelengths
Gault AC*; Bierman EM*; Hyland PO*; Keating BG*; Malu SS; Timbie PT*
IEEE Microwave and Wireless Components Letters, **22**, 212, 2012

18 Spectral and polarization study of the double relics in Abell 3376 using the Giant Metrewave radio telescope and the very large array
Kale, Ruta; Dwarakanath KS; Bagchi, Joydeep*; Paul, Surajit
Monthly Notices of the Royal Astronomical Society, **426**, 1204, 2012

19 Energy-dependent orbital modulation of X-rays and constraints on emission of the jet in Cyg X-3
Zdziarski, Andrzej A; Maitra, Chandreyee*****; Frankowski, Adam; Skinner, Gerald K; Misra, Ranjeev
Monthly Notices of the Royal Astronomical Society, **426**, 1031, 2012

20 Simulation of radiation-driven winds from disc galaxies
Chattopadhyay, Indranil; Sharma, Mahavir; Nath, Biman B; Ryu, Dongsu
Monthly Notices of the Royal Astronomical Society, **423**, 2153, 2012

21 Galactic winds driven by cosmic ray streaming
Uhlig M*; Pfrommer C*; Sharma, Mahavir; Nath, Biman B; Ensslin TA*; Springel V*
Monthly Notices of the Royal Astronomical Society, **423**, 2374, 2012

22 Spectrum and ionization rate of low-energy galactic cosmic rays
Nath, Biman B; Gupta, Nayantara; Biermann, Peter L*
Monthly Notices of the Royal Astronomical Society Letters, **425**, L-86, 2012

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

24 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

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

26 A new layout optimization technique for interferometric arrays, applied to the Murchison Wide Field array
Beardsley AP*; Hazelton BJ*; Roshi, Anish D; Udaya Shankar N; Srivani KS; Subrahmanyan, Ravi; Prabu T; Deshpande AA; +38 Co-authors
Monthly Notices of the Royal Astronomical Society, **425**, 1781, 2012

27 The EoR sensitivity of the Murchison wide field array
Beardsley AP*; Hazelton BJ*; Morales MF; Deshpande AA; Prabu T; Roshi A; Udaya Shankar, N; Srivani KS; Subrahmanyan, Ravi ; +19 co-authors
Monthly Notices of the Royal Astronomical Society, **429**, L5, 2013

28 Magnetic field amplification during gravitational collapse - influence of turbulence, rotation and gravitational compression
Sur, Sharanya; Federrath, Christoph; Schleicher, Dominik RG*; Banerjee, Robi*; Klessen, Ralf S*
Monthly Notices of the Royal Astronomical Society, **423**, 3148, 2012

29 Pulsed radio emission from the Fermi-LAT pulsar J1732-3131: search and a possible detection at 34.5 MHz
Mann, Yogesh; Aswathappa HA; Deshpande AA
Monthly Notices of the Royal Astronomical Society, **425**, 27, 2012

30 An effective field theory approach to Compton scattering in plasma
Kumar, Ravindra*; Ravishankar, V*; Krishan, Vinod
Physical Letters A, **376**, 2053, 2012

31 Testing hadronic models of gamma ray production at the core of Cen A
Joshi, Jagdish C*; Gupta, Nayantara
Physical Review D, **87**, 023002, 2013

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

33 Density and temperature effects on Compton scattering in plasmas
Kumar, Ravindra*; Ravishankar V*; Krishnan, Vinod
Physics of Plasmas, **19**, 093115, 2012

34 The Large Observatory for X-ray Timing (LOFT)
Feroci, M*; den Herder, J*; Paul, Biswajit; +125 co-authors
Proceedings of SPIE, **8443**, 84432D-1, 2012

35 The Murchison Wide Field Array: The square kilometre array precursor at low radio frequencies
SJ*; Goeke R*; Bowman JD*; Deshpande AA; Prabu T; Udaya Shankar N; Srivani KS; Subrahmanyan, Ravi; +25 co-authors
Publications of the Astronomical Society of Australia, **30**, 007, 2013

36 RRI-GBT multi-band receiver: motivation, design and development
Maan, Yogesh; Deshpande AA; Chandrashekar, Vinutha; Chennamangalam, Jayanth; Rao, Raghavendra KB; Somashekar R; Anderson, Gary; Ezhilarasi MS; Sujatha S; Kasturi; Sandhya P; Bauserman, Jonah; Duraichelvan R; Amiri, Shahram; Aswathappa HA; Barve, Indrajit V; Sarabagopalan G; Ananda HM; Beaudet, Carla; Bloss, Marty; Dhamnekar, Deepa B; Egan, Dennis; Ford, John; Krishnamurthy S; Mehta, Nikhil Mehta; Minter, Antony H; Nagaraja HN; Narayanaswamy N; Karen O'Neil; Raja, Wasim; Sahasrabudhe, Harshad; Shelton, Amy; Srivani KS; Venugopal HV; Viswanathan, Salna T
The Astrophysical Journal Supplement Series, 204:12 (10pp)

37 Radiation and thermal pressure driven galactic winds
Nath, Biman B
Astronomical and Astrophysical Transactions, **27**, 183-186, 2012

38 Science with the Murchison widefield array
Bowman, Judd D* ; Cairns, Iver* ; Kaplan, David L* ; Deshpande AA ; Prabhu T; Udaya Shankar, N ; Srivani KS ; Subrahmanyan, Ravi; +40 co-authors
Publications of the Astronomical Society of Australia, **30**, e031, 2013

39 The uncertainty product of position and momentum in classical dynamics
Devi, Usha AR; Karthik HS
American Journal of Physics, **80**, 708, 2012

40 Enhanced optical nonlinearity in β-$AgVO_3$ nanobelts on decoration with Ag nanoparticles
Parida MR; Vijayan C; Rout CS; Sandeep, Suchand CS; Philip, Reji
Applied Physics Letters, **100,** 121119, 2012

41 Enhanced optical limiting in nanosized mixed zinc ferrites
Chantharasupawong, Panit*; Philip, Reji; Endo, Tamio*; Thomas, Jayan*
Applied Physics Letters, **100**, 221108, 2012

42 X-ray topography, photopyroelectric and two-photon absorption studies on solution grown benzimidazole single crystal
Vijayan N*; Bhagavannarayana G*; Halder SK*; Verma S*; Philip J*; Philip, Reji; Rathi, Brijesh*
Applied Physics A, **110**, 55, 2013

43 Novel N-substituted-5-phenyl-1H-pyrazole-4-ethyl carboxylates as potential NLO materials
Chandrakanthaa B*; Isloorb, Arun M*; Sridharanc, Kishore; Philip, Reji; Shetty, Prakash*; Padaki, Mahesh*
Arabian Journal of Chemistry, **6**, 97-102, 2013

44 Large third-order nonlinearity of new-conjugated donor-acceptor polymers with substituted thiophene and 1,3,4-oxadiazole moieties
Sunitha MS*; Adhikari AV*; Vishnumurthy KA*; Safakath K*; Philip, Reji
International Journal of Polymeric Materials, **61**, 483, 2012

45 Beyond the Goldenberg-Vaidman protocol: Secure and efficient quantum communication using arbitrary, orthogonal, multi-particle quantum states
Shukla, Chitra*; Pathak, Anirban*; Srikanth, R
International Journal of Quantum Information, **10**, 1241009, 2012

46 Hetero-epitaxial Growth of Cubic La(Sr)MnO3 on Hexagonal ZnO, in-plane orientations of La(Sr)MnO3 (001), (110), and <111) Phases
Uehara, Kenichi*; Okada, Akira*; Okamoto, Akinobu* ; Philip, Reji; 8 co-authors
Japanese Journal of Applied Physics, **51**, 11PG07, 2012

47 Synthesis and optical limiting studies of HA(P) and HA(P)@SiO2 core-shell nanoparticles
Rahulan, Mani K; Vinitha G; Ganesan S; Philip, Reji; Aruna P
Journal of Materials Science, **23**, 877, 2012

78 Optical power limiting in fluorinated graphene oxide: An insight into the nonlinear optical properties
Chantharasupawong P; Philip, Reji; Narayanan NT; Sudeep PM; Mathkar A; Ajayan PM; Thomas J
Journal of Physical Chemistry C, **116,** 25955, 2012

49 Moments of non-Gaussian Wigner distributions and a generalized uncertainty principle: I. The single-mode case
Ivan, Solomon J; Mukunda N; Simon R
Journal of Physics A: Mathematical and Theoretical, **45**, 195305, 2012

50 Defect induced changes in the linear and non-linear optical properties of ZnO nanotetrapods
Egblewogbe M; Anand B; Podila R; Philip, Reji; Sai SSS; Rao AM
Materials Express, **2**, 351, 2012

51 Non-linear optical properties of composite naphthalocyanine thin films with nanocrystalline morphology
Panicker, Nisha S*; Smijesh N*; Philip, Reji; Menon CS*
Materials Letters, **89**, 188, 2012

52 A comparative study on the optical limiting properties of different nano spinel ferrites with Z-scan technique
Thomas, Jeevan Job*; Krishnan, Shiji*; Sridharan, K*; Philip, Reji; Nanadakumar, Kalarikkal*
Materials Research Bulletin, **47**, 1855, 2012

53 Investigations on the electrical, thermal and optical properties of the nonlinear optical allyl thio urea mercury chloride single crystal
Sreekanth G*; Chandralingam S*; Philip, Jacob*; Jayalakshmy MS*; Philip, Reji; Sridharan, Kishore; Kumar, Santhosh R*; Joseph, Ginson P*
Materials Research Bulletin, **47**, 4043,2012

54 Evolution of nonlinear optical properties: from gold atomic clusters to plasmonic nanocrystals
Philip, Reji; Chantharasupawong P; Qian H; Jin R; Thomas J
Nano Letters, **12**, 4661, 2012

55 Cooling and stabilization by collisions in a mixed ion-atom system
Ravi K; Lee, Seunghyun; Sharma, Arijit; Werth W; Rangwala SA
Nature Communications, **3,** 1126, 2012

56 Single step synthesis and optical limiting properties of Ni-Ag and Fe-Ag bimetallic nanoparticles
Sridharan, Kishore; Endo, Tamio; Cho, Sang-Geun; Kim, Jongryou; Joo Park, Tae; Philip, Reji
Optical Materials, **35**, 860, 2013

57 Aharon-Vaidman quantum game with a young-type photonic qutrit
Kolenderski, Piotr*; Sinha, Urbasi; Youning, Li*; Zhao, Tong*; Volpini, Matthew*; Cabello, Adan*; Laflamme, Raymond*; Jennewein, Thomas*
Physical Review A, **86**, 012321, 2012

58 Temperature measurement of laser-cooled atoms using vacuum Rabi splitting
Ray, Tridib; Sharma, Arjit; Jyothi S; Rangwala SA
Physical Review A, **87**, 033832, 2013

59 Size-dependent optical properties of Au nanorods
Smitha SL*; Gopchandran KG*; Smijesh N*; Philip, Reji
Progress in Natural Science: Materials International, **23**, 36, 2013

60 A measure of non-Gaussianity for quantum states
Ivan, Solomon J; Kumar, Sanjay M*; Simon R*
Quantum Information Processing, **11**, 853, 2012

61 Generation and distillation of non-Gaussian entanglement from nonclassical photon statistics
Ivan, Solomon J; Mukunda N*; Simon R*
Quantum Information Processing, **11**, 873, 2012

62 4-Nitrophenyl 4-hydroxy-3-methylbenzoate
Sreenivasa S*; Devarajegowda HC*; Srinivasa HT; Kumar, Vijith*; Palakshamurthy BS*
Acta Crystallographica E, **68**, 03490, 2012

63 Methyl 4-benzyloxy-2-hydroxybenzoate
PalakshamurthyBS*; Srinivasa HT; Kumar V*;Sreenivasa S*; Devarajegowda C*
Acta Crystallographica Section E, **68**,03382,2012

64 4-(Octyloxy)phenyl 2-oxo-2H-chromene-3-carboxylate
Palakshamurthy BS*; Sreenivasa HT; Srinivasa*; Roopashree KR*; Devarajegowda HC*
Acta Crytallographica Section E, **69**, 0212, 2013

65 4'-Cyanobiphenyl-4-yl 7-diethylamino-2-oxo-2H-chromene-3-carboxylate
Sreenivasa S*; Srinivasa HT; Palakshamurthy BS*; Kumar, Vijith*; Devarajegowda HC*
Acta Crystallographica Section E, ***E69,*** 0266, 2013

66 Ethanol electrocatalysis on gold and conducting polymer nanocomposites: A study of the kinetic parameters
Pandey, Rakesh K; Lakshminarayanan V
Applied Catalysis B: Environmental, **125**, 271, 2012

67 Modulated phases of phospholipid bilayers induced by tocopherols
Kamal, Md. Arif; Raghunathan VA
Biochimica et Biophysica Acta, **1818**, 2486, 2012

68 Phase behaviour of the cetyltrimethylammonium tosylate (CTAT) - water system
Pal, Antara; Mary, Rose; Raghunathan VA
J. Mol. Liq., **174**, 48, 2012

69 Modulated phases of phospholipid bilayers induced by sterol derivatives
Arif Kamal, Md.; Pal, Antara; Raghunathan VA
Soft Matter, **8**, 11600, 2012

70 Gold nanorods embedded discotic nanoribbons
Avinash BS*; Lakshminarayanan V; Kumar, Sandeep; Vij JK*
Chemical Communications, **49**, 978, 2013

71 Carbon-based liquid crystals: art and science
Bisoyi, Hari Krishna*; Kumar, Sandeep
ChemInform, **43**, 4, 2012

72 Studies on Langmuir monolayer of tricycloquinazoline based disk-shaped liquid crystal molecules
Gupta, Raj Kumar*; Manjuladevi V*; Karthik C*; Kumar, Sandeep; Suresh KA*
Colloids and Surfaces A, **410**, 91, 2012

73 Electro-catalytic activity of multiwall carbon nanotube-metal (Pt or Pd) nanohybrid materials synthesized using microwave-induced reactions and their possible use in fuel cells
Kumar, Lakshman V*; Ntim, Susana Addo*; Sae-Khow, Ornthida*; Janardhana, Chelli*; Lakshminarayanan, V; Mitra, Somenath*
Electrochimica Acta, **83**, 40, 2012

74 Effect of ring-substituted oxysterols on the phase behavior of dipalmitoylphosphatidyl-choline membranes
Kamal, Md. Arif; Raghunathan VA
European Biophysics Journal, **41**, 891, 2012

75 Functional discotic liquid crystals
Kumar, Sandeep
Israel Journal of Chemistry, **52**, 820, 2012

76 A brief review of Carbazole-based photorefractive liquid crystalline material
Manickama M*; Iqbal P*; Belloni M*; Kumar, Sandeep; Preece, Jon A*
Israel Journal of Chemistry, **32**, 917, 2012

77 Gray scales by cross pairing of select and data voltages in multi-line addressed liquid crystal displays
Ubaru, Shashanka*; Ruckmongathan TN
Journal of Display Technology, **8**, 669, 2012

78 Achiral bent-core azo compounds: effect of different types of linkage groups and their direction of linking on liquid crystalline properties
Nagaveni, Nagendrappa Gowdru*; Roy, Arun; Pradas, Veena*
Journal of Materials Chemistry, **22**, 8948, 2012

79 Investigations on photo and electrically switchable asymmetric bent-core liquid crystals
Srinivasan MV*; Kannan, Palaninathan*; Roy, Arun
Journal of Materials Science, **48**, 2433, 2013

80 Synthesis, characterization, and nonlinear optical properties of donor-acceptor conjugated polymers and polymer/Ag nanocomposites
Murali MG*; Dalimba, Udayakumar*; Sridharan, Kishore
Journal of Materials Science, **47**, 8022, 2012

81 Effect of functionalized carbon nanotube on electro-optic and dielectric properties of a liquid crystal
Manjuladevi V*; Gupta, Kumar, Raj*; Kumar, Sandeep
Journal of Molecular Liquids, **171**, 60, 2012

82 Ferroelectric liquid crystal matrix dispersed with Cu doped Zno nanoparticles
Singh, Dharmendra Pratap*; Gupta, Swadesh Kumar*; Pandey, Kamal Kumar*; Yadav, Satya Prakash*; Varia MC; Manohar, Rajiv*
Journal of Non-Crystalline Solids, **363**, 178, 2013

