RAMAN
RESEARCH
INSTITUTE
BANGALORE

ANNUAL REPORT

2013 - 2014

Raman Research Institute, 2014
Annual Report : 2013 – 2014
Bangalore, RRI

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Annual Report
2013 – 2014

Raman Research Institute
Bangalore

A meeting of minds

Sir C.V. Raman with Heisenberg


Overhead Water Tank
Mekri Circle
Air Force School Hebbal
CV Raman Rd
Raman Research Institute
Mekri Circle
Raman Research Institute
2nd Cross Rd
1st Cross Rd
Main Rd
6th Cross Rd
12th Main Rd
11th Main Rd
5th Cross Rd
Kempegowda Tower Park
Ramana Maharshi Park
6th B Cross Rd
6th A Cross Rd
9th Main Rd
3rd Cross Rd
2nd Cross Rd
1st Cross Rd
8th Main Rd
8th Main Rd
8th Main Rd
8th Main Rd

Contents

From the Director

During the year 2012-13 I was away from the Institute on a sabbatical stay and the last year has been a coming back to the Raman Institute anew. Really there is no 'coming back' but only a going forward – the Institute changes continually as any Research Institute ought to do if it needs to avoid obsolescence.

The Institute is at a stage of consolidating on several years of effort in building foundations that empower and enable significant enterprise research, and the coming year is expected to be eventful in embarking on directed research in a cooperative style in many areas.

The Light & Matter Physics group at RRI continues to grow towards becoming an established center of excellence for quantum atom optics and quantum information experiments – signaling a rebirth at RRI of the passions of the Founder of the Institute – but of course in a modern context. During the year of this report a new Quantum Information and Computing laboratory was set up.

These previous years has also seen the Soft Condensed Matter group benefit from the addition of modern equipment, and experience an evolution that expands the physics-biology interface.

Some years ago RRI entered into a key international partnership with universities and institutions in the US and Australia – to build together a radio telescope called the Murchison Widefield Array or MWA in the Australian outback, in one of the most radio-quiet regions of the world. In 2013 we had a celebration to mark the successful completion of the making of the telescope. The MWA building and commissioning are complete, and the transition to science operations has been smooth. Research proposals from the collaboration have led to long duration observing programs, with data being analyzed by the collaboration leading to numerous publications in front line astronomy journals.

The Institute had taken on a substantial technical role in the creation of the MWA telescope – the digital receivers were designed and built by RRI – and we owe it to many members of RAL, the Mechanical Engineering Services and the Astronomy & Astrophysics group of the Institute for having worked to make the telescope. Their effort has given the Institute an opportunity to do science with what is a most modern telescope that is viewed by the international community as a precursor to the futuristic Square Kilometer Array. The confidence and demonstration of ability to partner in the making of a leading radio astronomy facility also sets the stage for participation in whatever is the next stage in this discipline.

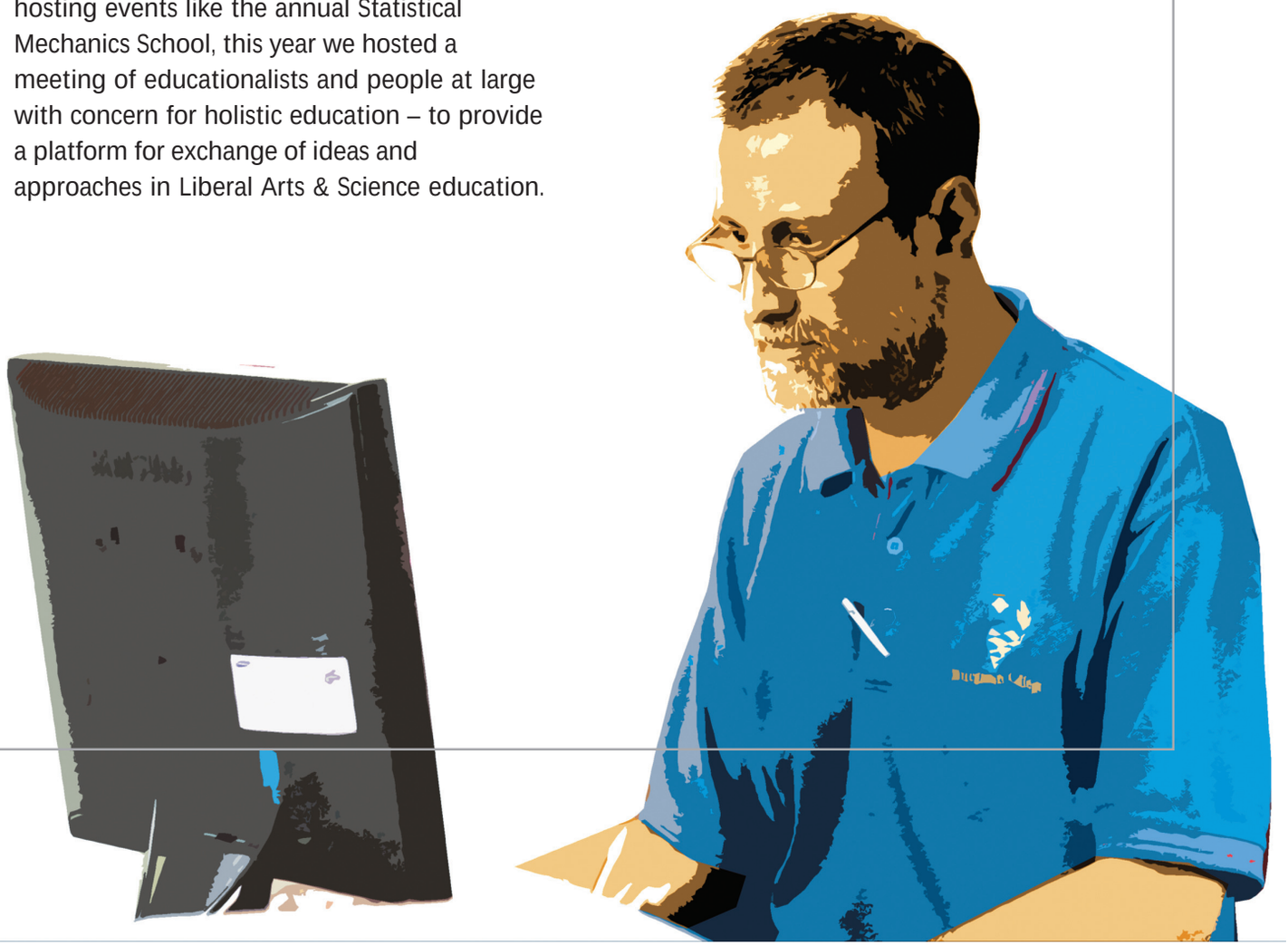
The top-level management of the Institute has evolved over the last few years to a more structured and consultative form with senior academic and administrative members playing key roles in decision-making. On the other hand, on matters related to the academic activities and knowledge transmission functions of the

Institute, the structure has been evolved to a flat non-hierarchical form with younger fresh members playing key roles in steering the course. Younger members of the Institute—indeed all members—have the academic freedom to pursue research of their choice, with this academic freedom enshrined by international peer review in the belief that the next generation has the unfettered right and responsibility to be better.

RRI strives to give the budding generation that goes through its gates a broader perspective of science and beyond, on and off the field. Apart from the PhD program, RRI has an extremely successful Visiting Students Program that opens its doors to a substantially greater number of postgraduate, undergraduate and even high school students, and gives them an opportunity to partake in the joys of research along with more experienced members. Apart from the scholarship we gift to the younger talent by hosting events like the annual Statistical Mechanics School, this year we hosted a meeting of educationalists and people at large with concern for holistic education – to provide a platform for exchange of ideas and approaches in Liberal Arts & Science education.

Any premier research institute like the Raman Institute needs to have flagship programs that are joint efforts of a number of researchers, which are of magnitudes only possible in such elite institutions, and which set the institute apart and in a class of its own. The outstanding success displayed by the technical staff of the Raman Institute in enabling a meaningful partnership in the MWA has opened the doors to participation in the "next big thing" in radio astronomy. Another flagship program that the Institute looks forward to embarking upon is in experimental research in foundational problems associated with sensitive detection of gravitational waves, involving theoretical physics and light-matter interaction physics. I really wish the LIGO-India project to take off at the earliest, which will make such an endeavor at RRI meaningful and give it a context.

Ravi
July 20, 2014



Mission

The Raman Research Institute is engaged in research in basic sciences in the areas of Astronomy and Astrophysics, Light and Matter Physics, Soft Condensed Matter and Theoretical Physics. Through the years members of RRI have pursued research with the aim of creating knowledge and adding to the understanding and scientific comprehension of natural phenomena from sub-atomic to cosmological scales.

Director

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

Organization

RRI is an autonomous research institute. It is an institute that stands apart from all other research institutes in India by virtue of its rich history. The supreme body of RRI is the RRI Trust. The director is the chief executive and academic officer. Appointed by the RRI Trust by invitation, he exercises general supervision over the programmes and research projects of the institute. The Governing Council is responsible for the administration and management of the Raman Research Institute. Its members hold office for five-year terms. The Administrative Officer is responsible for the general administration of the Institute and represents it in legal and other related proceedings. The Governing Council appoints the Administrative Officer. The Finance Committee helps the Council with financial matters.