83 Nonlinear optical studies of lead lanthanum borate glass doped with Au nanoparticles
Rajaramakrishna R*; Karuthedath, Safakath; Anaveka RV*; Jain H*
Journal of Non-Crystalline Solids, **358**, 1667, 2012

84 Electrochemical impedance analysis of adsorption and enzyme kinetics of calf intestine alkaline phosphatase on sam-modi ed gold electrode
Shrikrishnan, S*; Sankaran K; Lakshminarayanan V
Journal of Physical Chemistry, **116**, 16030, 2012

85 Photo and electrically switchable behavior of azobenzene containing pendant bent-core liquid crystalline polymers
Srinivasan, Vijay M*; Kannan P*; Roy, Arun
Journal of Polymer Science Part A : Polymer Chemistry, **51**, 936, 2013

86 Porphyrin aggregates in the form of nano fibers and their unusual aggregation induced emission
Pandey, Rakesh K; Chitgupi U; Lakshminarayanan V
Journal of Porphyrins and Phthalocyanines, **16**, 1055, 2012

87 Liquid crystal parameters through image analysis
Sastry, Sreehari S*; Kumar, Sandeep; Kumari, T Vindhya*; Malika K; Rao, Gowari Sankara B*; Tiong, Ha Sie*
Liquid Crystals, **39**, 1527, 2012

88 Novel triphenylene-ammonium-ammonium-triphenylene-based discotic ionic liquid crystalline dimers
Gupta, Satyam Kumar; Kumar, Sandeep
Liquid Crystals, **39**, 1443, 2012

89 Two distinct modulated layer structures of an asymmetric bent-shaped mecticliquid crystal
Zhang, Cuiyu*; Diorio, Nicholas*; Radhika S; Sadashiva BK; Sprunt, Samuel N*; Jakli, Antal*
Liquid Crystals, **39**,1149,2012

90 Dual switchable six-ring bent-core liquid crystals with azo linkages exhibiting B1 and B2 mesophases
Vijaysrinivasan M*; Kannan P*; Roy, Arun
Liquid Crystals, **39**, 1465, 2012

91 T-shaped non-symmetrical twin liquid crystalline compounds
Varia MC; Kumar, Sandeep; Prajapati AK*
Liquid Crystals, **39**, 933, 2012

92 19th Conference on Liquid Crystals
Kumar, Sandeep
Liquid Crystals Today, **21**, 42, 2012

93 Synthesis and characterisation of novel alkoxycyanobiphenyl-substituted rufigallols
Kumar Pal, Santanu; Kumar, Sandeep
Liquid Crystals, **40**, 281-292, 2013

94 Enhanced stability of the columnar matrix in a discotic liquid crystal by insertion of ZnO nanoparticles
Supreet; Pratibha R; Kumar S; Raina KK
Liquid Crystals, **40**, 228-236, 2013

95 Photoconductivity of doped hexa-alkoxy triphenylene nano composite structures
Kavitha C; Avinash BS; Kumar, Sandeep; Lakshminarayanan V
Materials Chemistry and Physics, **133**, 635, 2012

96 Synthesis and Liquid crystal property of new fluoro coumarin carboxylates
Mahadevana, Kittappa M*; Harishkumara, Hosanagara N*; Srinivasa HT
*Molecular Crystals and Liquid Crystals, **570**, 20,* 2013

97 Scaling behavior in the convection-driven Brazil nut effect
Hejmady, Prakhyat*; Bandyopadhyay, Ranjini; Sabhapandit, Sanjib; Dhar, Abhishek
*Physical Review E, **86**,* 050301(R), 2012

98 Nonequilibrium stationary state of a harmonic crystal with alternating masses
Kannan, Venkateshan*; Dhar, Abhishek; Lebowitz JL*
*Physical Review E, **85**,* 041118, 2012

99 Strain glass analogue in a bent-core liquid crystal exhibiting the dark conglomerate phase
Roy, Arun; Gupta, Meenal; Radhika S; Sadashiva BK; Pratibha R
Soft Matter, **8**, 3207, 2012

100 Phase behavior of phospholipid-phytosterol membranes
Kamal, Md. Arif; Raghunathan VA
Soft Matter, **8**, 8952, 2012

101 Spreading and retraction dynamics of a dye doped smectic liquid crystal domain at the air-water interface
Viswanath P; Suresh KA*; Kumar, Bharat
Soft Matter, **8**, 11180, 2012

102 Defect-mediated lamellar-isotropic transition of amphiphile bilayers
Pal, Antara; Pabst, Georg*; Raghunathan VA
Soft Matter, **8**, 9069, 2012

103 Modulated phase of liquid crystals: Covariant elasticity in the context of soft, achiral smectic-C materials
Venkatramanan PR; Hatwalne,Yashodhan; Madhusudana NV
Physical Review E, **87**, 020501(R), 2013

104 Studies on ultrathin films of tricycloquinazoline (TCQ) based discotic liquid crystal molecules
Gupta, Raj Kumar; Manjuladevi V; Karthik C; Kumar, Sandeep
Journal of Physics: Conference Series, **417**, 2013, 012068

105 Fifth ASTROD Symposium and Outlook of Direct Gravitational-Wave Detection
Arun KG, Iyer BR and Ni WT
Asia Pacific Physics Newsletter, Vol. 01, No. 02, pp. 6-11, 2012

106 Correlated spatio-temporal fluctuations in chromatin compaction states characterize stem cells
Talwar, Shefali*; Kumar, Abhishek*; Rao, Madan; Menon, Gautam I*; Shivashankar GV*
Biophysical Journal, **104**, 553, 2013

107 Active remodeling of cortical Actin regulates spatiotemporal organization of cell surface molecules
Gowrishankar, Kripa; Ghosh, Subhasri; Saha, Suvrajit*; Mayor, Satyajit*; Rao, Madan
Cell, **149**, 1353, 2012

108 Partitioning of ethanol in multi-component membranes: Effects on membrane structure
Polley, Anirban; Vemparala, Satyavani*
Chemistry and Physics of Lipids, **166**, 1, 2013

109 The third and a half post-Newtonian gravitational wave quadrupole mode for quasi-circular inspiralling compact binaries
Faye, Guillanme*; Marsat, Sylvain*; Blanchet, Lue*; Iyer, Bala R
Classical and Quantum Gravity, **29**, 175004, 2012

110 Corrigendum: The third post-Newtonian gravitational wave polarizations and associated spherical harmonic modes for inspiralling compact binaries in quasi-circular orbits in 2008
Classical and Quantum Gravity, **25,** 165003
Blanchet, Luc*; Faye, Guillaume*; Iyer, BR; Sinha, Siddhartha
Classical and Quantum Gravity, **29**, 239501, 2012

111 Evidence for a phase transition in 2D causal set quantum gravity
Surya, Sumati
Classical and Quantum Gravity, **29**, 1320001, 2012

112 Boundary term contribution to the volume of a small causal diamond
Khetrapal, Surbhi; Surya, Sumati
Classical and Quantum Gravity, **30**, 065005, 2013

113 Scientific objectives of Einstein telescope
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Varadarajan, Madhavan
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Journal of Physics, **360**, 012024, 2012

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Roy, Anjan; Narayan, Onuttom*; Dhar, Abhishek*; Sabhapandit, Sanjib
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Tomlin, Casey*; Varadarajan, Madhavan
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123 Radial infall of two compact objects: 2.5-post-Newtonian linear momentum flux and associated recoil
Mishra, Chandrakanth
Physical Review D, **85**, 104046, 2012

124 Topological parameters in gravity
Kaul, Romesh K*; Sengupta, Sandipan
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Sharma, Kamal*; Kumar N
Physical Review E, **86**, 032104, 2012

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Kumar N
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Physical Review E, **87**, 022138, 2013

128 Biopolymer elasticity: Mechanics and thermal fluctuations
Sinha, Supurna; Samuel J
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129 Bending elasticity of macromolecules: Analytic predictions from the wormlike chain model
Polley, Anirban; Samuel J; Sinha, Supurna
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Published by Ess Ess Publications, 2012

2 H-index as research performance Indicator : A study at Raman Research Institute
Meera BM
Book Chapter from *Metrics based research assessment and evaluation, Proceedings of the National Workshop* held during Feb 16-17, 2012 at New Delhi
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Iyer BR
25 Years of Indo-French S&T collaboration: CEFIPRA

3 IndIGO, LIGO-India and visit to EGO-Virg
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4 Book review: Sensitive Matter: Foams, Gels, Liquid Crystals and other Miracles
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2 Supernovae driven galactic outflows
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3 A Thomson X-ray polarimeter for a small satellite mission and its scientific prospects
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4 Pulse Phase resolved spectroscopy of HMXB accretion powered pulsars - a powerful tool to probe the dips in the pulse profiles
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Kavitha MK; John, Honey; Gopinath, Pramod; Philip, Reji
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Kumar, Sandeep

2 Book Review for Beyond the stars
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3 Chemistry of Columnar Liquid Crystals in Liquid Crystalline Semiconductors
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1 Detection of Linear Polarization from SNR Cassiopeia A at Low Radio Frequencies
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2 2.5PN kick from black-hole binaries incircular orbit: nonspinning case
Mishra CK, Arun KG, Iyer BR
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* *denotes co-authors who do not belong to RRI*

\+ *denotes co-authors who are Visiting Professors*

APPENDIX 2

CONFERENCES ATTENDED

Name	Conferences attended/Institutions visited	Title of paper/talk
Amruta C Gadge	School on Ultra Cold Atoms for Fundamental Science and Enabling Technologies Indian Institute of Science and Education Research, Pune (held at Goa) 17 – 21 December 2012	
Anagha Datar	Institute Curie Paris 22 September 2012 – 29 January 2013	
Andal Narayanan	University of Calgary Canada August 2011 – July 2012	
	Indian Academy of Sciences, Bangalore 29 November 2012	Coherent atom-field interactions: laser cooling and induced transparency
	International Conference on Quantum Information and Quantum Communication Indian Institute of Science, Bangalore 7 – 11 January 2013	Leggett-Garg inequalities with amplitude damping
Anirban Polley	RRI School on Statistical Physics-III Raman Research Institute, Bangalore 26 March – 7 April 2012	
	IBDML – Development Biology Institute of Marseille France 1 – 3 October 2012	Transbilayer-coupling of lipid-tethered proteins in an asymmetric multicomponent membrane

Name	Conferences attended/Institutions visited	Title of paper/talk
Anu Renjith	Joint Seminar of Globally Aware Young Researchers from Kyutech and Sisters Universities Kyutech Institute of Technology Japan 30 August – 9 November 2012	Redox potential variation of Ferrocene derivatives with solvents and substituents
Arnab Pal	RRI School on Statistical Physics-III Raman Research Institute Bangalore 26 March – 7 April 2012	
	School on Cell Mechanics Raman Research Institute Bangalore 31 January – 2 February 2013	
	Stochastic Thermodynamics Nordic Institute for Theoretical Physics Sweden 2 – 16 March 2013	Work fluctuations for a Brownian particle in a harmonic trap with fluctuating locations
Arpita Roy	In-house Symposium Indian Institute of Science Bangalore 16 November 2012	Superbubble breakout and galactic winds from disk galaxies
	Symposium on Astronomical and Cosmological surveys Tata Institute of Fundamental Research Mumbai 19 – 21 December 2012	Superbubble breakout and galactic winds from disk galaxies
	Astronomical Society of India Meeting 2013 Indian Institute of Science Education and Research, Trivandrum 20 – 22 February 2013	Superbubble breakout and galactic winds from disk galaxies
Arun Roy	24th International Liquid Crystal Conference Convention Center Rheingoldhalle Germany 19 – 24 August 2012	Aciral triclinic fluid lamellar phases exhibited by bent-core hockey stick shaped molecules (*invited*)
Avinash BS	Trinity College Ireland 31 October 2012 – 24 April 2013	

Name	Conferences attended/Institutions visited	Title of paper/talk
Avinash Deshpande	Radio Astronomy Centre Ooty 11 – 13 June 2012	Radio astronomy techniques (*2 lectures*)
	Curtin University Australia 1 November – 8 December 2012	
	MWA Project Meeting Geraldton Western Australia 28 November – 2 December 2012	
	Science Academies' Lecture Workshop on Introductory Astronomy SDM College, Ujire 20 – 22 December 2012	Radio astronomy (*2 lectures*)
	Indian Institute of Technology Indore 4 – 6 October 2012 1 – 28 February 2013	1. Fascinating life stories of pulsars 2. Radio astronomy techniques (*10 lectures*)
	International Conference on Transients and Timing: A multiwavelength approach Inter University Centre for Astronomy & Astrophysics Pune 4 – 8 March 2013	Optimizing strategies for radio transient searches (*invited*)
Bala Iyer	15th Annual Science Camp Raman Research Institute Bangalore 13 May 2012	Beyond insight and inspiration to Einstein's messengers (*invited*)
	Jawaharlal Nehru Planetarium Bangalore 23 May 2012	From relativistic gravitation to Einstein's messengers
	Institute for Plasma Research Bhat 13 June 2012	NSF Review of LIGO-India
	Meeting on Relativity and Gravitation – 100 years after Einstein in Prague Charles University Prague 24 – 30 June 2012	2.5PN kick from black-hole binaries in circular orbit: non spinning case

Name	Conferences attended/Institutions visited	Title of paper/talk
	Meeting on Living Reviews in Relativity Charles University Prague 27 June 2012	
	ASTROD 5 Meeting Raman Research Institute Bangalore 11 – 13 July 2012	
	LIGO Virgo Collaboration Meeting Sapienza University Rome 10 – 14 September 2012	Update on LIGO-India (*invited*)
	Annual GWIC Meeting Sapienza University Rome 11 September 2012	IndIGO, Report 2011-12 (*invited*)
	Meeting on Equations of Motion in Relativistic Gravity Physikzentrum Bad Honnef 17 – 22 February 2013	Gravitational waves for inspiraling compact binaries in general orbits and their applications to EOM (*invited*)
	IAGRG-27 Garhwal University Srinagar 7 – 9 March 2013	The long walk towards gravitational wave astronomy (*invited keynote)*
	LIGO Virgo Collaboration Meeting University of Maryland USA 18 – 22 March 2013	LIGO-India update (*invited*)
	Meeting of LIGO-India core group Bhabha Atomic Research Centre Mumbai 20 July 2012	
	Virgo, European Gravitational Observatory Cascina 16 – 19 September 2012	From IndIGO to LIGO-India
	Cardiff University United Kingdom 20 September – 10 October 2012	LIGO-India update

Name	Conferences attended/Institutions visited	Title of paper/talk
	GReCO Paris Institute of Astrophysics, France 5 – 25 November 2012	IndIGO and LIGO-India
	Institut des Hautes Études Scientifiques France 26 November – 5 December 2012	
	LIGO-India Meeting Raja Ramanna Centre for Advanced Technology Indore 24 January 2013	
	National Institute of Technology Surathkal 28 February 2013	LIGO-India: where do Einstein's messengers come from? Relativistic gravitation: from insight to inspiration
	Massachusetts Institute of Technology USA 25 – 26 March 2013	
	LIGO Observatory Livingston 27 – 30 March 2013	
	LIGO-India Meeting on Site Selection, Cabinet Note and Interaction with LIGO-Lab Inter University Centre for Astronomy & Astrophysics Pune 17 April 2012 8 January 2013 5 – 7 February 2013	
Bhargava Ram	DAE-BRNS Symposium on Atomic, Molecular and Optical Sciences Indian Institute of Science and Education Research Kolkata 14 – 17 December 2013	Femtosecond multi photon ionization of chiral molecules
	Indian Institute of Space Science and Technology Thiruvananthapuram 30 January 2013	Probing chiral molecules with mass-selective discrimination in a femtosecond reaction microscope

Name	Conferences attended/Institutions visited	Title of paper/talk
Biman Nath	39th COSPAR Scientific Assembly Global Education Center Mysore 18 July 2012	Outflows from starburst galaxies and the IGM (*invited*)
	IAU Symposium 296 – Supernova Environmental Impacts Raichak 10 January 2013	Supernova driven galactic outflows (*invited*)
	Indian Institute for Science and Education Mohali 23 – 27 April 2012	Outflows from galaxies
	Tata Institute of Fundamental Research Mumbai 24 – 25 July 2012	Outflows from galaxies
	S N Bose National Centre for Basic Science Kolkata 22 December 2012	Galactic outflows
Biswajit Paul	National Conference on Recent Trends in the Study of Compact Objects : Theory and Observation Indian Institute of Technology Guwahati 11 – 13 March 2013	Accretion torque on high magnetic field neutron stars (*invited*)
	Workshop on X-ray /astronomy North Bengal University West Bengal 23 – 25 March 2013	Introductory X-ray Astronomy and Accretion Powered Pulsars (*2 lectures*)
	International Conference on Transients and Timing Inter University Centre for Astronomy & Astrophysics Pune 4 – 8 March 2013	X-ray reprocessing in binaries (*invited*)
	Symposium on Astronomical Surveys Tata Institute of Fundamental Research Mumbai 19 – 21 December 2012	Upcoming Indian Space Astronomy Missions

Name	Conferences attended/Institutions visited	Title of paper/talk
	Workshop on Neutron Stars: Inside and Outside Saha Institute for Nuclear Physics Kolkata 18 – 19 October 2012	Neutron star observations in hard X-rays
	Dr. Vikram Sarabhai Research Award Ceremony Physical Research Laboratory Ahmedabad 10 August 2012	Extreme Gravity and Magnetism Research: Today and Tomorrow
	Fifth International ASTROD Symposium on Laser Astrodynamics, Space Test of Relativity and Gravitational-Wave Astronomy Raman Research Institute, Bangalore 11 – 13 July 2012	ASTROSAT: some key science prospects
	39th COSPAR Scientific Assembly Global Education Centre Mysore 14 – 22 July 2012	1. Simultaneous X-ray and optical observations of thermonuclear bursts in the LMXB EXO 0748-676 and prospects with ASTROSAT 2. Quasi Periodic Oscillations in HMXB Pulsars 3. A Thomson X-ray polarimeter for a small satellite mission and its scientific prospects
	X-ray views of the cosmos: A conference observational X-ray Astronomy Physical Research Laboratory Ahmedabad 23 – 25 April 2012	X ray polarisation measurement techniques, and prospects in near future
	Second IUCAA X-ray Astronomy School Inter University Centre for Astronomy and Astrophysics 3 February – 2 March 2013	1. X-ray astronomy instruments 2. X-ray binaries and pulsars
Buti Suryabrahmam	School on Ultra Cold Atoms for Fundamental Science and Enabling Technologies Indian Institute of Science and Education Research, Pune (held at Goa) 17 – 21 December 2012	

Name	Conferences attended/Institutions visited	Title of paper/talk
Chandreyee Maitra	39th COSPAR Scientific Assembly Global Education Center Mysore 14 – 22 July 2012	1. Thomson X-ray polarimeter, prospects for compact objects 2. Pulse phased resolved cyclotron line studies of accretion powered pulsars with Suzaku 3. Pulse Phase resolved spectroscopy of HMXB accretion powered pulsars with Suzaku
	National Conference on Recent Trends in Compact Objects-theory and observations Indian Institute of Technology Guwahati 11 – 13 March 2013	Pulse phase resolved spectroscopy of CRSFs in accretion powered pulsars
Dhason A	XXXIII Annual Meeting on Electron Microscopy in the 21st Century Indian Institute of Science Bangalore 2 – 4 July 2012	
	Workshop on Thin Film Processing, Material Characterization, Surface Science and Cryogenic Environment Indian Institute of Science Bangalore 20 – 21 November 2012	
Durai Chelvan	XXXIII Annual Meeting on Electron Microscopy in the 21st Century Indian Institute of Science Bangalore 2 – 4 July 2012	
	Workshop on Thin Film Processing, Material Characterization, Surface Science and Cryogenic Environment Indian Institute of Science Bangalore 20 – 21 November 2012	
	39th COSPAR Scientific Assembly Global Education Center Mysore 14 - 22 July 2012	Development of Thomson X-ray polarimeter for a small satellite mission

Name	Conferences attended/Institutions visited	Title of paper/talk
Dwarakanath KS	National Institute of Technology Surathkal 4 February 2013	Radio universe (*2 lectures*)
	St. Joseph's College Bangalore 12 February 2013	Atomic hydrogen in galaxies (*2 lectures*)
	Murchison Wide-field Array Meeting Western Australian Museum Geraldton 26 November – 4 December 2012	Simulations of cluster halo observations with MWA
Ezhilarasi MS	User Group Meeting of Agilent Technologies – Ees of India The Le-Meridian Bangalore 3 December 2012	RF / microwave and systems
Gayathri Raman	X-ray Astronomy School Inter University Centre for Astronomy & Astrophysics Pune 3 February – 2 March 2013	Timing studies of the HMXB Swift J1656.6-5156
	National Conference on Recent Trends in Compact Objects-theory and Observations Indian Institute of Technology Guwahati 10 – 14 March 2013	Multiwave length observations of thermonuclear X-ray burst reprocessing
Geetha S	National Conference on Libraries and Development: Present and Future Karnataka State Library Association Shravanabelagola 7 – 9 June 2012	
	Info-Vision 2012 –Summit on Social, Mobile, Analytics, Cloud is smart SAP Labs Bangalore 20 October 2012	
Gopalakrishna MR	39th COSPAR Scientific Assembly Global Education Center Mysore 14 - 22 July 2012	Development of Thomson X-ray Polarimeter for a small satellite mission

Name	Conferences attended/Institutions visited	Title of paper/talk
Hema Ramachandran	Science Academies' Lecture Workshop on Photonics and the Radio Universe NMK and SDM College Mysore 17 August 2012	Photonics (2 lectures)
	Indo German Workshop on Neurobionics in Clinical Neurology Jawaharlal Institute of Postgraduate Medical Education and Research Pondicherry 15 – 17 February 2013	1. Action selection based on SSVEP 2. Optimising frequency determination for real-time SSVEP-based BCI system 3. VACU - voice activated control unit
	Manipal University Manipal 23 February 2013	Single atoms and single photons – work leading to the Nobel Prize in Physics 2012
	Faculty Development Program on Medical Physics BMS College of Engineering Bangalore 7 – 12 January 2013	Brain computer interfaces
Jacob Rajan	Technical Workshop on the National Knowledge Network NIMHANS Convention Center Bangalore 18 April 2012	
	GARUDA NKN Partners Meet National Institute for Advanced Studies Bangalore 20 – 21 July 2012	
	High Performance Computing Conference Hotel ITC Gardenia Bangalore 3 August 2012	
Jagdish Chandra Joshi	Conference on TeV Particle Astrophysics Tata Institute of Fundamental Research, Mumbai 10 – 14 December 2012	

Name	Conferences attended/Institutions visited	Title of paper/talk
Joseph Samuel	International Conference on Quantum Information and Quantum Computing 2013 Indian Institute of Science Bangalore 7 – 11 January 2013	1. Controlling entanglement using the geometric phase 2. Quantifying multi-path effects in a three slit experiment
Jyothi S	School on Ultra Cold Atoms for Fundamental Science and Enabling Technologies Indian Institute of Science and Education Research Pune (held at Goa) 17 – 21 December 2012	Atoms in cavity and ions with atoms
Karthik HS	International Conference on Quantum Information and Quantum Computing 2013 Indian Institute of Science Bangalore 7 – 11 January 2013	1. Can quantum probabilities be retrieved from their moments? 2. Heat bath effects on the violation of Leggett-Garg inequalities
Narendra Kumar	Indian Institute of Science Bangalore 7 September 2012	Re-visiting classical orbital magnetism: a surprise (*invited*)
	Raman Research Institute Bangalore 3 October 2012	Classical orbital diamagnetism: a surprise (*invited*)
	Indian Institute of Scientific Education and Research Pune 30 January 2013	Re-visiting classical orbital diamagnetism: a surprise! (*invited*)
	National Science Day University of Mysore Mysore 28 February 2013	Why? (*invited*)
	Refreshers' Course Indian Academy of Sciences Bangalore 15 March 2013	Why? (*invited*)
Lakshminarayanan V	Conference on New trends in Chemical Sciences Sri Sathya Institute of Higher Learning Andhra Pradesh 8 September 2012	Electrochemical Sensors – Principles and Applications

Name	Conferences attended/Institutions visited	Title of paper/talk
	Symposium on Nanoscience and Technology Manipal University Manipal 24 February 2013	Electrochemistry of nanomaterials for biosensors and catalysis
	1st DST-CSIR Sensor Hub Workshop Kolkata 24 August 2012	Electrochemical sensors design
	SASTRA University Thanjavur 27 August 2012	Electrochemistry of nanomaterials
Lakshmi Saripalli	National Radio Astronomical Observatory USA 1 May 2012 – 28 April 2013	What shapes radio galaxies?
Madhuri Kumari	International Conference on Fiber Optics and Photonics Indian Institute of Technology Madras Chennai 9 – 12 December 2012	
Mahavir Sharma	Conference on Galaxies in Absorption Inter University Centre for Astronomy & Astrophysics Pune 24 – 28 November 2012	Galactic winds
	Astronomical Society of India Meeting 2013 Indian Institute of Science and Education Research Trivandrum 22 February 2013	Outflows from galaxies and AGN
Mamta Gulati	39th COSPAR Scientific Assembly Global Education Center Mysore 14 – 22 July 2012	
	30th Meeting of the Astronomical Society of India Thiruvananthapuram 20 – 22 February 2013	Slow unstable modes of counter-rotating nearly Keplerian stellar discs

Name	Conferences attended/Institutions visited	Title of paper/talk
	Indian Institute of Science and Education and Research Mohali 4 – 5 October 2012	Unstable modes of counter-rotating nearly Keplerian stellar discs
Mamatha TS	User Group Meeting of Agilent Technologies – Ees of India The Le-Meridian Bangalore 3 December 2012	R/F microwave circuit and systems
Mani M	Workshop on Thin Film Processing, Material Characterization, Surface Science and Cryogenic Environment Indian Institute of Science Bangalore 20 – 21 November 2012	
Manjunath M	58th International Library Conference on Indian Library Association on Next-generation Libraries: New Insights and Universal Access to Knowledge 2013 Karnataka University Dharwad 24 – 27 February 2013	
Mayuri S	39th COSPAR Scientific Assembly Global Education Center Mysore 14 - 22 July 2012	Investigation of KHZ QPOS of some LMXBS against their broad band spectral characteristics
Meena MS	Technical Seminar on FPGA design and new products AVNET Inc. Bangalore 17 July 2012	
Meera BM	XXVIII General Assembly of the International Astronomical Union China National Convention Center China 23 – 24 August 2012	H-Index of Astrophysists at Raman Research Institute: performance of difference calculators
	JSTOR Meeting National Institute of Advanced Studies Bangalore 6 September 2012	

Name	Conferences attended/Institutions visited	Title of paper/talk
	Seminar on Personality Development for Librarians Karnataka Library Association Bangalore 28 April 2012	
	International Society for Knowledge Organisation University of Mysore Mysore 6 – 7 August 2012	
	Informatics Program EContent – 2012 Convergence of Content and Technology The Capitol Bangalore 19 October 2012	
	Info-Vision 2012: The Knowledge Summit on Social, Mobile, Analytics, Cloud is smart SAP Labs Bangalore 20 October 2012	
Nagaraj M N	National Seminar on Emerging Frontiers of Digital Libraries University of Kashmir Jammu and Kashmir 4 – 6 November 2012	Preserving Raman Research Institute print resources in a hybrid library
	Proceedings of International Conference on Knowledge Management and Organization in the Digital Era 2013 Siddaganga Institute of Technology Tumkur 17 – 19 January 2013	Electronic theses and dissertation archives at Raman Research Institute: an overview
Nazma Islam Syeda	Conference on X-ray view of the Cosmos Physical Research Laboratory Ahmedabad 23-25 April 2012	Effect of variability of X-ray binaries on X-ray luminosity functions for our galaxy (*invited*)
	39th COSPAR Scientific Assembly Global Education Center Mysore 14 - 22 July 2012	Effect of variability of X-ray binaries on X-ray luminosity functions for our galaxy

Name	Conferences attended/Institutions visited	Title of paper/talk
	International Conference on Transients and Timing Inter University Centre for Astronomy & Astrophysics Pune 4 - 8 March, 2013	Revisiting the X-ray luminosity functions of Milky Way: Incorporating the effect of variability of X-ray binaries on X-ray luminosity functions
	National Conference on Recent Trends in the Study of Compact Objects : Theory and Observation Indian Institute of Technology Guwahati 11 - 13 March 2013	Average spectral properties of galactic X-ray binaries with 3 years of MAXI data
	RIKEN Japan 3 October – 24 December 2012	Effect of variability of X-ray binaries on X-ray luminosity functions for our galaxy
Nithyanandan Thyagarajan	Biannual MWA Project Meeting Raman Research Institute Bangalore 18 – 22 June 2012	Study of foreground contamination of the EoR
	EoR Global Signal Workshop The ARC Centre for Excellence for All-sky Astrophysics Australia 20 – 22 November 2012	Constraints on EoR detection with the MWA
	Biannual MWA Project Meeting Western Australian Museum Geraldton, Australia 28 November – 2 December 2012	New results from modelling contamination of EoR signal
Prabu T	Biannual MWA Project Meeting Raman Research Institute Bangalore 18 – 20 June 2012	Receiver commissioning plan
	MWA Project Meeting Geraldton, Western Australia 28 November – 2 December 2012	
	Pre-operations Meeting Curtin University Australia 25 – 26 February 2013	

Name	Conferences attended/Institutions visited	Title of paper/talk
Pramod Pullarkat	Ramanujan Fellows Meet Marriot Hotel Pune 4 – 6 May 2012	
	Bangalore Science Forum National College 17 July 2012	Physics of the cell
	Institut Curie Paris 20 September – 3 October 2012	
	Workshop on Active, Soft and Biological matter Ecole de Physique des Houches France 1 – 5 October 2012	Active mechanics and shape instabilities of axons (*invited*)
	University of Montpellier-II France 8 – 11 October 2012	Active mechanics and shape instabilities of axons (*invited*)
	RA Mashelkar Endowment Lecture Series on Advanced Materials National Chemicals Laboratory Pune 29 – 31 October 2012	The mechanical and dynamical properties of neuronal cells (*invited*)
	Indian Institute of Science Education and Research Pune 31 October 2012	
	Mahabaleswar International Workshop on Axonal Transport and Neurodegeneration Mahabaleswar 20 – 25 January 2013	Shape instabilities in axons (*invited*)
	Cell Mechanics Meeting Raman research Institute Bangalore 31 January – 2 February 2013	
Prasad VV	RRI School on Statistical Physics-III Raman Research Institute Bangalore 26 March – 7 April 2012	

Name	Conferences attended/Institutions visited	Title of paper/talk
Pratibha R	24th International Liquid Crystal Conference Convention Center Rheingoldhalle Germany 19 – 24 August 2012	Strain glass analogue in a bent-core liquid crystal exhibiting the dark conglomerate phase
Raghavendra Rao	Indo German Workshop on Neurobionics in Clinical Neurology Jawaharlal Institute of Postgraduate Medical Education and Research Pondicherry 15 – 17 February 2013	1. Action selection based on SSVEP 2. Optimising frequency determination for real-time SSVEP-based BCI system
Raghunathan VA	1st Asian Conference on Liquid Crystals Fuji Calm Japan 16 – 18 December 2012	Tuning DNA-amphiphile condensate architecture with strongly binding counterions (*invited*)
	INDO-US Symposium on structure, dynamics and mechanics of biological membranes Indian Institute of Science Bangalore 29 – 31 December 2012	Modulated phases of phosphatidylcholine bilayers induced by sterols (*invited*)
Rahul Sawant	Mini Winter School in Quantum Information and Computation Indian Institute of Science Bangalore 4 – 5 January 2013	
	International Conference on Quantum Information and Quantum Computing 2013 Indian Institute of Science Bangalore 6 – 11 January 2013	Quantifying multipath effects in a 3-slit experiment
Ramesh B	Indo German Workshop on Neurobionics in Clinical Neurology Jawaharlal Institute of Postgraduate Medical Education and Research Pondicherry 15 – 17 February 2013	1. Action based on SSVEP 2. Optimising frequency determination for real-time SSVEP based BCI system 3. Voice activated control unit
	Dhanalakshmi College for Women Perambalur 8 January 2013	Artificial eyes: maths and physics