At a Glance

Location

RRI is located on a 20-acre site in the north of Bangalore City, the IT capital of India. The brilliantly verdant campus provides a serene and soothing environment away from the hustle and bustle of the busy metropolis outside, perfectly suited for the creative research work being conducted within its confines.

Research Areas

Astronomy and Astrophysics
Light and Matter Physics
Soft Condensed Matter
Theoretical Physics

Facilities

1. LABORATORIES

   RAL/Electronics Lab
   X-ray Astronomy Lab
   Brain Computer Interface Lab
   Chemistry Lab
   Physical Measurements Lab
   Microscopy and Dielectric Spectroscopy Lab
   Liquid Crystal Display Lab
   Rheology and Light Scattering Lab
   X-ray Diffraction Lab
   Biophysics Lab
   Electrochemistry and Surface Science Lab
   Nanoscale Physics of Soft and Living Matter Lab
   SEM Lab
   AFM Lab
   NMR Lab
   Micro-Raman Spectroscopy Lab
   Magnetic Studies Lab
   Photophysical Studies Lab

2. MECHANICAL ENGINEERING
   Mechanical Workshop
   Sheet metal, paint and carpentry facility

3. LIBRARY

4. COMPUTER FACILITIES

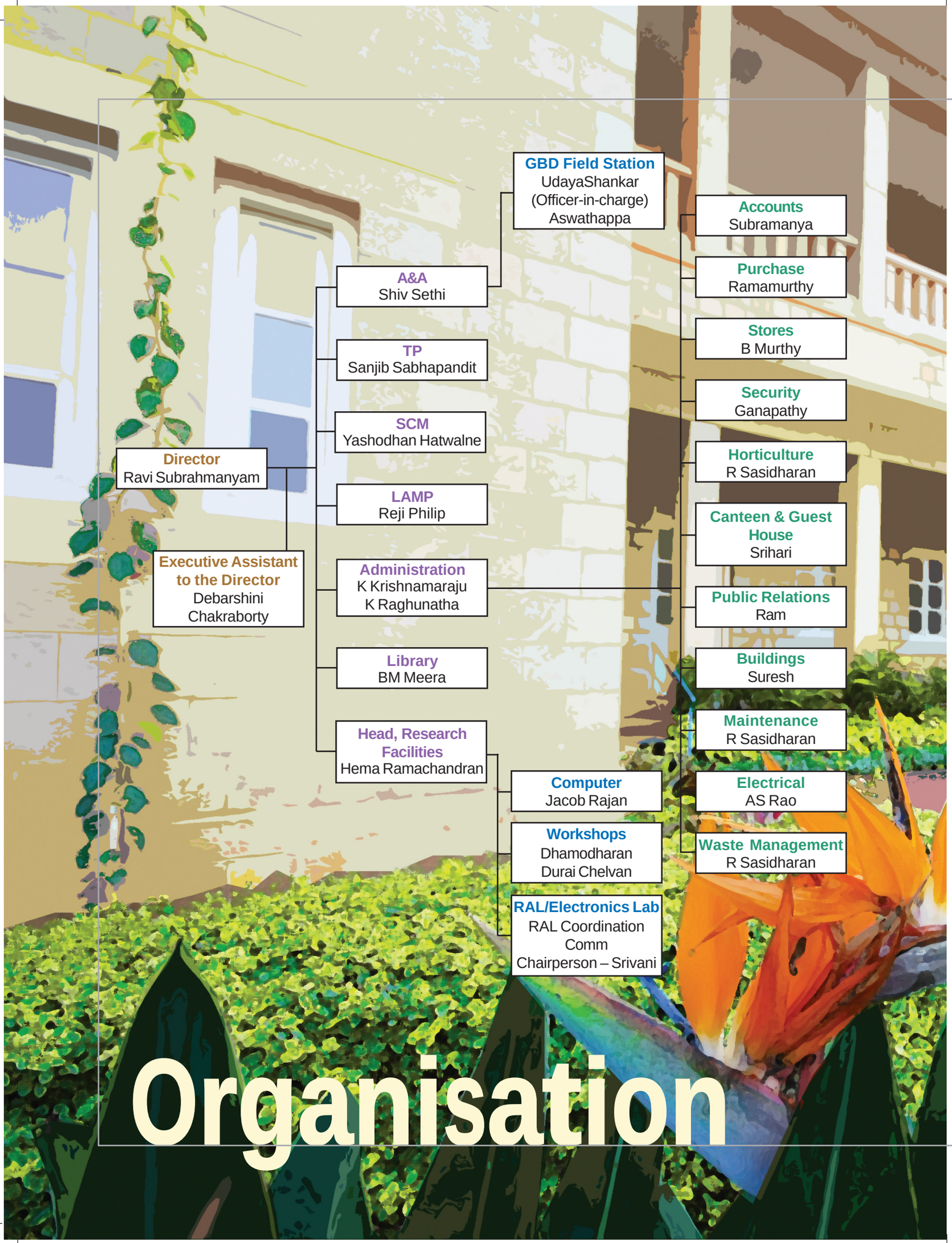
Education

RRI offers the following academic programmes:

– PhD Programme
– Post Doctoral Fellowship Programme
– Visiting Students Programme

Funding

The research of the Institute is nurtured and sustained by grants-in-aid from the Department of Science and Technology, Government of India.



Organisation

Director
Ravi Subrahmanyam

Executive Assistant to the Director
Debarshini Chakraborty

A&A
Shiv Sethi

TP
Sanjib Sabhapandit

SCM
Yashodhan Hatwalne

LAMP
Reji Philip

Administration
K Krishnamaraju
K Raghunatha

Library
BM Meera

Head, Research Facilities
Hema Ramachandran

GBD Field Station
UdayaShankar
(Officer-in-charge)
Aswathappa

Computer
Jacob Rajan

Workshops
Dhamodharan
Durai Chelvan

RAL/Electronics Lab
RAL Coordination Comm
Chairperson – Srivani

Accounts
Subramanya

Purchase
Ramamurthy

Stores
B Murthy

Security
Ganapathy

Horticulture
R Sasidharan

Canteen & Guest House
Srihari

Public Relations
Ram

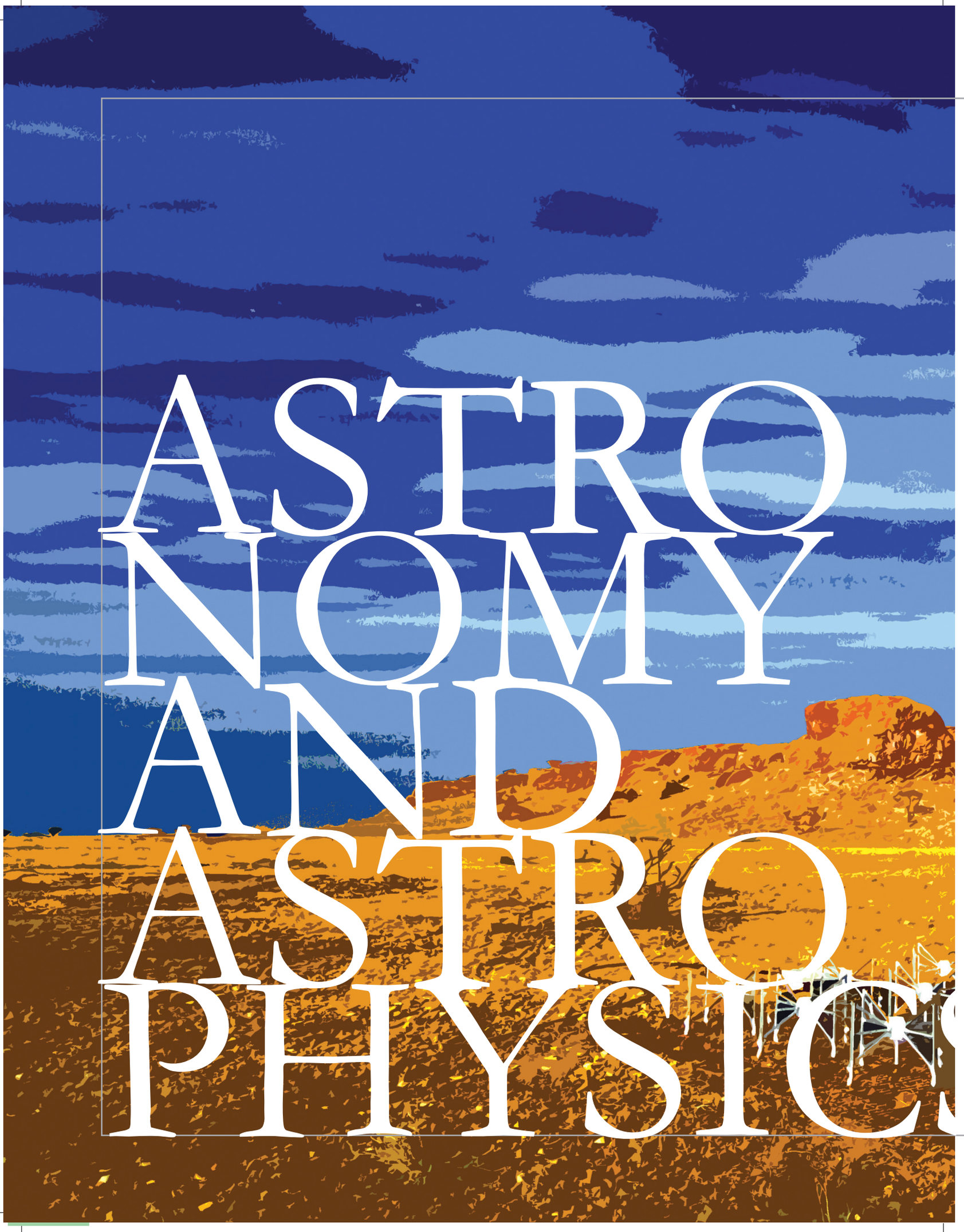
Buildings
Suresh

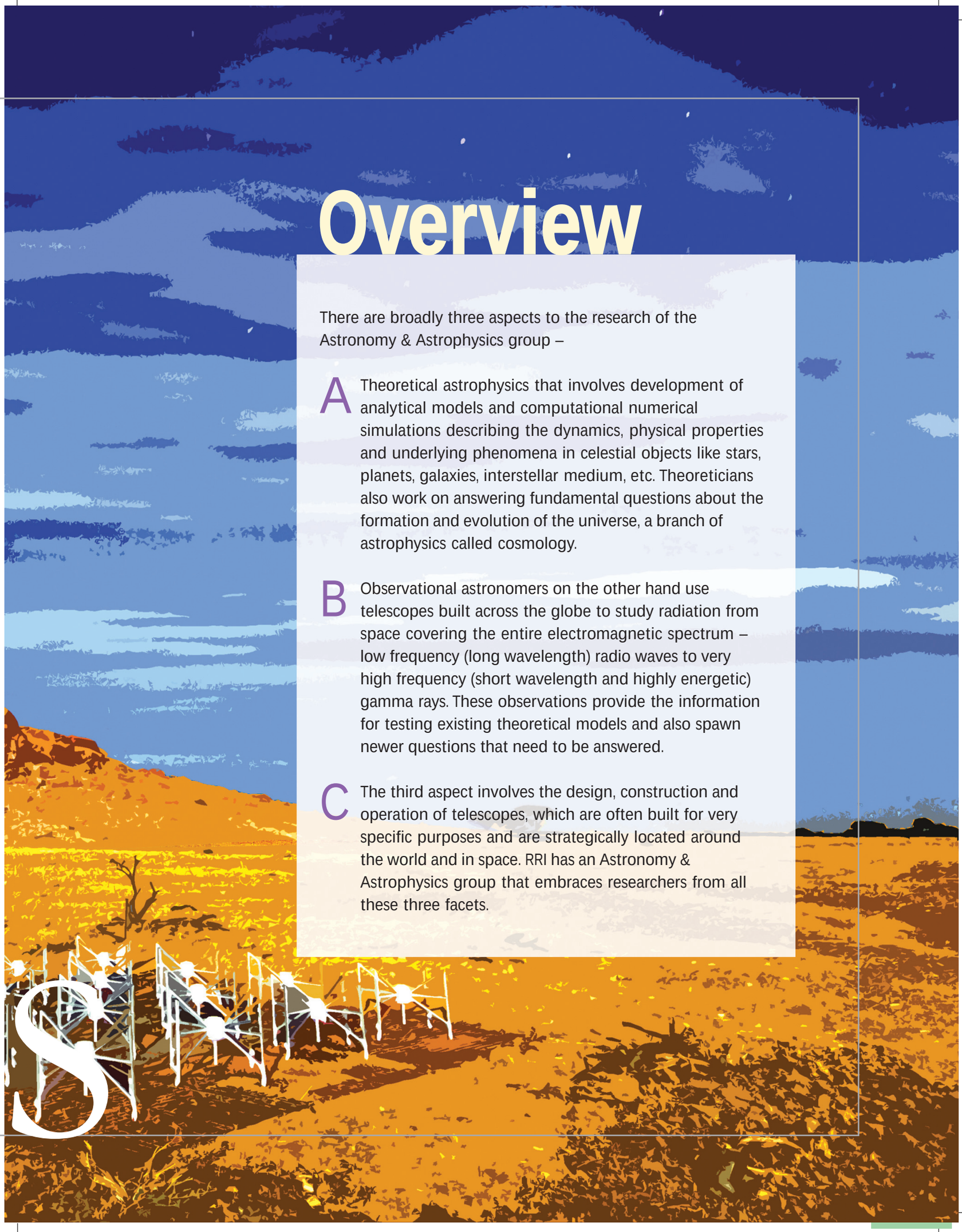
Maintenance
R Sasidharan

Electrical
AS Rao

Waste Management
R Sasidharan

Journal Club	Supurna Sinha
Colloquia	Joseph Samuel, Pramod Pullarkat, Sadiq Rangwala, Urbasi Sinha
Hostel Warden	Reji Philip, Arun Roy, B Ramesh, Urbasi Sinha
Admissions Coordinator	Arun Roy
SAAC	V A Raghunathan (Chairperson), Sadiq Rangwala, Sumati Surya, Pramod Pullarkat, Shiv Sethi
In-House Meeting	PhD students – 3rd Year
JAP Rep of RRI	S Sridhar
Complaints Committee	Srivani (Chairperson), Vrinda, K Raghunatha, Madan Rao, Mamatha Bai
Chairpersons of PhD Interview Committees	Ranjini Bandopadhyay, Urbasi Sinha
Overseas Travel Committee	Udaya Shankar (Chairman), Lakshminarayanan, Madan Rao
Evaluation Committee	Lakshminarayanan (Chairman), Joseph Samuel, Biman Nath, V A Raghunathan, Sadiq Rangwala
Committee for Administration	Lakshminarayanan (Chairperson), Hema Ramachandran, K Krishnamaraju, K Raghunatha and Group co-ordinators – Shiv Sethi, Reji Philip, Yashodhan Hatwalne, Sanjib Sabhapandit
Academics & Research Committee	Joseph Samuel (Chairperson), Udaya Shankar, T N Ruckmongathan
Coordinator of Visiting Students Programme	Arun Roy


ASTRONOMY
AND
ASTROPHYSICS



Overview

There are broadly three aspects to the research of the Astronomy & Astrophysics group –

A Theoretical astrophysics that involves development of analytical models and computational numerical simulations describing the dynamics, physical properties and underlying phenomena in celestial objects like stars, planets, galaxies, interstellar medium, etc. Theoreticians also work on answering fundamental questions about the formation and evolution of the universe, a branch of astrophysics called cosmology.

B Observational astronomers on the other hand use telescopes built across the globe to study radiation from space covering the entire electromagnetic spectrum – low frequency (long wavelength) radio waves to very high frequency (short wavelength and highly energetic) gamma rays. These observations provide the information for testing existing theoretical models and also spawn newer questions that need to be answered.

C The third aspect involves the design, construction and operation of telescopes, which are often built for very specific purposes and are strategically located around the world and in space. RRI has an Astronomy & Astrophysics group that embraces researchers from all these three facets.

Current Research Interests

Theoretical Astrophysics

Cosmology

The origin of magnetic fields in the universe remains a mystery. It is possible that they are of primordial origin and therefore affect cosmological observables, such as CMBR anisotropies and large-scale structure formation. Cosmology has turned into a precision science in the past twenty years and observations can now potentially reveal the nature of these fields. The effects of magnetic fields on different physical processes, structures and signals have been studied. Some of these are cosmological gravitational lensing, Lyman-alpha clouds, neutral hydrogen signals from the epoch of reionization, and the early formation of molecular hydrogen.

Cosmic rays, gamma rays and neutrinos

Highly energetic particles (protons, nuclei, photons and neutrinos) detected on earth are accelerated in Galactic and extragalactic environments. Theoretical modelling of the origin, production and propagation of these high-energy particles is used to interpret observations from gamma ray detectors, such as Fermi LAT, HESS, MAGIC, AGILE and the IceCube neutrino telescope. The applications include Galactic sources, extragalactic sources like gamma ray bursts, and the emission mechanisms and environment in active galactic nuclei.

Galaxies and their surroundings

The interaction between galaxies and their surroundings plays an important role in the evolution of galaxies and the intergalactic medium. The interactions involve the flow of gas acted upon by radiation pressure, cosmic rays and the galaxy's gravitational field. These complex processes are studied using both analytical methods and hydrodynamic simulations. Of interest are violent gaseous outflows from galaxies. Our research addresses their origin, evolution, feedback effects on the parent galaxy, and transport of heavy elements such as carbon, oxygen to the outer parts of the galaxy and beyond.

Stellar dynamics in galactic nuclei

The nuclei of galaxies have dense clusters of stars orbiting supermassive black holes (BH); two nearby examples are the Galactic centre and the nucleus of the Andromeda galaxy. Gravitational forces between all the bodies mainly govern the structure, dynamics and evolution of the stellar system. Both dynamical and statistical mechanical methods have been used to formulate a theory of the long-term evolution of these Keplerian stellar systems with long-range interactions. Phenomena studied include instabilities, relaxation to equilibrium, and fueling of the BH, which contributes to its mass and spin.