Name	Conferences attended/Institutions visited	Title of paper/talk
Ranjini Bandyopadhyay	Global Young Academy General Assembly Gordon Institute of Business Science South Africa 23 May 2012	Size segregation in granular matter
	Johannesburg Science Museum South Africa 24 May 2012	What are soft materials?
	Brandeis University USA 25 June 2012	Scaling behaviour in the convection-driven Brazil nut effect
	Johns Hopkins University USA 25 June 2012	Scaling behaviour in the convection-driven Brazil nut effect
	Rajabazar Science College Kolkata 18 October 2012	How do soft materials move when pushed really hard?
	Indian Academy of Sciences Workshop St. Joseph's College Bangalore 11 – 12 January 2013	1. Band theory of materials (*3 lectures*) 2. The flow of soft materials
	Indian Institute of Technology Kanpur 18 February 2013	Scaling behaviour in the convection-driven Brazil nut effect
	Jain College Bangalore 27 February 2013	Soft materials
	Mt. Carmel College Bangalore 4 March 2013	The curious case of soft materials
Reji Philip	MRS Spring Meeting Materials Research Society USA 9 – 13 April 2012	Applications of Oxide Nanomaterials in Nonlinear Optics (*invited*)
	IUMRS-International Conference on Electronic Materials 2012 International Union of Materials Societies Japan 23 – 28 September 2012	Optical limiting in Spinel Ferrites (*invited*)

Name	Conferences attended/Institutions visited	Title of paper/talk
	International Conference on Research in Condensed Matter Physics 2012 Madras University 1 – 3 October 2012	Nonlinear optical properties of ultrasmall gold nanoclusters (*invited*)
	2nd International Conference on Optoelectronic Materials and Thin Films for Advanced Technology 2013 Cochin University for Science and Technology Cochin 3 – 5 January 2013	Evolution of Nonlinear Optical Properties in Atomic Clusters of Gold (*invited*)
	Science Academies' Lecture Workshop on Condensed Matter Physics and Photonics St. Joseph's College Bangalore 10 – 11 January 2013	1. A brief history of light 2. Fundamentals of nonlinear optics
	Purdue University USA 23 July 2012	Laser plasma experiments and the Raman Research Institute, Bangalore
	International Conference on Molecular Spectroscopy of Advanced Materials and Biological Molecules 2012 Bishop Moore College Kerala 6 – 9 August 2012	Spectroscopy with ultrafast laser-induced plasmas (*invited*)
	Science Academies' Lecture Workshop on Photonics and the Radio Universe NMK and SDM College Mysore 17 – 18 August 2012	1. Nature of light 2. Nonlinear optic 3. Intense field nonlinear optics
	Macquarie University Australia 26 November 2012	
	Australian National University Australia 27 – 30 November 2012	Nonlinear optical properties of ultrasmall gold nanoclusters
	National University of Singapore Singapore 3 December 2012	

Name	Conferences attended/Institutions visited	Title of paper/talk
	Nanyang Technological University Singapore 4 December 2012	
	National Seminar on Current Trends in the Fields on Nanoscience and Nanotechnology KKTM College Kerala 14 December 2012	Nonlinear optics with ultrasmall gold nanoclusters (*invited*)
	INSPIRE Science Camp by DST Mahatma Gandhi University Kottayam 28 December 2012	History of light
	Refresher Course UGC Academic Staff College Trivandrum 15 January 2013	1. Experimental methods in nanotechnology 2. Raman spectroscopy for materials characterization
	National Seminar on Basic Theoretical and Experimental Techniques in Physics Govt. Victoria College Kerala 25 February 2013	Laser induced plasmas (*invited*)
	RBANMs College Bangalore 28 February 2013	Laser systems
	UGC National Seminar on Recent Trends in Experimental Physics Devamatha College Kerala 25 March 2012	Nanophotonics: an introduction (*Invited*)
Renu Vishavkarma	School on Cell Mechanics Raman Research Institute Bangalore 31 January – 2 February 2013	
Rishin PV	39th COSPAR Scientific Assembly Global Education Center Mysore 14 – 22 July 2012	Development of Thomas X-ray polarimeter for a small satellite mission

Name	Conferences attended/Institutions visited	Title of paper/talk
Ruckmongathan TN	Symposium of Society for Information Display Boston Convention and Exhibition Center USA 3 – 8 June 2012	Intensity modulation of light sources for gray scales in projection displays
	Indian Institute of Science Bangalore 9 November 2012	Towards simple drivers and low power in non-emissive displays
Sadiq Rangwala	International Conference on Fibre Optics and Photonics Indian Institute of Technology Madras Chennai 9 – 12 December 2012	Detection of cold dilute gases with cavities
	School on Ultra Cold Atoms for Fundamental Science and Enabling Technologies Indian Institute of Science and Education Research Pune (held at Goa) 17 – 21 December 2012	Atoms in cavity and ions with atoms
	International Conference on Quantum Information and Quantum Computing 2013 Indian Institute of Science 7 – 11 January 2013	Atom-ion and molecule-ion physics
Samim Ali	RRI School on Statistical Physics-III Raman Research Institute, Bangalore 1 April 2012	
	Indian Institute of Technology, Kanpur 25 February – 15 March 2013	
Sandeep Kumar	Course on microwave-assisted organic synthesis Vivanta Taj, Bangalore 6 April 2012	
	University of Allahabad, Allahabad 17 April 2012 8 May 2012	
	Universität Siegen Germany 25 – 27 August 2012	Discotic liquid crystalline nanocomposites (*invited*)

Name	Conferences attended/Institutions visited	Title of paper/talk
	24th International Liquid Crystal Conference Convention Center Rheingoldhalle Germany 19 – 23 August 2012	Nanoparticles in the supramolecular order of discotic liquid crystals (*invited*)
	University of Hull United Kingdom 25 October 2012	Discotic liquid crystalline nanocomposites (invited)
	University of Birmingham United Kingdom 26 October 2012	Discotic liquid crystalline nanocomposites (invited)
	1st Asian Conference on Liquid Crystals Fuji Calm Japan 16 – 18 December 2012	Playing with discs (*Plenary)*
	Birla Institute of Technology and Science Pilani 19 – 22 December 2012	The fascinating world of liquid crystals (*invited*)
	Conference on Condensed Matter and Biological Systems 2013 Banaras Hindu University Varanasi 11 – 14 January 2013	Nanoparticles in columnar mesophases (*Plenary/Invited*)
Sandipan Sengupta	27th Meeting of the Indian Association for General Relativity and Gravitation Hemwati Nandan Bahuguna Garhwal University Srinagar 7 – 9 March 2013	Gauge theory of gravity with topological invariants
	Institute of Mathematic Sciences Chennai 21 – 28 March 2013	
Sanjib Sabhapandit	Laboratouire de Physique Theorique at Modeles Statistiques France 24 September – 5 October 2012	Fluctuations and large deviations in non equilibrium processes
	Institut de Physique Theorique France 1 October 2012	Fluctuations and large deviations in nonequilibrium processes

Name	Conferences attended/Institutions visited	Title of paper/talk
Seshagiri Rao RV	Cell Mechanics Meeting Raman Research Institute Bangalore 31 January – 2 February 2013	Force measurement at pico scale
Seunghyun Lee	School on Ultra Cold Atoms for Fundamental Science and Enabling Technologies Indian Institute of Science and Education Research Pune (held at Goa) 17 – 21 December 2012	Atoms in cavity and ions with atoms
	International Conference on Quantum Information and Quantum Computing 2013 Indian Institute of Science 7 – 11 January 2013	Atom-ion and molecule-ion physics
Shabeeb PK	WMO College Kerala 16 January 2013	Fascinating world of modern physics
Somashekar R	Indo German Workshop on Neurobionics in Clinical Neurology Jawaharlal Institute of Postgraduate Medical Education and Research Pondicherry 15 – 17 February 2013	1. Action selection based on SSVEP 2. Optimising frequency determination for real-time SSVEP-based BCI system
	Interaction Meeting with Vigilance Officers of Sub-ordinate offices and aided institutions under the control of DST Aryabhatta Research Institute of Observational Sciences Nainital 26 – 27 June 2012	
Sridhar S	National Centre for Radio Astrophysics Pune 7 – 11 September 2012	Interstellar, interplanetary and MHD turbulence
	Indian Institute of Science and Education and Research Mohali 29 October – 9 November 2012	The milky way *(6 lectures)*

Name	Conferences attended/Institutions visited	Title of paper/talk
Srinivasa HT	19th National Conference on Liquid Crystals Thapar University Punjab 21 – 23 November 2012	Triphenylene - terphenyl discotic dimers: Synthesis and mesomorphic characterizations
Srivani KS	Conference on Monitor and Control Integration Activities Curtin University Western Australia 6 – 16 June 2012	
Sujatha S	Indo German Workshop on Neurobionics in Clinical Neurology Jawaharlal Institute of Postgraduate Medical Education and Research Pondicherry 15 – 17 February 2013	Action selection based on SSVEP
Sumati Surya	Summer School on Cosmology International Centre for Theoretical Physics Trieste 16 – 27 July 2012 23 – 27 August 2012	
	Workshop on Large Scale Structure International Centre for Theoretical Physics Trieste 30 August 2012	
	IAGRG-27 Garhwal University Srinagar 2 – 9 March 2013	The discrete geometry of a causal diamond
	Workshop on Algebraic Quantum Theory Indian Institute of Science and Education Research Trivandrum 14 – 15 March 2013	The discrete geometry of a causal diamond (*invited*)
Supurna Sinha	International Conference on Quantum Information and Quantum Computing 2013 Indian Institute of Science Bangalore 7 – 11 January 2013	1. Controlling entanglement using the geometric phase 2. Quantifying multi-path effects in a three slit experiment

Name	Conferences attended/Institutions visited	Title of paper/talk
Udaya Shankar	Special Lecture Series Bangalore University and KLE Society's Nijalingappa College Bangalore 19 May 2012	Measuring the size of the stars
	Science Academies' Lecture Workshop on Photonics and the Radio Universe NMK and SDM College Mysore 17 – 19 August 2012	Radio universe (2 lectures)
	Niramaya Yogakuteeram Bangalore 29 September 2012	Bhoutika Vishwaroopada Hudukaatadalli Vignanigalu
	MWA Project Meeting Geraldton Western Australia 28 November – 2 December 2012	
	Jesuit Colleges of India Workshop (Astrophysics) St. Joseph's College Bangalore 11 February 2013	Introduction to radio telescopes and cosmology through radio astronomy
	Newman College Kerala 12 February 2013	Exploring the universe using the invisible radiation
	Workshop on Fourier Transforms in (Astro)Physics Mahatma Gandhi University Kottayam 13 – 15 February 2013	Fundamentals of Fourier Transforms, Applications of Fourier Imaging to Radio Astronomy (*2 seminars and 2 tutorial sessions*)
	Kendriya Vidyalaya Indian Institute of Science Bangalore 3 January 2013	Challenges of observing the invisible universe
	Satellite Meeting on the DST family of institutions/Indian Science Congress Meeting Bose Institute Kolkata 6 January 2013	Radio Astronomy activities at RRI

Name	Conferences attended/Institutions visited	Title of paper/talk
	Student-Scientist Interaction Program Karnataka Vijnana Vidya Jagruthi 9 January 2013	Bhoutika Vishwaroopada Hudukaatadalli Vignanigalu
	Science Academies' Lecture Workshop on the Radio Universe National Institute of Technology Surathkal 1 – 3 February 2013	Radio universe *(2 lectures)*
	Indian Institute of Science Bangalore 5 March 2013	The Challenges of observing 21 cm emission from the Epoch Of Reionisation
	Biannual MWA Project Meeting Raman Research Institute Bangalore 18 – 20 June 2012	
Urbasi Sinha	International Conference on Quantum Information and Quantum Computing 2013 Indian Institute of Science Bangalore 7 – 11 January 2013	Multidimensional quantum systems: two's company but three's still not a crowd (*invited*)
	International Conference on Quantum Communication, Measurement and Computing 2012 Vienna University of Technology Austria 30 July – 3 August 2012	Playing a quantum game with a qutrit
	Tata Institute of Fundamental Research Mumbai 16 – 18 April 2012	Quantifying the quantum
	Indian Association for Cultivation of Sciences Kolkata 5 – 9 May 2012	Triple slits, born rule and beyond
Vijayaraghavan D	International Conference on Research in Condensed Matter Physics University of Madras 1 – 3 October 2012	Magnetic susceptibility studies on ferrofluid doped lyotropic liquid crystal systems

Name	Conferences attended/Institutions visited	Title of paper/talk
	19th National Conference on Liquid Crystals Thapar University Punjab 21 – 23 November 2012	Optical birefringence studies on single-wall carbon nanotubes dispersed lyotropic liquid crystal systems
Vrinda J Benegal	National Conference on Reaching out to Users through Technology 2013 CSIR-Structural Engineering Research Centre Chennai 13 – 15 March 2013	
	Proceedings of International Conference on Knowledge Management and Organization in the Digital Era 2013 Siddaganga Institute of Technology Tumkur 17 – 19 January 2013	
	Discussion Forum – Web of Science Indian Academy of Sciences Bangalore 16 April 2012	
	Informatics Program EContent – 2012 Convergence of Content and Technology The Capitol Bangalore 19 October 2012	
	XXVIII General Assembly of the International Astronomical Union China National Convention Center China 23 – 24 August 2012	Digital scholarship and resource sharing among Astronomy libraries
	National Conference on Libraries and Development: Present and Future Karnataka State Library Association Shravanabelagola 7 – 9 June 2012	Innovative information services and best library practices at RRI – a case study

APPENDIX 3

COLLOQUIA

Name	Title	Date
Giovanni Gallavotti Universita' di Roma, Italy	Universality in fluctuations of stationary chaotic systems	3 April 2012
Christopher Jarzynski University of Maryland, USA	Irreversibility and the second law of thermodynamics at the nanoscale	4 April 2012
Sergio Ciliberto Laboratoire de Physique de ENSL France	Information and thermodynamics: experimental verification of Landauer's erasure principle	5 April 2012
Urna Basu Saha Institute of Nuclear Physics Kolkata	Absorbing state phase transitions in presence of conserved fields	9 April 2012
Aditya Rotti Inter University Center for Astronomy & Astrophysics, Pune	Probing the universe with CMB weak lensing	17 April 2012
Mandip Singh University of Vienna, Austria	Atom entanglement and atom optics with Bose Einstein Condensates	18 April 2012
Dawood Kothawala University of New Brunswick Canada	Some semi-classical aspects of black hole entropy	23 April 2012
Stephane Ouvry Laboratoire de Physique Théorique et Modèles Statistiques, France	Arithmetic area for m planar Brownian paths	24 April 2012
Bibhu Ranjan Sarangi Institut Curie, France	Cellular capsules: a step towards true three dimensional cell structure	25 April 2012

Name	Title	Date
Abhishek Chaudhuri Oxford University, UK	Polymer translocation through active and patterned nano-pores	26 April 2012
Vasanthakumar G Ramu Universitat of Girona, Spain	Supramolecular multivalency in modulation of protein interactions: small molecules, synthesis, characterization and applications	26 April 2012
Willem A Baan Netherlands Institute for Radio Astronomy, The Netherlands	Low frequency radio in space	27 April 2012
Yogesh M Joshi Indian Institute of Technology Kanpur	New insights into the phase behavior of aqueous suspensions of laponite	9 May 2012
Borriello Enrico Institute for Theoretical Physics Germany	My research activity so far and my plans for the near future	11 May 2012
Jasjeet Bagla Indian Institute of Science Educationand Research, Mohali	Hyperfine transition of Helium-3 as a probe of the epoch of reionization	18 May 2012
Harvinder K Jassal Indian Institute of Science Education and Research, Mohali	Prospects for observing perturbations in dark energy	21 May 2012
Vikram Rana California Institute of Technology USA	The nuclear spectroscopic telescope array (NuSTAR)	30 May 2012
Ajith P California Institute of Technology USA	Interfacing analytical and numerical relativity for gravitational wave astronomy	8 June 2012
Dibyendu Das Indian Institute of Technology Bombay, Mumbai	Giant number fluctuations in interacting and growing microbial populations	13 June 2012
Ajit Srivastava Institute of Physics, Bhubaneshwar	From the universe to relativistic heavy-ion collisions: CMBR anisotropies and flow fluctuations	18 June 2012
Jishad Kumar Saha Institute of Nuclear Physics Kolkata	Dynamics and thermodynamics of quantum Brownanian motion	25 June 2012
Rukmini Dey Harishchandra Research Institute Allahabad	Some aspects of minimal surfaces	27 June 2012

Name	Title	Date
Santhanam MS Indian Institute of Science Education and Research, Pune	Extreme events on complex networks	28 June 2012
Rau ARP Louisiana State University, USA	Explorations in quantum information	2 July 2012
Rajaram Nityananda National Centre for Radio Astronomy Pune	Strong phase modulation: from Raman to Nath to scintillation	3 July 2012
Rajaram Nityananda National Centre for Radio Astronomy Pune	The optics of scintillation at radio wavelengths	6 July 2012
Bhimsen Shivamoggi University of Central Florida, USA	Beltrami States in Plasmas	9 July 2012
Sajal Kumar Ghosh University of California, USA	Soft supported membranes: Effect of Ca2+ ions on structures and lipid organization	18 July 2012
Guglielmo M Tino University of Florence, Italy	Testing gravity with cold atom interferometry	23 July 2012
Ashok K Singal Physical Research Laboratory Ahmedabad	Our large peculiar motion in the universe determined from the radio sky brightness anisotropy at 1.4 Ghz.	23 July 2012
Manabendra Chandra Florida State University and National High Magnetic Field Laboratory, USA	Nanoscale structure-specific plasmonics	25 July 2012
Sunita Srivastava Brookhaven National Laboratory USA	Structural transformations and rheological response in DNA-functioned nanoparticles assemblies at the solid-liquid and liquid-air interfaces	30 July 2012
Mark Dijkstra Max Planck Institute for Astrophysics Germany	Lyman alpha emitting galaxies as a probe of the young Universe	1 August 2012
Rahul Siddharthan The Institute of Mathematical Sciences, Chennai	The language of DNA: sequences and correlations	2 August 2012
Pulak Kumar Ghosh RIKEN, Japan	Quantum effects in energy and charge transfer in a wheel-shaped artificial photosynthetic complex	6 August 2012

Name	Title	Date
Arijit Saha Weizmann Institute of Science Israel	A quantum dot close to Stoner instability: the role of Berry's phase	9 August 2012
Niraj Kumar University of California, USA	Stochastic thermodynamics: twin elevator and molecular machine	10 August 2012
Peeyush Prasad University of Amsterdam The Netherlands	AARTFAAC and the search for radio transients using LOFAR	16 August 2012
B Ananthanarayan Indian Institute of Science, Bangalore	The discovery of the Higgs Boson and consequences	16 August 2012
Divya Sharma MESA + Institute for Nanotechnology, Netherlands	Coherent control: creating the 'right' quantum interferences to control molecular dynamics	17 August 2012
Katherine Blundell University of Oxford United Kingdom	Episodic feedback from winds and jets in quasars and microquasars	17 August 2012
John Katsaras Oak Ridge National Laboratory, USA	Rutherford, his laboratory and the Nobel Prize	5 September 2012
Kabir Ramola Tata Institute of Fundamental Research, Mumbai	Columnar order and Ashkin-Teller criticality in the hard square lattice gas	5 September 2012
Sanjay P Sane National Centre for Biological Sciences, Bangalore	How do insects fly?	6 September 2012
Dutta Gupta S University of Hyderabad, Hyderabad	Coherent perfect absorption mediated bending of light the wrong way	7 September 2012
Valdiya KS Jawaharlal Nehru Centre for Advanced Scientific Research Bangalore	The three great rivers of Himalayas (Hindi Day Celebration)	14 September 2012
Matin Durrani Physics World, IOP Publishing United Kingdom	Physics world and the top 10 Physics breakthroughs of 2011	17 September 2012
Bhargava Ram N VU University, Amsterdam	Probing molecular chirality with a femtosecond reaction microscope	21 September 2012

Name	Title	Date
Kumar N Raman Research Institute, Bangalore	Classical orbital diamagnetism: a surprise	3 October 2012
Subinoy Das Institute for Theoretical Physics and Cosmology, Germany	Mysteries of dark matter, dark energy and their possible connection to the neutrino	15 October 2012
Rajarshi Chakrabarti Universität Stuttgart, Germany	Theoretical investigation of stochasticity in molecular motion	18 October 2012
Sathyaprakash BS Cardiff University, UK	Black holes sing their past	2 November 2012
Nandan Singh Bisht University of Delhi, New Delhi	Quantum metrology and coincidence imaging	5 November 2012
Anand Srivastava University of Chicago, USA	Molecular mechanism of membrane binding and membrane targeting by the GRP1 PH domain	6 November 2012
Georg Pabst University of Graz, Austria	Physics of cellular signaling	7 November 2012
Vinod K Gaur Indian Institute of Astrophysics Bangalore	Safe seismic design of critical structures	15 November 2012
Musti J Swamy University of Hyderabad Hyderabad	Interaction of the major bovine seminal plasma protein, PDC-109 with lipid membranes and its chaperone activity	23 November 2012
Manodeep Sinha Vanderbilt University, USA	Flybys in the universe: first results from cosmological simulations	5 December 2012
Neeraj Gupta Netherlands Institute for Radio Astronomy, The Netherlands	Tracing the evolution of cold gas in galaxies using 21-cm absorption	13 December 2012
Sastry VSS University of Hyderabad Hyderabad	Phase diagram of the quadratic Hamiltonian of biaxial molecules: insights from Monte Carlo simulations	18 December 2012
Saptarshi Pal University of Edinburgh, UK	What is the colour of sound? Analyzing colouration and the role of midrange loudspeakers in high fidelity (Hi-Fi) audio reproduction	19 December 2012
Srinivas Sridhar Northeastern University, USA	Nanoplatforms for personalized medicine	19 December 2012

Name	Title	Date
Rafael Sorkin Perimeter Institute, Canada	If spacetime is a causal set then Lorentz symmetry is unbroken	20 December 2012
Zoltan Haiman Columbia University, USA	The origin and detection of high-redshift supermassive black holes	4 January 2013
Bidya Binay Karak Indian Institute of Science, Bangalore	Understanding grand minima and the predictability of the solar cycle using a dynamo model	7 January 2013
Pinaki Choudhuri University of Dusseldorf, Germany	Yielding and flow of soft amorphous materials	8 January 2013
Onkar Parrikar University of Illinois Urbana-Champaign	Chiral gravity and torsional anomalies in topological insulators	8 January 2013
Subrahmanyam A Indian Institute of Technology Madras, Chennai	Surface enhanced Raman scattering (SERS): a powerful tool in sensing	9 January 2013
Chirag Kalelkar Indian Institute of Technology, Mandi	Crash-course on rheology and rheometry covering shear and extensional (bulk) rheology – lecture series	9 – 11 January 2013
Rafael Sorkin Syracuse University,USA and Perimeter Institute for Theoretical Physics, Canada	Solved and unsolved problems of time in quantum gravity	15 January 2013
Arvind Ayyer University of California, USA	Exactly solvable models for nonequilibrium statistical physics	15 January 2013
Atish Kamble University of Wisconsin, USA	The puzzle of isolated neutron stars	16 January 2013
Dipanjan Mukherjee Inter University Centre for Astronomy and Astrophysics, Pune	Magnetic field structure in accretion mounds on neutron stars and the effect on CRSF	21 January 2013
Mark Humphrey Australian National University Canberra	Metal alkynyls for nonlinear optics: molecular light switches and molecular trees	21 January 2013
Chandrashekar CM Okinawa Institute of Science and Technology, Japan	Quantum percolation of two-state particle and Anderson transition	1 February 2013
Singh RP Physical Research Laboratory Ahmedabad	Experiments with phase singularities of light	12 February 2013

Name	Title	Date
Ashish Lele National Chemical Laboratory, Pune	From molecular structure to polymer processing: bridging length and time scales	13 February 2013
Shriharsh Tendulkar California Institute of Technology USA	Magnetars: kinematics, ages and birth places	13 February 2013
Kanan K Datta Stockholm University, Sweden	Cosmic reionization with 21cm fluctuations	15 February 2013
Navinder Singh Physical Research Laboratory Ahmedabad	Yang-Rice-Zhang theory of high temperature cuprate superconductivity and its application to compute optical response of cuprates	20 February 2013
Sivaramakrishnan R National University of Ireland Galway, Ireland	Dynamics of proteins and peptides in the membrane and living cells using fluorescence (cross) correlation spectroscopy	21 February 2013
Lisa Glaser University of Copenhagen, Denmark	A CDT Hamiltonian from Horava-Lifshitz gravity	25 February 2013
Mahadev Savadatti	Hindi Workshop – Official Notings and Draftings	26 February 2013
Banani Chakraborty RWTH Aachen University, Germany	DNA in nanotechnology: journey from double helix to origami: secret of life to secret of new generation biosensing	1 March 2013
EPJ van den Heuvel University of Amsterdam The Netherlands	ESA's INTEGRAL gamma-ray satellite and X-ray Binaries	1 March 2013
Pradeep Kumar Mohanty Saha Institute of Nuclear Physics Kolkata	Does an independent Manna universality class exist?	4 March 2013
Aparna Venkatesan University of San Fransisco, USA	Signatures of hard ionizing radiation from the first galaxies	15 March 2013
Sushan Konar National Centre for Radio Astrophysics, Pune	Is glitch-induced field enhancement possible in neutron stars?	18 March 2013
Manoj Kaplinghat University of California, USA	Is the dark matter particle a WIMP?	21 March 2013
Abhirup Datta University of Colorado, USA	Exploring the dark ages and epoch of reionization with the HI signal	22 March 2013

Name	Title	Date
Subhadeep De National Physical Laboratory New Delhi	Dynamics of spin domains with spinor Bose condensed rubidium and future experiment with mixtures of BEC and degenerate fermionic lithium	26 March 2013
Harsha Mohan Paroor Max Planck Institute for Polymer Research, Germany	Microemulsions: prediction of the phase diagram using a modified Helfrich free energy	27 March 2013
Radhika Vathsan Birla Institute of Technology and Science, Pilani, Goa	Einstein's recoiling slit experiment, complementarity and uncertainty	28 March 2013

CELL MECHANICS MEETING

31 January – 2 February 2013
Raman Research Institute, Bangalore

Speaker	Broad area of presentation/discussion
	Thursday, Jan 31
Madhulika Dixit (IIT-M)	Role of shear stress in endothelial biology
Mandar Inamdar (IIT-B)	Theoretical modeling of single cell, collective cell, and sub-cellular mechanics
Bidisha Sinha (IISER-Kolkata)	Towards understanding membrane homeostasis under 'stretch'
Special lecture: GK Ananthasuresh (Mech. Eng., IISc)	Micromanipulation and mechanical characterization of biological cells
Aurnab Ghose (IISER-Pune)	Neuronal traction forces and axonal mechanics
	Friday, Feb 1
Rumi Dey (IISER-Kolkata)	Dynamics of active cellular response to time varying stretch
Shamik Sen (IIT-B)	Cell mechano adaptation to ECM properties
Namrata Gundiah (Mech. Eng., IISc)	Cell and tissue mechanics
Ranjith Padinhateeri (IIT-B)	Non-equilbrium self-assembly proteins
Deepak Sinha (IACS-Kolkata)	Photo control of protein activity for exploring viscoelasticity of live tissue
Special lecture: Satyajit Mayor (NCBS)	Cell membrane organization and dynamics

Speaker	Broad area of presentation/discussion
	Saturday, Feb 2
Raja Paul (IACS-Kolkata)	Mitotic spindle assembly & Mechanical interaction among cells
Neetu Singh (NCL-Pune)	Tuning Nano structures for Enhanced Bio-Functionality
Nagaraj Balasubramaniam (IISER-Pune)	Adhesion dependent regulation of caveolar endocytosis
Surat Saravanan (Maithreyi Narsimha) (TIFR)	Cell delamination and reorganization during development (dorsal closure)
Darius Koester (NCBS)	Reconstitution of cortical actin dynamics templating membrane organization
Pramod Pullarkat (RRI)	Shape instabilities in axons

MWA PROJECT MEETING

Raman Research Institute, Bangalore
18 June – 22 June 2012

Monday, June 18

Session 1	**Welcome**
09:30 – 09:40 Ravi Subrahmanyan	Welcomefrom RRI Director
09:40 – 09:50 Rachel Webster	Welcomefrom MWA Board Chair
Session 2	**Project Office reports (Chair: Rachel Webster)**
09:50 – 10:30 Steven Tingay	Project Director Report
11:00 – 11:45 Tom Booler	Project Manager Report
11:45 – 12:30 Bob Goeke	Project Engineer Report
13:30 – 14:15 Judd Bowman	Project Scientist Report
14:15 – 15:00	Open discussion of Project Plan and project status

Speaker	Broad area of presentation/discussion
Session 3	**Commissioning #1 (Chair: Uday Shankar)**
15:00 – 15:30 Randall Wayth	Commissioning Scientist Report
16:00 – 16:20 Hurley-Walker	Science Commissioning progress report #1
16:20 – 16:40 Martin Bell	Science Commissioning progress report #2
16:40 – 17:00 Steve Ord (Correlator capabilities)	Science Commissioning progress report #3

Tuesday, June 19

Session 4	**32T science results (Chair: Melanie Johnston-Hollitt)**
09:00 – 09:30 Chris Williams	Deep EoR fields with 32T
09:30 – 10:00 Ben McKinley	Imaging Centaurus A with 32T
10:00 – 10:30 Gianni Bernardi	32T sky surveys
11:00 – 11:30 Murphy/Kaplan/Nadia	Transients with 32T
11:30 – 12:00 Nithyanandan Thyagarajan	EoR detection and foregrounds
12:00 – 12:30 Stephen Ord	Pulsars
Session 5	**Science collaboration presentations and plans (Chair: Randall Wayth)**
13:30 – 14:00 Murphy/Kaplan/Bell	Transients, commissioning and 128T
14:00 – 14:30 Hewitt	EoR, commissioning and 128T
14:30 – 15:00 Staveley-Smith	GEG, commissioning and 128T

Speaker	Broad area of presentation/discussion
15:00 – 15:30 Divya Oberoi	SHI, commissioning and 128T
16:00 – 17:00	Open discussion
	Wednesday, June 20
Session 6	**EoR open session (Chair: JackieHewitt)**
09:00 – 10:30 Hewitt	EoR open session
Session 7	**Transients open session (Chair: Kaplan/Murphy/Bell)**
11:00 – 12:30	Transients open session
Session 8	**Commissioning #2 (Chair: Steven Tingay)**
13:30 – 14:00 Tom Booler	Detailed schedule for construction/commissioning
14:00 – 14:30 Bob Goeke	Detailed Engineering Commissioning
14:30 – 15:00 Randall Wayth/Bob Goeke	Detailed Engineering/Science Commissioning
15:00 – 15:30	Open discussion
16:00 – 16:45	Open discussion
16:45 – 17:00 Steven Tingay	Closing remarks
	Thursday, June 21
	Breakout sessions (self-organised): Science collaborations Commissioning team Sub-system teams
	Friday, June 22
	MWA Board meeting

APPENDIX 4

VISITORS

Name and Institution	Duration of stay
Bibhu Ranjan Sarangi Institut Curie, France	4 – 7 April 2012 24 – 26 April 2012
Urna Basu Saha Institute of Nuclear Physics, Kolkata	8 – 11 April 2012
Jincy Devasia Mahatma Gandhi University, Kottayam	16 April – 24 May 2012
Stephane Ouvry Laboratoire de Physique Théorique et Modèles Statistiques, France	23 – 27 April 2012
Willem A Baan Netherlands Institute for Radio Astronomy, The Netherlands	23 – 28 April 2012
Aurnab Ghose Indian Institute of Science Education and Research, Pune	19 – 20 April 2012 24 – 25 April 2012
Abhishek Chaudhuri Oxford University, United Kingdom	26 April 2012
Vasanthakumar G Ramu University of Girona, Spain	26 – 27 April 2012
Yogesh M Joshi Indian Institute of Technology, Kanpur	8 – 12 May 2012
Deepak Mathur Tata Institute of Funamental Research, Mumbai	9 – 11 May 2012
John Thomas Manipal University, Manipal	9 – 11 May 2012