Turbulent magnetic fields

The ionized gas in astrophysical bodies (stars, galaxies) is often differentially rotating and magnetized, with the magnetic field generated by electric currents in the highly conducting gas. Not only is the magnetic field strongly coupled to the gas, but it also acts back on the gas through Lorentz forces. Astronomical observations raise questions concerning the

origin and growth of magnetic fields on large scales (dynamo action), and the organization of the field on small scales (turbulence). Some problems of interest are (a) dynamo action in turbulent shear flows, and (b) magneto-hydrodynamic turbulence.

Observational Astronomy

Diffuse Radio Emission from Galaxy Clusters

Galaxy Clusters are some of the largest gravitationally bound structures in the Universe. As many as hundreds of galaxies can be bound in a volume with linear extents of a few million light years. The space between the galaxies, the Intra Cluster Medium (ICM), is often home to sources of bright diffuse radio emission. This radio emission is known to be of non-thermal origin and is due to relativistic electrons radiating in the cluster magnetic field. Observations and interpretations of the origin of diffuse radio emission from galaxy clusters has implications on the studies of large scale magnetic fields in clusters, cluster mergers, and cluster evolution. These observations are being carried out using a variety of radio telescopes like the Giant Meterwave Radio Telescope, the Very Large Array and the Murchison Widefield Array, which was built by RRI and international partners in a collaborative project. Archival X-ray observations are used along with these radio observations to understand these intriguing sources of radio emission.

Pulsars

Pulsars are high magnetic field neutron stars that originate in supernovae and spin rapidly due to the conservation of angular momentum. They emit radio waves, X-rays and Gamma rays periodically. Pulsar emissions provide information about their structure, the high-energy processes in the magnetosphere, their interactions with their environment and can also be used as a test platform for General Relativity. Millisecond pulsars are one of the most accurate clocks found in the universe. RRI conducts active research on pulsars and develops radio receivers and X-ray detectors that can help us understand their nature.

Lifecycles of radio galaxies

A particular type of galaxy called the restarting radio galaxy was first discovered by astronomers of the Institute and has been their research interest for two decades. It is believed that activity in the nucleus of the galaxy had stopped and then started again afresh in multiple epochs. Using increasingly sensitive and high resolution radio telescopes it has now become possible to address questions like why the nucleus died, how long it was dead before activity restarted, what mechanisms triggered a rebirth and so on. Astronomers at RRI are working on these questions together with other international collaborators.

Radio Galaxy Morphologies

Amongst the population of radio galaxies, it is the X-shaped radio galaxy in particular, with its two typical lobes accompanied by two others shaped like the letter X that is currently being investigated by some members of the Astronomy group at RRI. How the two additional lobes are generated is debatable and is of importance to the coalescence of supermassive black holes and generation of Gravitational wave background. In the X-shaped radio galaxy, two lobes appear to be active while the other two are relics or spillovers of plasma from the main axis. Research is on at RRI to test the various existing theories on the shape and structure 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. Their high-energy emission, mostly X-rays, can be accessed using space X-ray observatories. Astronomers at RRI use observations made using a range of international space observatories to investigate topics such as orbital evolution of binary X-ray stars and orbital glitches, quasi-periodic oscillations in X-ray pulsars, self absorption in X-ray pulsars and dips in the pulse profiles, cyclotron absorption lines in X-ray pulsars, neutron star magnetic field and optical reprocessing of thermonuclear X-ray bursts. The upcoming Indian multi-wavelength astronomy satellite ASTROSAT and an Indian X-ray polarimeter POLIX that is being built at the Raman Research Institute will enhance X-ray binary research at RRI substantially.

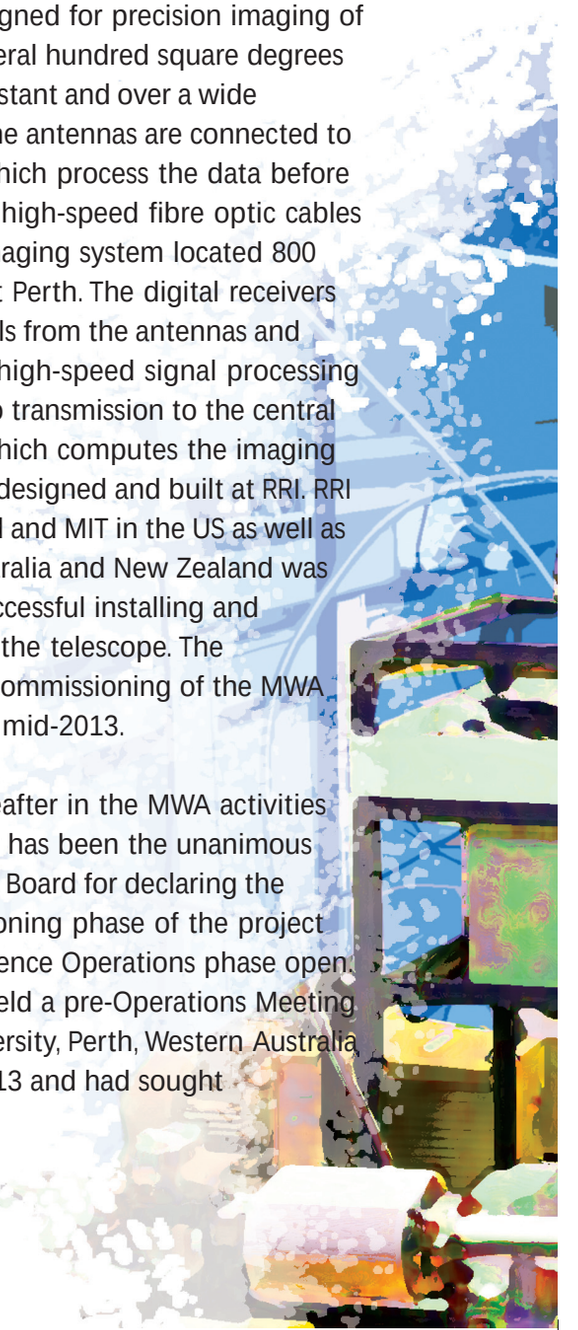
Radio Telescopes and Astronomy

Members of the Astronomy & Astrophysics group along with the Electronics Laboratory of the Institute are involved in projects concerning various telescopes throughout the world. Questions like radio signatures from the Epoch of Reionization and transient radio phenomena, particularly fast radio transients, have changed the frequency range of interest for many next generation radio telescopes to less than a GHz with significantly improved sensitivity, larger bandwidths and wide fields of view. Modern radio telescopes are now realized as phased arrays, or Aperture Arrays, where the number of beams depends only on the available processing power and signal transport, unlike earlier radio telescopes that were based on large reflectors with a single or small number of feeds. The Gauribidanur Radio Telescope, Mauritius Radio Telescope, Murchison Widefield Array and the development of a broadband feed for the Green Bank Radio Telescope are some examples of radio telescope projects in which astronomers at RRI have been actively engaged.

Murchison Widefield Array (MWA)

The MWA radio telescope or the Murchison Widefield Array radio telescope located in Murchison Shire in the Australian outback is an array of antennas arranged as square 'tiles' consisting of a total of 2048 dual-polarization wide-band 'bow-tie shaped' antennas that operate in the frequency range 80-330 MHz. They are arranged as 128 square 'tiles' each having 16 pairs of antennas. The antenna distribution is designed for precision imaging of a wide field of several hundred square degrees of the sky at any instant and over a wide frequency band. The antennas are connected to digital receivers which process the data before transmitting it via high-speed fibre optic cables to a centralized imaging system located 800 kilometres away at Perth. The digital receivers that take the signals from the antennas and perform complex high-speed signal processing of the data prior to transmission to the central processing unit, which computes the imaging information, were designed and built at RRI. RRI along with Harvard and MIT in the US as well as institutions in Australia and New Zealand was involved in the successful installing and commissioning of the telescope. The construction and commissioning of the MWA was completed in mid-2013.

A major step thereafter in the MWA activities this academic year has been the unanimous voting of the MWA Board for declaring the Science Commissioning phase of the project closed and the Science Operations phase open. MWA board had held a pre-Operations Meeting in the Curtin University, Perth, Western Australia, 25-26 February 2013 and had sought



Expressions of Interest (EoIs) from the international community in using the 128-tile MWA. The EoI step was a precursor to the preparation of full observing proposals in the March/April 2013 timeframe, anticipating the commencement of the first MWA operations period from July 2013. According to plans, MWA commenced scientific operations in mid 2013. The MWA has already begun gathering weak radio signals from deep space that will be analyzed by scientists at RRI and in the US and Australia using massively parallel computing systems. The data is expected to provide astronomers an insight into the dramatic evolution experienced by primordial cosmic gas as the first stars and galaxies formed in the early universe. That apart, MWA data will help study structure of the intergalactic hydrogen gas in our Milky Way galaxy and galaxies beyond, and the influence of the Sun on inter-planetary weather close to the Earth.

Currently, RRI is leading the effort to incorporate a mode that will allow targeted observations over the full 300 MHz bandwidth of the MWA as against the present 30 MHz bandwidth used for its prime imaging mode.

The completion of MWA is a precursor to the setting up of the Square Kilometre Array (SKA), a massive global project to build the world's largest radio telescope across Australia and South Africa. SKA is slated to be the world's largest and most sensitive radio telescope ever built. It will be sensitive enough to detect even airport radar on a planet 50 light years away.

Gauribidanur Radio Telescope (GRT)

This decametre wave radio telescope at Gauribidanur is operated in collaboration with the Indian Institute of Astrophysics. Operating at 34.5 MHz, this meridian-transit instrument has some tracking capabilities. It consists of 1000 fat dipoles arranged in the form of a letter 'T'. The dipole orientation is along East-West making it sensitive to only polarization in that direction. The bandwidth is about 10 MHz centred at 32MHz, while maximum effective collecting area is about 18,000 square metres. The N-S arm of the beam can be tilted within a declination range of -45° to 75° while the E-W beam can be tilted in Hour Angle within 10° around the meridian enabling tracking for a minimum of 42 min. Members of the astronomy group currently study emissions from pulsars and build models for the emission regions at the polar caps of pulsars. They infer the astrophysics of this phenomenon using the GRT.

X-ray polarimeter (POLIX)

Anisotropy in the Thomson scattering of polarised X-rays is used to measure the degree and angle of linear polarisation of cosmic X-rays. Several types of the cosmic X-ray sources are expected to have some linear polarisation, with very strong polarisation in some sources like accretion powered X-ray pulsars and Blazars. Important breakthrough can be made in some key scientific aspects of these sources from their X-ray polarisation measurements. In spite of this, X-ray polarisation measurement is an as yet unexplored area. To date, only one experiment for X-ray polarization measurement has been done and Crab Nebula is the only source with a definite measurement of its polarisation. RRI astronomers are developing methods of detecting polarized X-rays from celestial bodies and building X-ray instruments for detecting these polarized X-rays. For this, the development of an X-ray polarimeter sensitive in the range of 5-30 keV is underway, and is well along the road towards being launched into space in collaboration with ISRO. A laboratory model has been built and tested successfully. The design and fabrication of the engineering model is now under progress. During the period of this report the following developmental works have been carried out at RRI.

1. Polarimeter assembly: The engineering model of the polarimeter has been assembled with two working detectors, two dummy detectors and the collimator. They will next be subjected to space qualification tests like vibration and thermo-vac tests and preparation for these tests is ongoing.

2. Space qualified electronics: Space qualified layouts for the front electronics cards have been made and the same have been tested in laboratory. Fabrication and population of the space-qualified cards is ongoing.

3. The X-ray polarimeter has some special requirements for the spacecraft like a stable spin and long-duration three-axes stabilisation pointing towards different X-ray sources. The configuration of the satellite has to be done to meet these and the power and telemetry requirements. Studies are ongoing at the ISRO Satellite Centre (ISAC) towards the satellite configuration to meet requirements of the X-ray polarimeter. RRI is working together with ISAC on this and preparation of an observation plan with the mission.

Based on the development that has been achieved in this project and the research potential, a committee has been constituted by the Programme Director of the Small Satellite Programme at ISRO to configure a satellite mission. A review by the Advisory Committee for Space (ADCOS) of ISRO is scheduled for May 2014.

ASTROSAT

This ISRO satellite mission for multi-wavelength astronomy is designed for broadband spectroscopic studies of X-ray binaries, AGNS, clusters of galaxies and stellar coronae, sky surveys etc. RRI has been working on the Large Area X-ray Proportional Counter (LAXPC), one of the Astrosat payloads, which is to be used for X-ray timing and low-resolution spectral studies over a broad energy band. LAXPC is designed to have a large photon collection area enabling detailed studies of high-energy features in X-ray light curves of bright and medium intensity point X-ray sources. Currently work is being done on the timing and spectral calibration of the Astrosat-LAXPC instrument and a software design for LAXPC data reduction. The main goal of the timing qualification and calibration work is to minimize systematic uncertainties in the timing response of LAXPC detectors and the processing electronic units. There has been significant progress in the development and testing of Level-2 data reduction software and standard processing pipeline for LAXPC. Also the LAXPC calibration document has been recently submitted to ISRO.

15-Metre Fan-Beam Telescope

Members of the Astronomy & Astrophysics group at RRI have proposed two new optical designs for radio telescopes that use a Fan Beam Telescope (FBT) as a component. Currently, RRI is engaged in building a Fan Beam Telescope - Low Frequency (FBT-LF) with the purpose of demonstrating its functioning and the expected benefits of the new designs. Once commissioned, it will pave the way for the realization of the above two optics designs. For this purpose, a Ku-band receiver chain is also being built, including low-noise amplifiers, covering the 7-14 GHz range. Recently, a method has been proposed that enables single dishes to add short-spacing data to synthesis instruments. This method also allows for the measurement of the surface deviations of antennas accurately using Ku-band receivers.

APSERa

In 2012-2013, it was proposed that an Array of Precision Spectrometers be built to detect recombination lines from the Epoch of Cosmological Recombination. (Project APSERa described in www.rri.res.in/apsera) These are predicted to manifest as 'ripples' in wideband spectra of the cosmic radio background (CRB) since recombination of the primeval plasma in the early Universe adds broad spectral lines to the relic Cosmic Radiation. The lines are extremely wide because recombination is stalled and extended over redshift space. The spectral features are expected to be isotropic over the whole sky.

The project will ultimately be an array of 128 small radio telescopes that are built to detect a set of adjacent lines from cosmological recombination in the spectrum of the radio sky in the 2.5-6.0 GHz range. State of the art low-noise high-dynamic-range interference-tolerant radio receivers are being designed and built at the Institute, tested in nearby radio-quiet locations and will then be relocated to a remote site for long duration exposures to detect the subtle features in the cosmic radio background arising from recombination.

Future Directions

SWAN: (Indian Sky Watch Network)

RRI has proposed the design, development and use of a broad-band Sky Watch Array Network across India with the following objectives –

A To facilitate and conduct searches and studies of fast (typically of sub-second duration) and slow transient radio radiation originating from astronomical sources.

B To facilitate and conduct high angular resolution imaging of discrete galactic and extragalactic sources at low radio frequencies.

C To train, involve and provide hands-on experience to a large number of undergraduate and postgraduate students in all aspects of the SWAN, through their direct and active participation starting from the design stage to research using the array network.

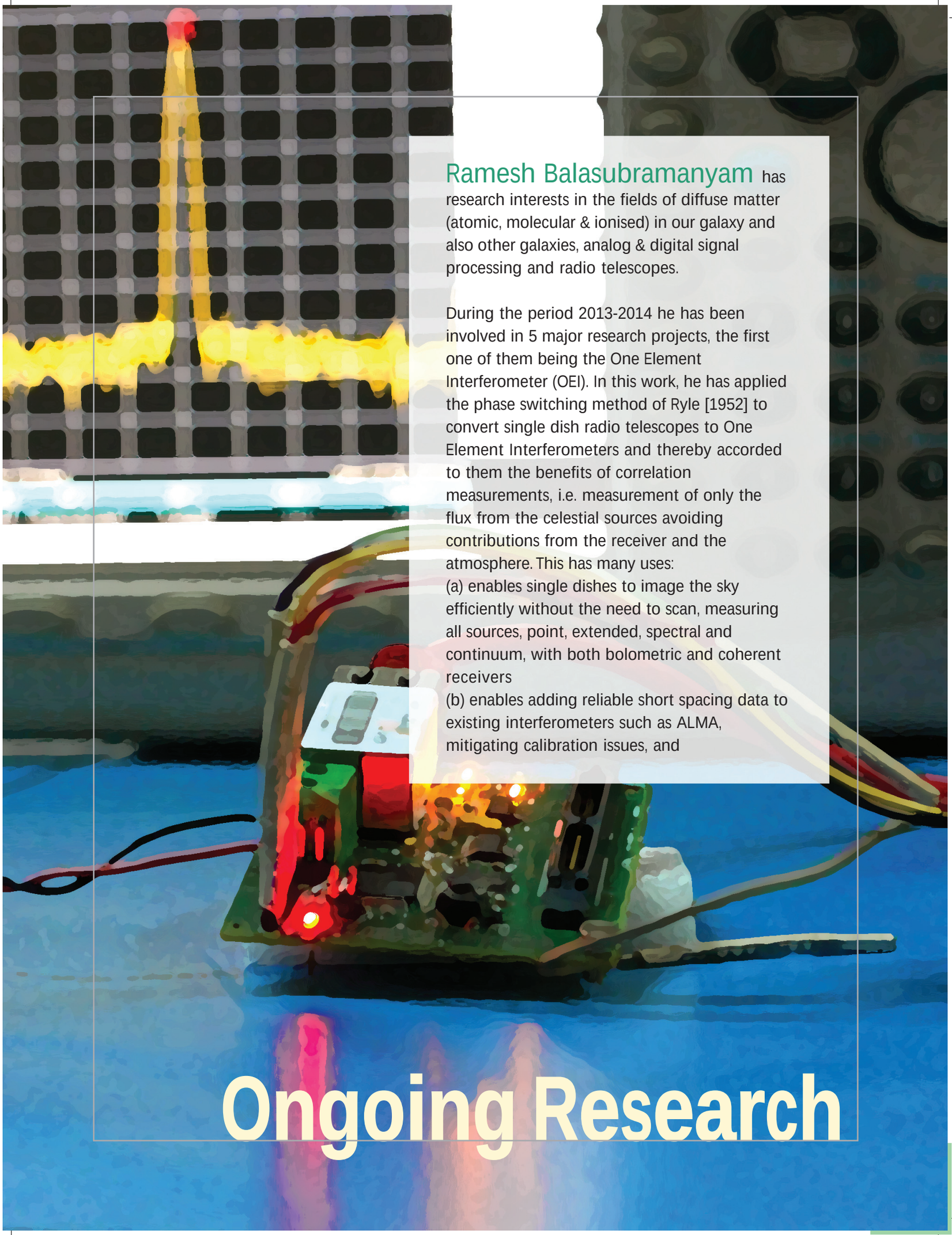
The proposed competitive coordinated network with nominally 1000 sq. m array area at each location and operation spanning a decade in frequency over 50-500 MHz will be developed in three phases.