Name and Institution	Duration of stay
Benoy Anand Sri Sathya Sai Institute of Higher Learning, Andhra Pradesh	9 – 27 May 2012
Harigopal B Department of Science and Technology, New Delhi	15 – 16 May 2012
Reetanjali Moharana Indian Institute of Technology Bombay, Mumbai	9 May – 10 June 2012
Aru Beri Indian Institute of Technology, Ropar	14 May – 15 August 2012 11 January – 17 May 13
Ajith P California Institute of Technology, USA	3 – 15 June 2012
Jasjeet Bagla Indian Institute of Science Education and Research, Mohali	16 – 25 May 2012
Harvinder K Jassal Indian Institute of Science Education and Research, Mohali	16 – 25 May 2012
Seshadri TR Delhi University, Delhi	20 May 2012 16 – 21 November 2012
Soobash Daiboo Kapteyn Astronomical Institute, The Netherlands	20 – 31 May 2012
Siji Narendran National Institute of Technology, Calicut	28 May – 2 June 2012
Smijesh N National Institute of Technology, Calicut	28 May – 2 June 2012 16 November 2012
Vikram Rana California Institute of Technology, USA	29 May – 1 June 2012
Rukmini Dey Harishchandra Research Institute, Allahabad	3 – 30 June 2012
Dabasish Chaudhuri Indian Institute of Technology, Hyderabad	10 June – 25 July 2012
Dibyendu Das Indian Institute of Technology, Bombay	13 – 15 June 2012
Ajit Srivastava Institute of Physics, Bhubaneshwar	17 – 20 June 2012

Name and Institution	Duration of stay
Remyamol T Indian Institute of Space Science and Technology, Trivandrum	22 – 26 June 2012 5 – 6 March 2013
Abhay Ashtekar The Pennsylvania State University, USA	
Haripadmam PC Indian Institute of Space Science and Technology, Trivandrum	22 – 26 June 2012 17 – 20 November 2012 14 – 16 December 2012 15 – 17 February 2013
Kavitha MK Indian Institute of Space Science and Technology, Trivandrum	17 – 20 November 2012 5 – 6 March 2013
Aparna A Nair College of Engineering, Trivandrum	29 November – 1 December 2012
Raghwinder Singh Indian Institute of Technology, Madras	26 December 2012 – 15 January 2013 18 – 19 January 2013
Jishad Kumar Saha Institute of Nuclear Physics, Kolkata	24 – 26 June 2012
Swarup G National Centre for Radio Astronomy, Pune	25 – 28 June 2012 17 – 21 November 2012
Santhanam MS Indian Institute of Science Education and Research, Pune	28 – 29 June 2012
Nityananda R Tata Institute of Fundamental Research, Mumbai	30 June – 8 July 2012
Rau ARP Louisiana State University, USA	1 – 10 July 2012
Keiji Saito Keio University, Japan	1 – 8 July 2012
Jayanth Syracuse University, USA	16 July – 20 August 2012
Sajal Kumar Ghosh University of California-San Diego, USA	17 – 19 July 2012
Andrzej Zdiarski Nicholas-Copernicus Institute, Poland	21 – 25 July 2012 17 – 19 March 2013
Ashok K Singal Physical Research Laboratory, Ahmedabad	22 – 24 July 2012

Name and Institution	Duration of stay
Manabendra Chandra Florida State University and National High Magnetic Field Laboratory USA	25 July 2012
Phil Charles Southampton University, United Kingdom South African Large Telescope, South Africa	26 – 27 July 2012
Kishore Sridharan Hanyang University, South Korea	26 – 31 July 2012
Sunita Srivastava Brookhaven National Laboratory, USA	29 July – 1 August 2012
Mark Dijkstra Max Planck Institute for Astrophysics, Germany	29 July – 4 August 2012
Pulak Kumar Ghosh RIKEN Japan	5 – 7 August 2012
Udaya Baskar R National Institute of Technology, Trichy	8 – 10 August 2012
Arijit Saha Weizmann Institute of Science, Israel	8 – 11 August 2012
Niraj Kumar University of California – San Diego, USA	8 – 11 August 2012
J.N. Chengalur National Centre for Radio Astrophysics, Pune	14 August 2012
Katherine Blundell University of Oxford, UK	8 – 20 August 2012 11 – 20 December 2012 12 February 2013
Steven Lee University of Oxford, UK	8 – 20 August 2012 11 – 20 December 2012 12 February 2013
Archana Sharma	8 – 30 August 2012 1 September – 4 October 2012
Peeyush Prasad University of Amsterdam, The Netherlands	14 – 16 August 2012
Kabir Ramola Tata Institute of Fundamental Research, Mumbai	4 – 6 September 2012

Name and Institution	Duration of stay
John Katsaras National Laboratory, USA	5 September 2012
Dutta Gupta University of Hyderabad, Hyderabad	5 – 8 September 2012
Matin Durrani Physics World, IOP Publishing Bristol, United Kingdom	17 September 2012
Kumar MP Manipal University, Manipal	1 and 3 June 2012 9 – 15 October 2012
Subinoy Das Institute of Theoretical Physics and Cosmology, Germany	15 – 16 October 2012
Rajarshi Chakrabarti Univesity of Stuttgart, Germany	17 – 18 October 2012
Pragati Pradhan St. Joseph's College, Darjeeling	23 October – 1 November 2012 23 November 2012 18 – 20 December 2012
Ann Mary Mahatma Gandhi University, Kerala	29 October – 11 November 2012 16 – 26 May 2012 28 – 30 January 2013
Nandan Singh Bisht University of Delhi, Delhi	31 October – 2 November 2012
Bidisha Bandyopadhyay Delhi University, Delhi	31 October – 1 December 2012 4 February – 4 April 2013
Anand Srivastava University of Chicago, USA	5 – 9 November 2012
Georg Pabst University of Graz, Austria	5 – 11 November 2012
Robert Goeke Massachusetts Institute of Technology, USA	18 – 23 June 2012 6 – 7 November 2012
Keiichi Kaneto Kyushu Institute of Technology, Japan	12 November 2012
Shuzi Hayase Kyushu Institute of Technology, Japan	12 November 2012
Shyam S Pandey Kyushu Institute of Technology, Japan	12 November 2012

Name and Institution	Duration of stay
Mitsuyoshi Onoda University of Hyogo, Hyogo	12 November 2012
Jinto Thomas Institute of Plasma Research, Ahmedabad	24 November – 8 December 2012
Mohandas Institute for Plasma Research, Ahmedabad	24 November – 8 December 2012
Ravi Kumar AV Institute for Plasma Research, Ahmedabad	24 – 26 November 2012
Monodeep Sinha Vanderbilt University, USA	4 – 6 December 2012
Pritpal Kaur Sandhu Indian Institute of Technology, Indore	4 – 15 December 2012
Neeraj Gupta Netherlands Institute for Radio Astronomy, The Netherlands	12 – 14 December 2012
Rafael Sorkin Perimeter Institute, Canada	16 December 2012 – January 17 2013
Sastry VSS University of Hyderabad, Hyderabad	18 December 2012
Srinivas Sridhar Northeastern University, USA	19 December 2012
Siddharth Savyasach Malu Indian Institute of Technology, Indore	23 – 31 December 2012
Alok Laddha Chennai Mathematical Institute, Chennai	19 August 2012 31 October 2012 18 – 30 December 2012
Chiragkalelkar Indian Institute of Technology, Mandi	21 December 2012 – 15 January 2013
Chandra Kant Mishra Indian Institute of Science and Education Research, Trivandrum	31 December 2012 – 11 January 2013
Onkar Parrikar University of Illinois at Urbana-Champaign, USA	7 – 9 January 2013
Pinaki Choudhuri University of Dusseldorf, Germany	8 January 2013

Name and Institution	Duration of stay
Subrahmanyam A Indian Institute of Technology Madras, Chennai	9 January 2013 28 – 29 March 2013
Arvind Ayyer University of California, USA	14 – 15 January 2013
Atish Kamble Harvard University, USA	10 – 14 July 2012 14 – 18 January 2013
Dipanjan Mukherjee Inter University Centre for Astronomy and Astrophysics, Pune	19 – 28 January 2013
Swapnesh Panigrahi Tata Institute of Fundamental Research, Mumbai	20 – 22 January 2013
Chandrashekar C M Okinawa Institute of Science and Technology, Japan	1 – 6 February 2013
Ashish Lele National Chemical Laboratory, Pune	16 – 17 July 2012 12 – 13 February 2013
Shriharsh Tendulkar California Institute of Technology, USA	12 – 13 February 2013
Singh R P Physical Research Laboratory, Ahmedabad	12 – 14 February 2013
Navinder Singh Physical Research Laboratory, Ahmedabad	17 – 21 February 2013
Christien Zier BSA, Bonn, Germany	18 – 19 February 2013
Lisa Glaser University of Copenhagen, Copenhagen	3 February – 15 March 2013
Sivaramakrishnan R National University of Ireland Galway, Ireland	21 February 2013
Nishant K Singh Inter University Centre for Astronomy & Astrophysics, Pune	25 February – 11 March 2013
EPJ can den Heuvel Astronomical Institute, The Netherlands	27 February – 2 March 2013
Banani Chakraborty RWTH Aachen University, Germany	28 February – 3 March 2013

Name and Institution	Duration of stay
Pradeep Kumar Mohanty Saha Institute of Nuclear Physics, Kolkata	2 – 6 March 2013
Sushan Konar National Centre for Radio Astronomy, Pune	17 – 21 March 2013
Aparna Venkatesan University of San Francisco, USA	5 – 8 March 2013 14 – 15 March 2013
Anand Puthirath Cochin University of Science and Technology, Kerala	14 – 16 March 2013
Dibyakrupa Sahoo Institute of Mathematical Sciences, Chennai	17 – 24 March 2013
Abhirup Datta University of Colorado, USA	21 – 24 March 2013
Subhadeep De National Physical Laboratory, New Delhi	25 – 26 March 2013
Harsha Mohan Paroor Max Planck Institute for Polymer Research, Germany	27 March 2013
Radhika Vathsan Birla Institute of Technology and Science, Pilani, Goa	28 March 2013
Divyashree M C National Institute of Technology, Calicut	28 – 30 March 2013
Thushara E National Institute of Technology, Calicut	29 – 30 March 2013

APPENDIX 5

JOURNAL CLUB

Discussed by	Paper discussed	Date
Chandrakant Mishra	Measuring cosmological distance-redshift relationship using only gravitational wave observations of binary neutron star coalescences C Messenger, Cardiff University UK J Read, The University of Mississippi, USA *Phys. Rev. Lett*, **108**, 91101-91105 (2012)	12 April 2012
Raghunathan A	DSS-28: A novel wide bandwidth radio telescope devoted to educational outreach Glenn Jones *et al* *Proceedings of SPIE*, 73333-773330 (2010)	12 April 2012
Madhukar S	Curvature-driven capillary migration and assembly of rod-like particles Kathleen J Stebe *et al* *Proceedings of the National Academy of Sciences*, **108** (52), 20923-20928 (2011)	19 April 2012
Anu Renjith	Electrochemical nanobiosensor for express diagnosis of acute myocardial infarction in undiluted plasma Elena Suprun *et al* *Biosensors and bioelectronics*, **25**, 1694-1698 (2010)	19 April 2012
Prasad VV	Shape of a ponytail and the statistical physics Raymond E Goldstein, Patrick B Warren and Robin C Ball *Phys. Rev. Lett.,* **108**, 078101 (2012)	28 June 2012
Arnab Pal	Quantum Szilard engine Sang Wook Kim *et al* *Phys. Rev. Lett,* **106**, 070401 (2011)	28 June 2012

Discussed by	Paper discussed	Date
Vijayaraghavan D	Reducing Blood viscosity with magnetic fields R Tao *et. al.* *Physical Review Letters E,* **84**, 011905 (2011)	12 July 2012
Santosh Prasad Gupta	General solution for multiple foldings of hexaflexagons Yutaka Nishiyama *International Journal of Pure and Applied Mathematics*, **58**, 113-124 (2010)	12 July 2012
Priya Rose	Topological transitions in metamaterials Harish N S Krishnamoorthy, *et al* *Science*, **336,** 6078 pp. 205-209	26 July 2012
Jyothi S	Optically trapped gold nanoparticle enables listening at the microscale Alexander Ohlinger *et al* *Physical Review Letters,* **108**, 018101 (2012)	26 July 2012
Ranjini Bandyopadhyay	Capillary fracturing in granular media Ran Holtzman, Michael, *et. al.* *Physical Review Letters*, **108**, 264504 (2012)	9 August 2012
Harsha Raichur	Terrestrial expoplanets: rare or common objects Buchhave, L A *et al* *Nature,* Vol. 486, Pg. **375** (2012)	9 August 2012
Avinash BS	Understanding and controlling the substrate effect on grapheme electron-transfer chemistry via reactivity imprint lithography *Nature,* Chemistry*,* (2012) doi: 10.1038/nchem.1421	23 August 2012
Udaya Shankar N	Towards a complete treatment of the cosmological recombination problem J Chluba[1, 2] and R M Thomas[1] arXiv:1010.3631v3 [astro-ph.CO] *Mon. Not. R. Astron. Soc.*, **412**, 748-764 (2011)	23 August 2012
Anjan Roy	Impact-activated solidification of dense suspensions via dynamic jamming fronts Scott R Waitukaitis & Heinrich M Jaeger *Nature*, **487**, 205-209 (2012)	13 September 2012
Kshitij Thorat	A gas cloud on its way towards the supermassive black hole at the Galactic Centre Gillessen *et al* *Nature,* **7379**, pp. 51-54, volume 481 (2012)	13 September 2012
Joseph Samuel	Hyperbolic Interfaces Luca Giomi *Physical Review Letters,* **109**, 136101 (2012)	11 October 2012

Discussed by	Paper discussed	Date
Tridib Ray	Ultrafast all-optical switching by single photons Thomas Volz *et al* *Nature Photonics,* **6**, 607-611 (2012)	11 October 2012
Avinash Deshpande	Melting a granular glass by cooling Jan plagge and Claus Heussinger *arXiv:1210.1945v1* [cond-mat.soft] (2012)	25 October 2012
Ananthasubramanian PG	On a new kind of rays W.C. Rontgen, translated by Arthur Stanton from thesitzungsberichteder Wursburger physic – medic. Gesellschaft, 1895 *Nature,* No. 1369, **53**, 274-277 (1896)	25 October 2012
Sadiq Rangwala	The Nobel Prize in Physics 2012	8 November 2012
Swamynathan K	Copper (II) mediated facile and ultra-fast peptide synthesis in methanol Sachitanand M Mali, Sandip V Jadhav and Hosahudya N Gopi *Chem. Commun*., 2012, **48**, 7085-7087	22 November 2012
Chaitra Hegde	Universally Sloppy Parameter Sensitivities in Systems Biology Models Gutenkunst RN, Waterfall JJ, Casey FP, Brown KS, Myers CR, *et al* *PLoS Comput Biol,* **3**(10): e189 (2007)	22 November 2012
Biswajit Paul	Strategies for detection and characterization of habitable planets: eclipsing brown dwarfs Adrian R Belu *et al* *The Astrophysical Journal*	14 February 2013
Arnab Pal	Equilibrating temperature like variables in jammed granular subsystems James G Puckett and Karen E Daniels *Physical Review Letters,* **110**, 058001 (2013)	14 February 2013
Bhargava Ram	A clock directly linking time to a particle's mass Shau-Yu Lan, Pei-Chen Kuan, Brian Estey, Damon English, Justin M Brown, Michael A Hohensee *et al* *Science*, **339**, 554-557 (2013)	28 February 2013
Joseph Samuel	Acoustic analog to the dynamical casimir effect in a Bose-Einstein condensate J -C Jaskula *et al* *Physical Review Letters*, **109**, 220401 (2012)	28 February 2013

Discussed by	Paper discussed	Date
Renu Vishavkarma	Hydrodynamics of writing with Ink J Kim *et al* *Physical Review Letters*, **107**, 264502 (2011)	14 March 2013
Mahavir Sharma	Origin of bulgeless dwarf galaxies and dark matter cores *Nature,* **463**, 203-206 (2010)	14 March 2013
Andal Narayanan	Using interface for high fidelity quantum state transfer in optomechanics *Physical Review Letters,* **108**, 153603 (2012)	28 March 2013
Chaitra Hegde	From black swans to dragon kings – is there life beyond power laws? Didier Sornette (2012) *The European Physical Journal Special Topics*, **205**, (May 1 2012), "Dragon-kings: mechanisms, statistical methods and empirical evidence"	28 March 2013

RAMAN RESEARCH INSTITUTE

Bangalore

Audited Statements of Account

2012-2013

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

AUDITOR'S REPORT

The Members of Raman Research Institute

Report on the Financial Statements

We have audited the financial statements of the "RAMAN RESEARCH INSTITUTE", C. V. Raman Avenue, Sadashivanagar Bangalore - 560 080, which comprise the Balance Sheet as at 31st March, 2013 and the Statement of Income and Expenditure Account for the year then ended and a summary of significant accounting policies and other explanatory information.