In the first phase the plan is for a moderate setup to be attempted for realizing and demonstrating the essential features. In the coming months, the focus will be on realizing a setup with 8 independent stations operating over a common narrow band, using available hardware from previous projects (e.g. GBT receiver, MWA tiles and beam-formers). After such a setup is fully developed and tested at Gauribidanur field station, relocation of the system at 8 different sites will be considered. Test observations will include targeted searches for radio transients in a few select directions of specific astronomical interest, and coordinated observations with the GMRT.

In the second phase, the aperture size and spectral coverage will be increased. Digital receivers required for this will be developed in parallel with the first phase activities. An 8-station setup, now with the final spectral coverage and the aimed aperture size per station, will be developed providing most of the observational modes. This setup will be subjected to extensive tests, also including fruitful test observations.

On successful completion of this crucial second phase, the network will be swiftly expanded in a timely manner to the full set of locations and array configurations to reach with the aimed watch (or survey) sensitivity and volume coverage, etc., for the transient search. The scope of routine operations and modalities will be assessed carefully before this expansion.

The implicit aim is to initiate a collective effort to develop the SWAN with as many of the 40+ technology and science institutes, such as the IITs, NITs, IISERs & NISERs, as well as many universities across India. The prospective institutes and particularly motivated people from these institutes, will be approached for partnership. To prepare for student involvement, appropriate schools/workshops (in co-ordination with existing programs) are to be arranged to formally introduce under-graduate and master's students to radio astronomy, basic concepts and advanced topics/techniques, over a few weeks each year, along with hands-on experience with systems. Active participation from students in all aspects of the SWAN, including studies of astronomical sources, will be sought and explicitly encouraged/supported.



Ongoing Research

Ramesh Balasubramanyam has research interests in the fields of diffuse matter (atomic, molecular & ionised) in our galaxy and also other galaxies, analog & digital signal processing and radio telescopes.

During the period 2013-2014 he has been involved in 5 major research projects, the first one of them being the One Element Interferometer (OEI). In this work, he has applied the phase switching method of Ryle [1952] to convert single dish radio telescopes to One Element Interferometers and thereby accorded to them the benefits of correlation measurements, i.e. measurement of only the flux from the celestial sources avoiding contributions from the receiver and the atmosphere. This has many uses:
(a) enables single dishes to image the sky efficiently without the need to scan, measuring all sources, point, extended, spectral and continuum, with both bolometric and coherent receivers
(b) enables adding reliable short spacing data to existing interferometers such as ALMA, mitigating calibration issues, and

(c) offers accurate surface measurements, with no additional antenna, for any single dish fitted with only a total power receiver, using a strong spectral or continuum source. It is also expected to help ground-based NIR/MIR imaging by accurately removing atmospheric contributions. This work is currently under review for publication in *MNRAS*.

Ramesh's second major area of research in the past one year has been in the designing of Fan-beam Telescope and off-axis performance simulations. 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 e.g. 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 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 fan-beam telescopes (FBT) 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 (R. Balasubramanyam, 2004, *MNRAS* **354**, 1189); (b) to use two FBTs in a cross-configuration to realise a focal-plane Mills' cross high frequency telescope that promises great advantages (R. Balasubramanyam, 2014, *MNRAS*, under review).

With this background, studying the off-axis performance of the fan-beam telescope has become important. Last year, he has carried out ray-trace based investigation for a Cassegrain FBT and found the results to be encouraging. Now, he and his team are extending this study to include physical optics simulations. The results will soon be reported to the *MNRAS*.

Along with Parvathi Chandrasekaran, visiting student, RRI, Ramesh has also been involved in a systematic study of coding performance in a MIMO-STBC-OFDM link. High data rate wireless communication is essential for modern applications such as Mobile television, 3D Telepresence and Internet of Things. Inter Symbol Interference (ISI) and frequency selective fading caused by multi-path propagation hinders this. These are mitigated by Orthogonal Frequency Division Multiplexing (OFDM) and Multi-Input Multi-Output (MIMO) antenna system.

Forward Error Correction Codes (FECCs) use redundancy to detect and correct errors that still occur. Existing studies analyse the performance of different FECCs but none focus on a systematic analysis using a common link configuration. Ramesh and his collaborator fill this gap in this simulation study using a common MIMO-STBC-OFDM communication link, transferring data at a base rate of 100 Mbps. They analyse the performance of three different FECCs, each with multiple code rates in the range 0.5 to 1, over a range of SNR of the AWGN channel for four symbol mapping schemes and two fading types. Their simulation results show that, (a) LDPC is the best choice as a single FECC with BPSK and to some extent in QPSK for all code rates; (b) CC with 1/2 code rate works well for all symbol mapping schemes under Rayleigh and Rician fading. This work has been submitted

to Wireless Networks for publication. This work in the area of digital signal processing is useful for both wireless and wired digital communication as well as data storage and retrieval. These are relevant for arrays such as SKA, which will generate vast amounts of data that will need to be communicated from the widely distributed elements to the central processing building at high speeds, stored and retrieved.

Through the year, Ramesh has also been working on an instrumentation development project: that of the Fan-beam Telescope at low frequency. As mentioned above, working out new optics that results in key benefits to telescope design has been one of his research themes. It is also important to demonstrate that the idea works in practice and the projected benefits are indeed realized. This is done by constructing prototype equipment and using them to produce demonstrative science. As mentioned above, over the years he has developed two key ideas for a radio telescope and he is keen to demonstrate that they work in reality. Both use fan-beam telescopes (FBT) as a part in their optical scheme. As mentioned in the report during 2012-2013, setting the surface to 1mm accuracy is needed for FBT-LF. Towards this, he has built a simple, coordinate measuring machine using a commercial laser distance meter, a couple of stepper motors with their driver boards, an Arduino Uno and Cubie boards. This uses trigonometry to obtain the distances to the desired accuracy and has been demonstrated to work. He is now equipping the unit with an appropriate mount system to enable its use at the construction site. With this done, setting up the FBT-LF surface will be completed soon. VSP students Vivek and Aditya, have assisted Ramesh in this work.