Management's Responsibility for the Financial Statements

Management is responsible for the preparation of the financial statements. This responsibility includes the design, implementation and maintenance of internal control relevant to the preparation of the financial statements that are free from material misstatement, whether due to fraud or error.

Auditor's Responsibility

Our responsibility is to express an opinion on the financial statements based on our audit. We conducted our audit in accordance with the Standards on Auditing issued by the Institute of Chartered Accountants of India. Those Standards require that we comply with ethical requirements and plan and perform the audit to obtain reasonable assurance about whether the financial statements are free from material misstatement.

An audit involves performing procedures to obtain audit evidence about the amounts and disclosures in the financial statements. The procedures selected depend on the auditor's judgment, including the assessment of the risks of material misstatement of the financial statements, whether due to fraud or error. In making those risk assessments, the auditor considers internal control relevant to the preparation and fair presentation of the financial statements in order to design audit procedures that are appropriate in the circumstances. An audit also includes evaluating the appropriateness of accounting policies used and the reasonableness of the accounting estimates made by management, as well as evaluating the overall presentation of the financial statements.

We believe that the audit evidence we have obtained is sufficient and appropriate to provide a basis for our audit opinion.

No 37/1, 1st Floor, M.N.K. Rao Road | TeleFax: 080 - 26566337
Basavanagudi, Bangalore - 560 004 | E-mail: audit@brvgoud.co.in

Opinion

In our opinion and to the best of our information and according to the explanations given to us, the said accounts give the information required and give a true and fair view in conformity with the accounting principles generally accepted in India:

1) In the case of the Balance Sheet, of the state of affairs of Raman Research Institute as at 31st March, 2013.

2) In the case of the Income and Expenditure Account, of the Excess of Income over Expenditure for the year ended on that date.

We further report that:

a) The Balance Sheet and Income and Expenditure Account dealt with by this report, are in agreement with the books of accounts.

b) In our opinion, proper books of account as required have been kept by the Institute so far as appears from our examination of those books.

for B.R.V. GOUD & CO.,
Chartered Accountant
FRN No. 000992S

B.R.V. GOUD & CO. CHARTERED ACCOUNTANTS B'LORE-4

(A.B.ShivaSubramanayam)
Partner
M No. 201108

Place: Bangalore
Date: 11.09.2013

RAMAN RESEARCH INSTITUTE

Bangalore

Balance Sheet as at 31st March 2013

I SOURCES OF FUNDS	SCH.	As at 31.3.2013 Rs.	As at 31.3.2012 Rs.
CAPITAL FUND	1	103,69,32,812	100,60,79,708
GENERAL FUND	2	77,93,670	67,05,448
RETIREMENT FUNDS	3	30,60,43,044	28,65,63,190
UNUTILISED GRANTS	4	5,15,07,195	3,85,75,999
SUNDRY CREDITORS	5	1,90,86,827	2,18,80,890
PROVIDENT FUND (contra)	6	9,94,79,359	8,70,84,116
PENSION FUND (contra)	7	6,83,47,127	5,54,90,088
TOTAL		159,21,90,034	150,23,79,439

II APPLICATION OF FUNDS			
FIXED ASSETS	8	90,30,07,129	88,07,02,141
INVESTMENTS - RETIRMENT FUND	9	30,60,43,044	28,65,63,190
CURRENT ASSETS, ADVANCES AND DEPOSITS	10	12,55,70,648	11,58,61,115
CASH AND BANK BALANCES	11	8,97,42,727	7,66,78,789
PROVIDENT FUND (contra)	12	9,94,79,359	8,70,84,116
PENSION FUND (contra)	13	6,83,47,127	5,54,90,088
TOTAL		159,21,90,034	150,23,79,439

Notes on accounts. 17

Schedules 1 to 17 form an integral part of the accounts

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

B.R.V. GOUD & CO. CHARTERED ACCOUNTANTS B'LORE-4

K. KRISHNAMA RAJU
Administrative Officer

RAVI SUBRAHMANYAN
Director

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

Place : Bangalore
Date : Sept.11,2013

RAMAN RESEARCH INSTITUTE

Bangalore

Income and Expenditure Account for the year ended 31.03.2013

A INCOME	SCH.	2012-2013 Rs.	2011-2012 Rs.
GRANT-IN-AID:			
Non-Plan-Recurring		1,07,10,000	1,42,00,000
Plan-Recurring		25,43,51,849	24,08,01,830
Interest & Miscellaneous Income	14	1,11,99,110	1,10,19,068
TOTAL (A)		27,62,60,959	26,60,20,898
B EXPENDITURE			
Salaries & Allowances	15	17,44,38,223	16,13,64,176
Working Expenses	16	10,07,34,514	10,63,65,079
TOTAL(B)		27,51,72,737	26,77,29,255
C SURPLUS/(DEFICIT)FOR THE YEAR (A-B)		10,88,222	(17,08,357)

Notes on accounts. 17

Schedules 1 to 17 form an integral part of the accounts

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

B.R.V. GOUD & CO. CHARTERED ACCOUNTANTS B'LORE-4

K. KRISHNAMA RAJU
Administrative Officer

RAVI SUBRAHMANYAN
Director

A. B. SHIVA SUBRAMANYAM
Partner
M No. 201108

Place : Bangalore
Date : Sept.11,2013

RAMAN RESEARCH INSTITUTE
Bangalore

Receipts and Payments account for the year ended 31.03.2013

RECEIPTS	SCH.	2012-2013 Rs.	2011-2012 Rs.
Opening Balance	A	1,70,78,789	2,62,14,001
Grant-in-aid	B	35,97,01,815	40,82,81,533
Advance to Suppliers	C		9,99,57,268
Miscellaneous Receipts	D	1,20,90,853	1,20,03,414
Deposits and other Items	E	3,60,79,409	3,71,29,583
Short term Bank Deposits & Investments		57,06,82,750	56,16,90,510
TOTAL		99,56,33,616	114,52,76,309

PAYMENTS			
Recurring Expenditure (Plan and Non-Plan)	F	27,71,52,277	26,70,04,951
Plan - Non-Recurring Expenditure	G	6,91,68,839	16,99,34,536
Expenditure out of Grants/ Assistance from Government Agencies	H	54,08,670	1,24,35,746
Advance to Suppliers	I	85,48,116	-
Deposits and other items	J	3,45,30,236	3,73,38,242
Short term Bank Deposits & Investments		59,96,63,782	64,14,84,045
Closing Balance	K	11,61,696	1,70,78,789
TOTAL		99,56,33,616	114,52,76,309

Notes on accounts. 17
Schedules A to K & 17 form an integral part of the accounts

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

B.R.V. GOUD & CO. CHARTERED ACCOUNTANTS B'LORE-4

K. KRISHNAMA RAJU
Administrative Officer

RAVI SUBRAHMANYAN
Director

A. B. SHIVA SUBRAMANYAM
Partner
M No. 201108

Place : Bangalore
Date : Sept.11,2013

RAMAN RESEARCH INSTITUTE

Bangalore

Schedules forming part of the Audited Statements of Account for the year ended 31st March 2013

PARTICULARS		As on 31.03.2013 Rs.	As on 31.03.2012 Rs.
SCHEDULE - 1			
Capital Fund			
Balance as on 1.4.2012		100,60,79,708	97,29,13,333
Add: Assets acquired/transferred during the year			
1) Plan - Non - Recurring		7,77,16,955	7,99,77,268
2) Scientific Publications acquired during the year		1,16,06,350	1,02,95,812
3) Amount Invested in SBI Life for past service Liability due to 6 CPC			3,19,93,535
		109,54,03,013	109,51,79,948
Less: Assets deleted during the year	3,09,469		
Less : Accu.depn.(Vide Sch.8 col. 9)	1,03,061	2,06,408	20,22,717
Less: Amount invested in SBI Life for past service Liability due to 6 CPC			3,19,93,535
		109,51,96,604	106,11,63,696
Less: Depreciation		5,82,63,793	5,50,83,988
TOTAL		103,69,32,812	100,60,79,708
SCHEDULE - 2			
General Fund			
Balance as on 1.4.2012		67,05,448	84,13,805
Add/((Less) : Surplus/ (Deficit) for the year		10,88,222	(17,08,357)
TOTAL		77,93,670	67,05,448

PARTICULARS		2012-2013 Rs.	2011-2012 Rs.
SCHEDULE - 3			
Retirement Funds - vested with SBI Life Insurance			
1. Gratuity Fund			
Opening Balance	6,82,38,837		
Add : Interest earned	59,18,819		
Less: Claims paid	35,92,950		
		7,05,64,706	6,82,38,837
2. Leave Salary			
Opening Balance	5,78,67,576		
Add : Interest earned	50,49,306		
Less: Claims paid	23,05,609		
		6,06,11,273	5,78,67,576
3. Commutation of Pension Fund			
Opening Balance	16,04,56,777		
Add : Interest earned	1,44,10,288	17,48,67,065	16,04,56,777
TOTAL		30,60,43,044	28,65,63,190
SCHEDULE - 4			
Unutilized Grants			
Plan Non- Rccurring		5,45,07,195	3,85,75,999
TOTAL		5,45,07,195	3,85,75,999

PARTICULARS		As on 31.03.2013 Rs.	As on 31.03.2012 Rs.
SCHEDULE - 5			
Sundry Creditors			
a. Un-Utilised Grants - Projects/Meetings etc.,			
1. Enabling New Sciences- MWA		16,18,540	17,80,000
2. DBT - Biomechanics of synaptogensis		7,321	10,969
3. ISRO - for SSO Project		39,96,781	67,91,007
4. INSA Fellowship		1,40,000	83,465
5. TIFR			5,04,473
6. CSIR - Jr. Research Fellowship		33,609	
7. IFCPAR Research Project		3,72,300	
b. Others			
1. Earnest Money Deposits		10,21,505	5,01,505
2. Contractors' Security Deposits		9,35,850	5,45,427
3. Group Insurance Scheme		1,091	2,591
4. Indian Academy of Sciences (for Land)		1,00,00,000	1,00,00,000
5. Service benefits and other liabilities		6,56,054	6,39,927
6. Duties & Taxes (TDS)		93,112	74,616
7. Caution Deposits (Hostel)		1,54,500	1,44,000
8. R R I Pension A/c			8,02,910
9. Profession Tax		40,950	
10. N P S		15,214	
		1,90,86,827	2,18,80,890
SCHEDULE - 6			
Provident Fund			
FUND BALANCES:			
A. Employees Subscription			
a) Contributory Provident Fund		3,72,44,899	3,29,10,086
b) General Provident Fund		1,79,33,696	1,48,27,689
B. Institute Contribution to Contributory Provident Fund		3,12,02,124	2,85,86,145
C. New Pension Scheme		6,09,591	2,98,223
GENERAL FUND -	85,25,126		85,25,126
Add: Excess of income over expenditure for 2012-13	10,79,874		
Add: Amortization of Investment premia & discount	2,42,500	98,47,500	
RRI Pension Fund		26,41,549	19,36,847
TOTAL		9,94,79,359	8,70,84,116
SCHEDULE - 7			
Pension Fund			
Capital Fund-Opening Balance	5,54,90,088		5,54,90,088
Add: Institute's Contribution for the year (Corpus Fund)	98,13,823		
Add : G P F Contribution for the year	27,84,660		
Add: Amortization of Investment premia & discount	2,58,556	6,83,47,127	
TOTAL		6,83,47,127	5,54,90,088

SCHEDULE - 8
Fixed Assets

o	DESCRIPTION	GROSS BLOCK				DEPRECIATION BLOCK					NET BLOCK	
		Original Cost as on 01.04.2012	Addition during the year	Deletion during the year	Original cost as on 31.03.2013	Rate	Total up to 01.04.2012	Less Accu.Depn.on Deletion (on col. No.5)	For the year 2012-2013 (on Col.No.6)	Total up to the end of 31.03.2013 (8-9+10)	As on 31.03.2013 (6-11)	As on 1.04.2012
	2	3	4	5	6	7	8	9	10	11	12	13
		Rs.	Rs.	Rs.	Rs.	%	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.
	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
	Building	15,35,01,158	75,14,699		16,10,15,857	1.63	1,89,49,019		26,24,558	2,15,73,577	13,94,42,280	13,45,52,139
	Capital Equipment	70,69,54,763	5,48,29,369	3,09,469	76,14,74,663	4.75	19,61,20,596	1,03,061	3,61,70,046	23,21,87,582	52,92,87,081	51,08,34,167
	Canteen Infrastructure	42,76,021			42,76,021	4.75	4,06,222		2,03,111	6,09,333	36,66,688	38,69,799
	Computers	12,16,57,841	45,28,282		12,61,86,123	16.21	11,43,68,789		79,05,808	12,22,74,597	39,11,526	72,89,052
	Furniture & Fixture	1,17,56,107	5,55,953		1,23,12,060	6.33	48,10,146		7,79,353	55,89,499	67,22,561	69,45,961
	Vehicles	43,09,188			43,09,188	9.50	29,23,169		4,09,373	33,32,542	9,76,646	13,86,019
	Books and Journals	20,07,90,852	1,33,46,886		21,41,37,738	4.75	6,85,27,280		1,01,71,543	7,86,98,823	13,54,38,915	13,22,63,572
	TOTAL	1,28,68,07,362	8,07,75,189	3,09,469	1,36,72,73,082		40,61,05,221	1,03,061	5,82,63,793	46,42,65,953	90,30,07,129	88,07,02,141

PARTICULARS	As on 31.03.2013 Rs.	As on 31.03.2012 Rs.
SCHEDULE - 9		
Investments - Retirement Funds - vested with SBI Life Insurance		
Gratuity Fund	7,05,64,706	6,82,38,837
Leave Salary	6,06,11,273	5,78,67,576
Commutation of Pension Fund	17,48,67,065	16,04,56,777
TOTAL	30,60,43,044	28,65,63,190
SCHEDULE - 10		
Current Assets, Advances and Deposits		
a) Stock on Hand	13,67,825	11,46,301
b) Advances and Deposits:		
1. Advance to Suppliers	2,37,37,773	1,51,89,657
2. Advance for purchase of Land	8,89,61,800	8,89,61,800
3. Advances to Staff	43,97,115	34,62,158
4. Other Advances/Deposits	14,43,084	34,04,374
5. Tax Deducted at Source	17,344	17,344
6. Indian Academy of Sciences	6,271	6,271
7. Ramanujan Fellowship	18,60,071	4,71,086
8. Swarana Jayanthi Fellowship	7,61,984	4,11,004
9. Customs Duty Receivable	27,91,120	27,91,120
10. TIFR	46,261	
11. CSIR - Extra Murual Research project	1,80,000	
TOTAL (a+b)	12,55,70,648	11,58,61,115
SCHEDULE - 11		
Cash and Bank Balances		
Cash at Banks - In Savings Bank Accounts/MODs :		
State Bank of India	37,78,373	1,45,72,514
State Bank of Mysore	67,16,403	21,88,817
Canara Bank	1,65,348	2,14,163
Union Bank of India	7,90,62,031	5,96,60,174
Central Bank of India	17,008	16,347
Stamps on hand (Franking Machine)	3,564	26,774
TOTAL	8,97,42,727	7,66,78,789