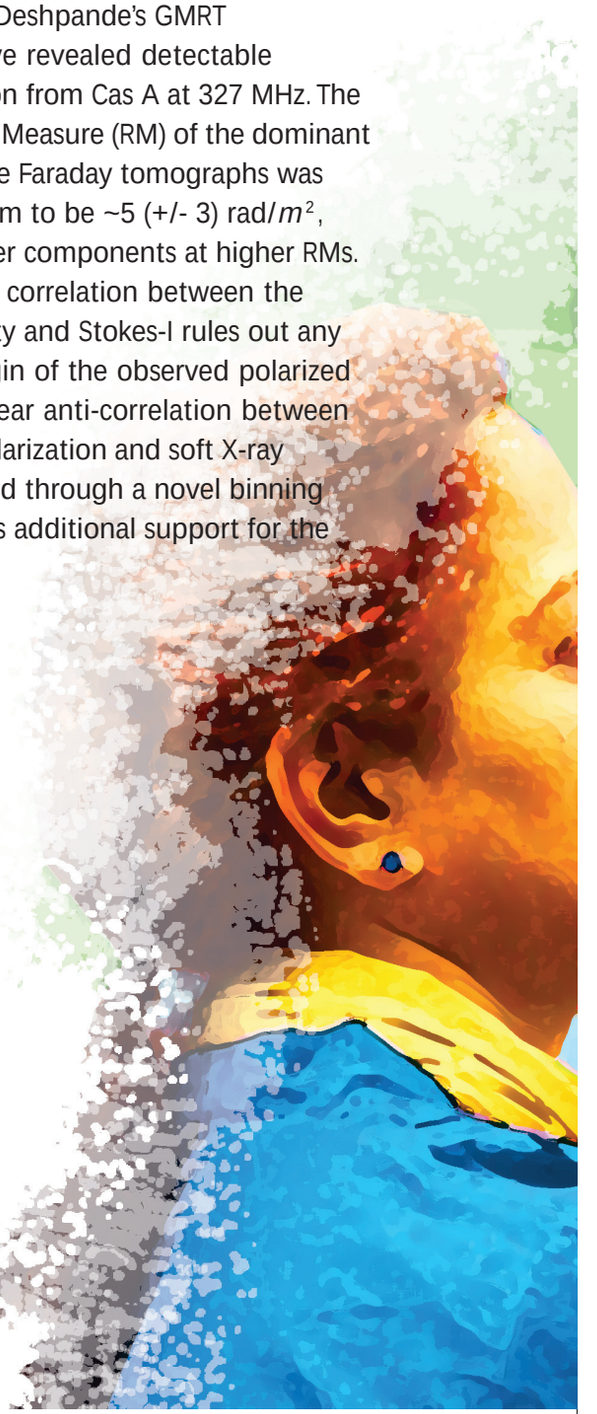
Another instrumentation development project that Ramesh has been involved in is the Voice Command Interface Kit under the aegis of the Brain-Computer interface lab. His collaborators in this project have been Junaid Ahmed, Project Engineer, RRI; M.S. Ezhilarasi, RAL, RRI. As a part of assistance systems for the disabled, motorised wheel chairs are becoming more common in India. Currently, they are joystick driven. An economical kit has been developed that can be added to the current electric wheel chairs and make them voice-driven. The kit is conceived as a buffer unit between the joystick and the drive controller: i.e., signals from the joy stick flow via this unit to the drive controller. A Cubie board, running Pocket Sphinx on Cubiuntu lies at the heart of this kit. It also has an interface card that connects to various sensors (magnetic, ultrasonic, infrared) and limit-switches that are used for direction control and collision avoidance. They are mask enabled so that only sensors actually connected are used. This board also generates various DC voltages from a single 12V input and the necessary PWM and other signals, equivalent to those from the joystick, to be sent to the drive controller. A GUI based voice training application has also been developed to train the users to improve command recognition accuracy. Currently, the lexicon is being optimised and the system is being tested for robustness. Once the tests are completed, they plan to release the kit for general users in the lines of open-source hardware. To begin with, they are capable of servicing only one type of joystick-drive controller pair. It is easy to augment the software and they hope to add to their ability to service more types of joysticks, by crowd-sourcing the required information for augmentation, once the kit details are published.

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

During the year gone by, in collaboration with Yogesh Maan of RRI, Deshpande studied the sub-pulse fluctuations of Pulsar B1237+25. This study was specifically aimed at finding out whether the outer and inner cones of the pulsar B1237+25 share a common origin or not. They have mapped and studied the underlying emission patterns for a number of pulse sequences from this star. The emission patterns corresponding to the outer and the inner cones were found to be significantly correlated with each other, implying that the emission in the two cones share a common seed pattern of sparks. This main result is consistent with the same radio frequency emission in the two cones, originating from a common seed pattern of sparks at two different altitudes. More interestingly, the observed azimuthal offset of about 10 degrees between the two conal emission patterns suggests a twist in the emission columns, and most likely in the magnetic field geometry, across the two different emission altitudes. The possibility that some part of the core component — contrary to common belief — also shares its origin with the conal counterparts was examined, and it was found that presence of a compact, diffuse and further-in carousel of sub-beams can consistently explain the generally observed slow modulation, or lack thereof, in the core component.

The underlying carousel of sparks for this pulsar appears to seriously lack stability over long durations. Even for the shorter sub-sequences, the sweep of the modulation phase across the pulse longitudes deviates significantly from that predicted by the carousel model. Unless these deviations have significant contributions from pulse-nulling, mode-changing and/or inherent irregularities in the carousel on timescales much lesser than the lengths of their individual sub-sequences, they pose a serious challenge to the widely accepted standard carousel model.

Linear polarization from the supernova remnant Cas A at low radio frequencies constitutes the other research problem addressed by Deshpande and his collaborator, Wasim Raja (RRI) in the time period between 2013-2014. Despite the expected severe depolarization, Wasim Raja and Deshpande's GMRT observations have revealed detectable polarized emission from Cas A at 327 MHz. The Faraday Rotation Measure (RM) of the dominant component in the Faraday tomographs was estimated by them to be ~5 (+/- 3) rad/m^2, along with weaker components at higher RMs. Observed lack of correlation between the polarized intensity and Stokes-I rules out any instrumental origin of the observed polarized component. A clear anti-correlation between the degree of polarization and soft X-ray emission, assessed through a novel binning method, provides additional support for the



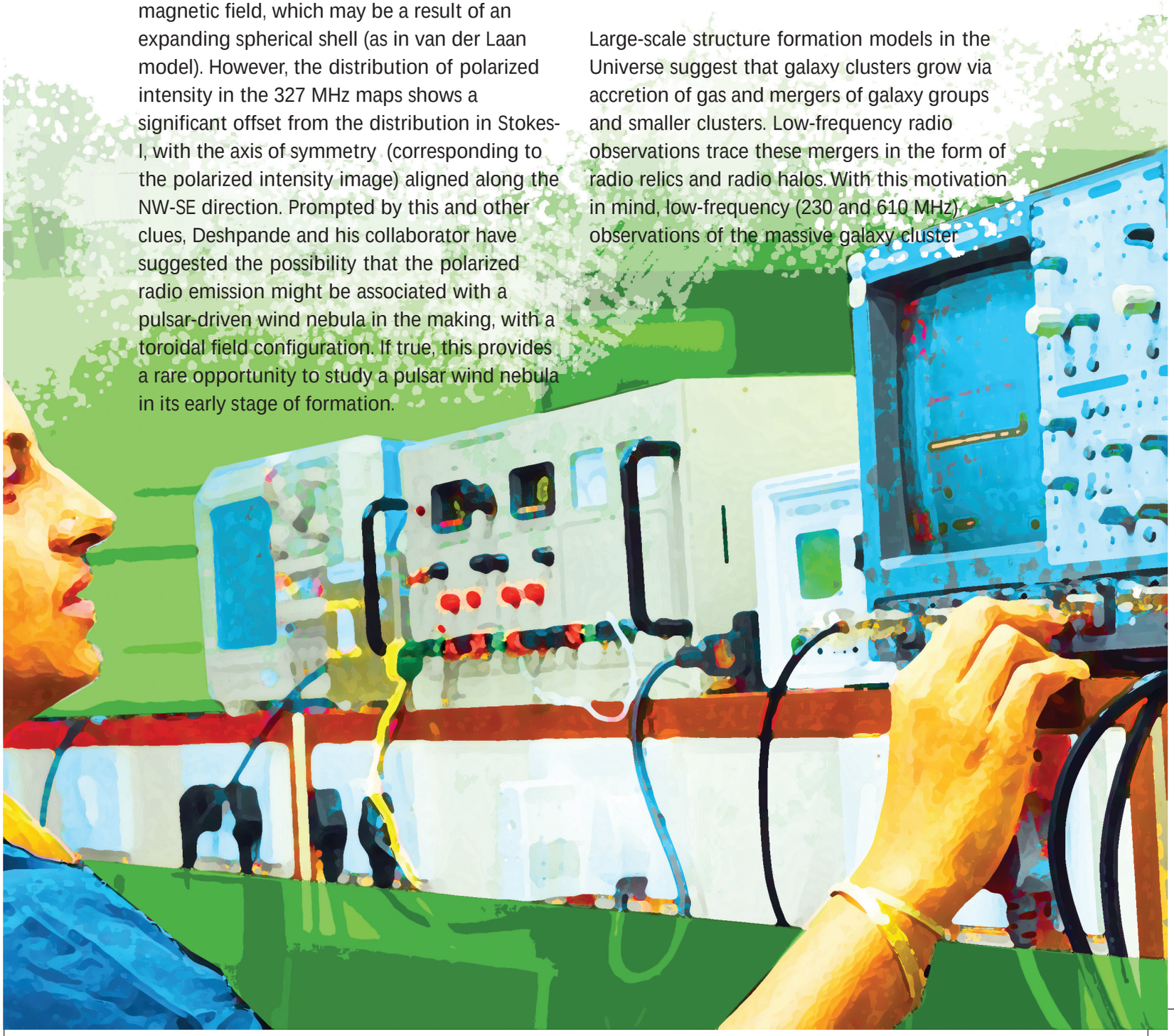
polarization being intrinsic to the source. The dominant polarized emission component shows a nearly constant position angle (PA) across the remnant, with small dispersion (~5 degrees) in the PA. This constancy of the PA is intriguing and is in direct contrast with the PA variation apparent in earlier studies of the remnant at higher frequencies.

The constancy of the PA associated with the polarized emission could, in principle, be a manifestation of compressed ambient uniform magnetic field, which may be a result of an expanding spherical shell (as in van der Laan model). However, the distribution of polarized intensity in the 327 MHz maps shows a significant offset from the distribution in Stokes-I, with the axis of symmetry (corresponding to the polarized intensity image) aligned along the NW-SE direction. Prompted by this and other clues, Deshpande and his collaborator have suggested the possibility that the polarized radio emission might be associated with a pulsar-driven wind nebula in the making, with a toroidal field configuration. If true, this provides a rare opportunity to study a pulsar wind nebula in its early stage of formation.