PARTICULARS	As on 31.03.2013 Rs.	As on 31.03.2012 Rs.
SCHEDULE - 12		
Provident Fund		
Investments (At Cost)	8,95,13,889	8,00,79,986
Refundable Advances	18,06,365	16,95,760
Interest earned on Investments	12,92,782	10,31,340
Income-tax Deducted at Source Receivable	3,72,108	3,09,549
Cash at Banks:		
State Bank of India	58,67,361	39,58,095
HDFC Bank	6,26,854	9,386
TOTAL	9,94,79,359	8,70,84,116
SCHEDULE - 13		
Pension Fund		
Investments (At Cost)	4,88,41,107	3,82,96,166
Interest earned on investments	12,73,905	11,06,546
Income-tax deducted at source	3,40,334	2,93,881
Raman Research Institute	1,50,25,628	124,45,692
Raman Research Institute (PF A/c)	20,35,236	19,36,847
Cash at Banks:		
Central Bank of India	1,54,109	4,58,179
State Bank of India	3,49,661	2,10,767
HDFC Bank	3,27,147	7,42,010
TOTAL	6,83,47,127	5,54,90,088
SCHEDULE - 14		
Interest & Miscellaneous Income		
Interest on :		
Letters of Credit Margins	2,08,827	40,49,914
Short Term Deposits & Savings Bank A/cs	87,14,862	41,27,832
Miscellaneous Income		
Grant-in-aid from -		
Raman Research Institute Trust	1,00,000	1,00,000
License fee from quarters	3,69,177	3,74,893
Other Receipts	12,25,994	10,52,779
Sale of unserviceable items	5,80,250	13,13,650
TOTAL	1,11,99,110	1,10,19,068
SCHEDULE - 15		
Salaries & Allowances		
Pay	6,10,74,701	5,93,46,007
Allowances	7,49,71,595	6,40,08,758
Medical Reimbursement	52,51,662	41,73,312
Leave/Home Travel Concession	6,60,432	4,69,395
Leave Salary Encashment - LTC	2,28,363	99,015
Leave Salary on Retirement/Resignation	1,52,640	
Contributions towards :		
Retirement Funds		
Provident Fund	77,81,886	95,57,497
Pension Fund	19,53,743	19,84,842
N P S Contribution	54,25,430	1,11,60,833
SBI Life Insurance - Annual premia	11,80,279	9,03,132
Shortfall in Pension	33,11,800	1,38,796
	1,24,45,692	95,22,589
TOTAL	17,44,38,223	16,13,64,176

PARTICULARS	As on 31.03.2013 Rs.	As on 31.03.2012 Rs.
SCHEDULE - 16		
Working Expenses		
Travelling Expenses	20,78,179	33,65,984
Wages	4,30,625	2,89,810
Honoraria and Professional Fees	16,54,664	13,80,815
Printing, Stationery (Schedule - 16 A)	12,96,178	11,24,880
Telephone and Communication Charges	21,69,008	23,36,938
Electricity Charges (including maintenance of generators)	93,20,927	79,72,654
Water Charges	6,06,016	3,78,631
Advertisement	13,809	26,108
Vehicle Maintenance/Transport	18,96,239	13,96,729
Liveries and Uniforms	2,32,418	99,820
Postage and Courier Services	2,81,105	2,91,932
Seminars/Conferences/Colloquia, Summer School Programme etc.,	21,94,494	18,68,649
Bank Charges	8,739	5,492
Amenities	11,20,605	9,66,518
Crèche	2,40,000	2,20,000
Entertainment and Hospitality	1,86,380	2,45,158
Audit fee	47,191	42,466
Repairs and Maintenance	65,00,036	69,79,865
Campus Maintenance	68,96,652	49,77,076
Payroll processing charges	3,56,234	7,00,295
Safety Audit Expenses	92,898	
Security	68,64,915	53,60,559
Stores and Consumables (Schedule - 16 A)	2,45,35,752	2,74,89,670
Project Working Expenses	40,99,037	132,90,300
Subscriptions to Journals & Publications	1,22,97,586	1,11,84,869
Ph.D. Programme	23,81,901	23,34,271
Pancharatnam Fellowship	6,45,782	4,90,174
Lease Rent of Land	2,39,932	2,15,004
Corporation Taxes	3,03,779	3,04,257
Freight, etc.	2,39,704	1,52,866
Conveyance	3,78,457	3,40,132
Visiting Students Programme	64,92,675	57,89,001
Inter Institutional Collaboration & Visiting Scientists' expenses	11,40,171	14,66,611
Outreach		
Patent Fees	7,99,894	2,78,751
Miscellaneous Expenses	19,14,607	21,98,161
Affiliation Fee for Universities	5,77,925	6,00,633
	2,00,000	2,00,000
TOTAL	10,07,34,514	10,63,65,079

SCHEDULE - 16 - A

Stores / Consumables & Stationery items

SL. NO.	DESCRIPTION	OPENING STOCK AS ON 1.4.2012	PURCHASE DURING THE YEAR	LESS:CLOSING STOCK AS ON 31.3.2013	CONSUMPTION DURING THE YEAR
		Rs.	Rs.	Rs.	Rs.
1	Stores and Consumables	8,00,029	2,48,34,166	10,98,443	2,45,35,752
2	Printing & Stationery	3,46,272	12,19,288	2,69,382	12,96,178
	TOTAL	11,46,301	2,60,53,454	13,67,825	2,58,31,930

PARTICULARS	2012-2013 Rs.	2011-2012 Rs.
SCHEDULE - A		
Opening Balance		
Cash at Banks -		
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
SCHEDULE - B		
Grants-in-aid		
a) Ministry of Science & Technology (Department of Science & Technology)		
1. Non-Plan Recurring	1,07,10,000	1,42,00,000
2. Plan Recurring	25,43,51,849	24,08,01,830
3. Plan Non-Recurring	9,36,48,151	14,89,98,170
4. PAC/National Meetings SJF		13,00,000
5. Enabling New Sciences- MWA		17,80,000
b) INSA - Fellowship	3,34,586	4,36,533
c) CSIR - Extra Murual Research project		7,65,000
d) CSIR - Jr. Research Fellowship	2,84,929	
e) IFCPAR Research Project	3,72,300	-
TOTAL	35,97,01,815	40,82,81,533

PARTICULARS	2012-2013 Rs.	2011-2012 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	3,69,177	3,74,893
Interest on Letters of Credit Margins	2,08,827	40,49,914
Interest on Short term Deposits & SB Accounts	87,14,862	41,27,832
Other Receipts	12,25,994	10,52,779
Sale of unserviceable items	5,80,250	13,13,650
Recoveries/Adjustments of Advance		
Conveyance Advance	1,90,010	2,66,170
House Building Advance	4,53,958	4,39,228
Festival Advance	1,81,425	1,97,100
Computer Advance	66,350	81,848
TOTAL	1,20,90,853	1,20,03,414
SCHEDULE - E		
Deposits and other items		
Recoveries from Staff towards:		
Provident Fund-Subscriptions & loan repayments	1,42,64,596	1,34,46,386
N P S Subscription	15,09,454	11,97,852
Profession Tax	4,97,600	5,11,100
LIC - Salary Savings Scheme	22,96,646	23,74,157
Group Insurance Scheme (LIC)	14,29,889	13,55,876
Income Tax deducted at Source	1,01,48,806	85,08,674
Housing and other loans	7,63,434	5,14,824
Caution Deposits for Hostel	30,500	30,000
Staff/Miscellaneous Advances & Deposits (Net)	18,92,607	
Indian Academy of Sciences	13,300	
Sundry Creditors	16,127	8,16,673
Recoveries from Contractors towards:		
Income Tax Deducted at Source	8,48,512	7,74,274
Earnest Money Deposits	18,83,000	7,61,505
Security deposits	4,84,938	3,38,262
Others (amounts received for meetings etc.,)		
Programme on Random Matrix Theory		25,00,000
TIFR - Bombay		40,00,000
TOTAL	3,60,79,409	3,71,29,583

PARTICULARS	2012-2013 Non-Plan Rs.	2012-2013 Plan Rs.	2012-2013 Total Rs.	2011-2012 Rs.
SCHEDULE - F				
Recurring Expenditure (Non-Plan and Plan)				
Pay	79,12,511	5,31,62,190	6,10,74,701	5,93,46,007
Allowances	1,25,47,547	6,29,51,752	7,54,99,299	6,40,08,758
Medical Reimbursement	8,33,170	44,18,492	52,51,662	42,39,782
Leave/Home Travel Concession	1,32,320	5,79,102	7,11,422	4,67,885
Leave Salary Encashment - LTC tour	66,438	1,61,925	2,28,363	99,015
Leave Salary on Retirement/Resignation		1,52,640	1,52,640	-
Contribution towards:				
Provident Fund		19,53,743	19,53,743	19,84,842
Pension Fund	8,61,789	45,63,641	54,25,430	1,11,60,833
N P S Contribution	69,584	11,10,695	11,80,279	9,03,132
Retirement Fund		77,81,886	77,81,886	95,57,497
SBI Life Insurance - Annual premia		33,11,800	33,11,800	1,38,796
Shortfall in Pension		1,24,45,692	1,24,45,692	95,22,589
	2,24,23,359	15,25,93,558	17,50,16,917	16,14,29,136
Travelling Expenses	21,295	29,77,456	29,98,751	17,40,778
Wages		4,30,625	4,30,625	2,89,810
Honoraria & Profession fees		16,54,664	16,54,664	13,80,815
Printing Stationery & binding of		12,19,288	12,19,288	10,97,333
Scientific journals				
Telephone and Communication charges		21,69,008	21,69,008	23,36,938
Electricity Charges		93,20,927	93,20,927	79,72,654
(incl.Rs.3,36,866/- being				
outlay on maintenance of generators)				
Water Charges		6,06,016	6,06,016	3,78,631
Advertisement	13,809		13,809	26,108
Vehicle Maintenance/Transport		18,96,239	18,96,239	13,96,729
Liveries & Uniforms		2,32,418	2,32,418	99,820
Postage & Courier Services		2,81,105	2,81,105	2,91,932
Seminars, Conferences, Colloquia, etc.,		21,94,494	21,94,494	18,68,649
Bank Charges	8,739		8,739	5,492
Amenities		11,20,605	11,20,605	9,66,518
Crèches expenses		2,40,000	2,40,000	2,20,000
Entertainment and Hospitality		1,86,380	1,86,380	2,45,158
Audit Fee	47,191		47,191	42,466
Repairs & Maintenance		65,00,036	65,00,036	69,79,865
(incl. Maintenance of Computers)				
Campus Maintenance		68,96,652	68,96,652	49,77,076
Payroll processing charges		3,56,234	3,56,234	7,00,295
Safety Audit Expenses		92,898	92,898	
Carried forward	2,25,14,393	19,09,68,603	21,34,82,996	19,44,46,203

PARTICULARS	2012-2013			2011-2012
	Non-Plan Rs.	Plan Rs.	Total Rs.	Rs.
Brought forward	2,25,14,393	19,09,68,603	21,34,82,996	19,44,46,203
Security		68,64,915	68,64,915	53,60,559
Stores & Consumables		2,48,34,166	2,48,34,166	2,75,22,854
Project Working Expenses		40,99,037	40,99,037	1,32,90,300
Subscription to Scientific Journals & other Publications	27,285	1,22,70,301	1,22,97,586	1,11,84,869
Ph.D. Programme		23,81,901	23,81,901	23,34,271
Pancharatnam Fellowship		6,45,782	6,45,782	4,90,174
Lease Rent of Land		2,39,932	2,39,932	2,15,004
Corporation Taxes		3,03,779	3,03,779	3,04,257
Freight, etc.,		2,39,704	2,39,704	1,52,866
Conveyance		3,78,457	3,78,457	3,40,132
Inter Institutional Collaboration & Visiting Scientists' expenses and Visiting Students programme		76,32,846	76,32,846	72,55,612
Outreach		7,99,894	7,99,894	2,78,751
Patent Fees		19,14,607	19,14,607	21,98,161
Miscellaneous Expenses		5,77,925	5,77,925	6,00,633
Affiliation Fee for Universities		2,00,000	2,00,000	2,00,000
Advances to Staff (HBA, Vehicle, Festival & Computer advances)	2,58,750		2,58,750	8,30,305
TOTAL	2,28,00,428	25,43,51,849	27,71,52,277	26,70,04,951

PARTICULARS	2012-2013 Rs.	2011-2012 Rs.
SCHEDULE - G		
Plan Non-Recurring Expenditure		
Capital Equipment	5,93,57,651	15,94,96,478
Buildings, Works and Services	75,14,699	82,09,664
Books	17,40,536	13,49,438
Furniture & Fixture	5,55,953	8,78,956
TOTAL	6,91,68,839	16,99,34,536
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
2) Joint Programme of India Australia S & T Co-Operation		1,53,987
3) Ramanujam Fellowship	13,88,985	11,04,111
4) DBT - Biomechanics of synaptogensis	3,648	5,57,219
5) Swarna Jayanthi Fellowship	3,50,980	5,76,999
6) Enabling New Sciences- MWA	1,61,460	
b) ISRO - SSO Project	27,94,226	66,11,268
c) British Council Division		52,114
d) INSA - Fellowship	2,78,051	2,88,671
e) CSIR - Extra Murual Research project	1,80,000	15,30,000
f) CSIR - Jr. Research Fellowship	2,51,320	
g) D A E Homi Bhaba Chair		87,707
TOTAL	54,08,670	1,24,35,746
SCHEDULE - I		
Advance to Suppliers (Net)		
Plan -Non-Recurring	85,48,116	-
TOTAL	85,48,116	-

PARTICULARS	2012-2013 Rs.	2011-2012 Rs.
SCHEDULE - J		
Deposits & Other Remittances		
Remittances of recoveries from staff:		
Provident Fund Subscriptions and Loans	1,42,64,596	1,34,46,386
N P S Subscription	15,09,454	11,97,852
Professional Tax	4,56,650	5,11,100
LIC - Salary Savings Scheme	22,96,646	23,74,157
Group Insurance Scheme	14,31,389	13,56,376
Income Tax Deducted at Source	1,01,48,806	85,08,674
Housing and other loans	7,63,434	5,14,824
Caution Deposits for Hostel	20,000	16,000
Sundry Creditors	8,00,996	41,591
Staff/Miscellaneous Advances & Deposits (Net)		2,71,750
Remittances/Refunds of recoveries from Contractors:		
Income Tax deducted at Source	8,30,016	7,99,853
Earnest Money Deposits	13,63,000	14,90,000
Security Deposits	94,515	8,14,152
Others (amounts received for meetings etc.,)		
Programme on Random Matrix Theory TIFR - Bombay	5,50,734	25,00,000 34,95,527
TOTAL	3,45,30,236	3,73,38,242
SCHEDULE - K		
Closing Balance		
Cash at Bank:		
State Bank of India	71,886	1,45,72,514
State Bank of Mysore	3,51,859	21,88,817
Canara Bank	1,65,348	2,14,163
Union Bank of India	5,52,031	60,174
Central Bank of India	17,008	16,347
Stamps on hand	3,564	26,774
TOTAL	11,61,696	1,70,78,789

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

K. KRISHNAMA RAJU
Administrative Officer

RAVI SUBRAHMANYAN
Director

B.R.V. GOUD & CO. CHARTERED ACCOUNTANTS B'LORE-4

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

Place : Bangalore
Date : Sept. 11, 2013

RAMAN RESEARCH INSTITUTE
BANGALORE

SCHEDULE: - 17

SIGNIFICANT ACCOUNTING POLICIES AND NOTES ON ACCOUNTS FOR THE YEAR ENDED 31.03.2013

A. SIGNIFICANT ACCOUNTING POLICIES:

1. ACCOUNTING CONVENTION:

The Financial Statements are prepared on the basis of Historical cost convention and on the Cash method 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 **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 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 a 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'. The effect of amortization of Investments, premia paid over and above the face value under lying investments and discounts availed below the face

value of the investments have been squared off and the net positive effects have been carried to the Pension Fund and the General Reserve of Provident Fund.

7. FOREIGN CURRENCY TRANSACTIONS:

Transactions denominated in foreign currency are accounted at the exchange rates prevailing at the dates of the transaction.

8. 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. There has not been any deficit in Provident Fund.

- Estimated liability for gratuity on the date of Balance Sheet has not been quantified. The same is accounted for, on actual payment.

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 Funds/Insurance Policies with the SBI Life Insurance, for quantifiable liabilities of service benefits viz., Gratuity, Leave Encashment.

II. The Institute also taken a Fund/Policy for for commutable portion of the Pension with the SBI Life Insurance.

III. 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 in Balance Sheet. The interest earned on these funds is ploughed back to the funds and the claims are met out of these funds.

IV. In pursuance of the directions of the Council, the amount representing the Institute's contribution to the Contributory Provident Fund in respect of eligible senior scientific and technical staff who are on contracts renewal 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 as same which is awaited for a No objection forms from 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. Figures pertaining to the previous year have been regrouped / reclassified to suit the current years classification.

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

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

B.R.V. GOUD & CO. CHARTERED ACCOUNTANTS B'LORE-4

K. KRISHNAMA RAJU
Administrative Officer

RAVI SUBRAHMANYAN
Director

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

Place : Bangalore
Date : 11th Sept. 2013