K.S. Dwarakanath's major research interests are in the areas of halo and relic radio sources in clusters of galaxies.

During the years 2013-2014 his research activities were mainly focussed on the following problems:
i) Low-frequency radio emission in the massive galaxy cluster MACS J0717.5 + 3745
ii) HI in the Arp 202 system and its tidal dwarf candidate
iii) Galaxy cluster studies using the MWA.

Large-scale structure formation models in the Universe suggest that galaxy clusters grow via accretion of gas and mergers of galaxy groups and smaller clusters. Low-frequency radio observations trace these mergers in the form of radio relics and radio halos. With this motivation in mind, low-frequency (230 and 610 MHz) observations of the massive galaxy cluster



MACS J0717.5 + 3745 (z=0.5548) were carried out using the GMRT. These observations were supplemented by archival data from the VLA (at 74 and 1400 MHz) and the WSRT (325 MHz). These data were used to investigate the spectral index distribution of the non-thermal radio emission from the cluster. Furthermore, Chandra X-ray and HST data were used to study the distribution of the hot thermal gas and of the galaxies respectively.

A highly complex non-thermal diffuse radio emission is seen in the cluster at low frequencies, with an average spectral index of -1.17 between 235 and 610 MHz. At 235 MHz, Dwarakanath and his collaborators have detected a giant radio halo of 1.58 Mpc extent within the cluster and a "Chair-shaped" filamentary structure of linear size 853 kpc between the merging subclusters. This is the most powerful radio halo ever observed with a spectral power at 1400 MHz of 9.88 x 10^{25} W/Hz. This halo has an equipartition magnetic field strength of about 6.5 micro gauss. The bright filamentary structure is located in the central merging region of subclusters with enhanced temperature, as shown by Chandra and HST data. The formation of this filamentary structure appears to be due to shocks encountered within the intra cluster medium during the merger events. This work was done in collaboration with M. Pandey-Pommier (ULyon), J. Richard (ULyon), F. Combes (LERMA), B. Guiderdoni (ULyon), C. Ferrari (UNice), S. Sirothia (NCRA-TIFR) and D. Narasimha (TIFR).

HI 21 cm-line observations of the interacting system of galaxies Arp 202, NGC2719 and NGC2719A carried out with the Giant Metrewave Radio Telescope (GMRT) constitutes the second major research theme for Dwarakanath in the year gone by. Earlier deep UV (GALEX) observations of this system revealed a tidal tail with a diffuse object towards its end, proposed as a tidal dwarf galaxy (TDG) candidate. HI 21 cm-line emission is detected from the Arp 202 system, including HI counterparts for the tidal tail and the TDG candidate. The GMRT HI morphological and kinematic results clearly link the HI tidal tail and the HI TDG counterparts to the interaction between NGC2719 and NGC2719A, thus strengthening the case for the TDG. The Arp 202 TDG candidate belongs to a small group of TDG candidates with extremely blue colours. In order to better understand the properties of this group a comparative study of their properties from the available data was carried out. It was observed that HI (and probably stellar) masses of this extremely blue group are similar to the lowest HI mass TDGs in the literature. However the number of such blue TDG candidates examined so far is too small to conclude whether or not their properties justify them being considered to be a subgroup of the TDGs. Dwarakanath had collaborated with C. Sengupta (KASSI), T.C. Scott (U Hertfordshire), D.J. Saikia (NCRA, CCSU) and B.W. Sohn (KASSI and US and T) for this work.

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 on galaxy clusters from the Galactic and Extragalactic MWA survey and from tracking observations are being analysed to produce continuum images for further analysis and interpretation by K.S. Dwarakanath (RRI), Lijo George (RRI) and MWA collaborators.

Nayantara Gupta's research interests are in cosmic rays, neutrinos, gamma rays and gamma ray bursts.

In the year gone by her research focused on mainly three themes:
i) How Many of the Observed Neutrino Events Can Be Described by Cosmic Ray Interactions in the Milky Way? in collaboration with Jagdish C. Joshi (RRI) and Walter Winter (DESY, Germany) [published in *MNRAS* **439** (2014) 3414]
ii) Photo-Disintegration of Heavy Nuclei at the Core of Cen A, in collaboration with Esha Kundu (TIFR, Mumbai) [published in *JCAP* **04**, article id. 030, pp. (2014)]
iii) p-γ interactions in Galactic jets as a plausible origin of the positron excess, in collaboration with Diego F. Torres (ICREA & Institute of Space Sciences (IEEC-CSIC, Spain) [accepted for publication in *MNRAS*]

Cosmic rays diffuse through the interstellar medium and interact with matter and radiations as long as they are trapped in the Galactic magnetic field. The IceCube experiment has detected some TeV-PeV neutrino events whose origin is yet unknown. She has studied if all or a fraction of these events can be described by the interactions of cosmic rays with matter. They consider the average target density needed to explain these events for different halo sizes and shapes, the effect of the chemical composition of the cosmic rays, the impact of the directional information of the neutrino events, and the constraints from gamma ray bounds and their direction. They do not require knowledge of the cosmic ray escape time or injection for our approach. It is found that, given all constraints, at most 0.1 of the observed neutrino events in IceCube can be described by cosmic ray interactions with matter. In addition, it has been demonstrated that the currently established chemical composition of the cosmic rays contradicts a peak of the neutrino spectrum at PeV energies.

Fermi LAT has detected gamma ray emissions from the core of Cen A. More recently, a new component in the gamma ray spectrum from the core has been reported in the energy range of 4 GeV to tens of GeV. Gupta and her collaborator show that the new component and the HESS detected spectrum of gamma rays from the core at higher energy have possibly a common origin. That being in photo-disintegration of heavy nuclei. Assuming the cosmic rays are mostly Fe nuclei inside the core and their spectrum has a low energy cut-off at 52 TeV in the wind frame moving with a Doppler factor 0.25 with respect to the observer on earth, the cosmic ray luminosity required to explain the observed gamma ray flux above 1 GeV is found to be 1.5 × 1043 erg/sec.

The positron flux measured near Earth shows a rise with energy beyond 30 GeV. Gupta along with Torres show that this rise may be compatible with the production of positrons in photo-hadronic interactions in the jets of microquasars.

Biman B. Nath's current professional research interests lie primarily in the interaction of diffuse gas with galaxies, galactic outflows, cosmic rays and intracluster medium.

His research in the year gone by has been focused on 5 major problems which are as follows:
i) Extra-planar gas in galaxies as a result of outflows
ii) Conditions for supernovae driven outflows
iii) Cosmic background from the formation of the first supermassive black holes
iv) Evolution of multiple supernovae
v) Superbubble vs multiple supernovae feedback

In this work, for the first time the interaction of galactic wind with the hot halo gas in galaxies has been studied using hydrodynamic simulation with PLUTO. It was found that the outcome of this interaction crucially depends on two parameters: wind injection speed and density. Various phases of the observed extra-planar media, such as infalling clouds, outflowing clouds and OVI regions (circum-galactic medium) have been identified, depending on the wind speed and density. For high speed and large density, the interaction produces outflowing clouds, and a widespread warm-hot medium in the halo. It has also shown how the injection speed and density depends on the star formation rate and the efficiency of energy deposition. This work was done along with Sharma, Chattopadhyay and Shchekinov and has been published in *MNRAS*.

Nath along with Shchekinov has pointed out that a commonly assumed condition for galactic outflows, that supernovae heating are efficient in the central regions of starburst galaxies, is based on an invalid assumption. They have shown that this is difficult to achieve, unless the

supernovae from OB associations in the central regions are taken into account, and they have derived a lower limit for this to happen on the molecular surface density. The limit was found to be 1000 solar mass per square parsec. This analytical paper was published in *ApJL*.

Nath has also investigated the possible cosmic background resulting from the formation of the first supermassive black holes in a work done along with Biermann, Caramete, Harms, Stanev and Becker-Tjus. They have considered the possibility of formation of black holes of masses above 10^6 solar masses at redshift of ~20, and how this phenomenon will produce observable background at present epoch at various wavelengths, in particular, radio, high energy and neutrino background. This work has also been published in *MNRAS*.

Based on the analytical paper mentioned above and its effect on multiple supernovae, Nath, in collaboration with Eugene Vasiliev and Yuri Schchekinov, has carried out hydrodynamical simulations to confirm their analytical results. Interestingly, the effect of merging of multiple supernovae has never been considered in the literature. In these 2-d and 3-d simulations, they have considered the effect of merging, collisions of multiple supernovae, either exploding at a single epoch, or staggered in time, and found the conditions under which they can give rise to galactic outflows. They have also come up with various observational diagnostics, such as the distribution of radio of OVII/OVIII in starbursts to determine these conditions. Nath has contributed mainly in the interpretation of the results and devising the observational diagnostics. This work is under review by *MNRAS*.

In collaboration with Prateek Sharma (IISc), Yuri Shchekinov and Arpita Roy (JAP student) Nath has looked into various methods of implementation of supernovae feedback in numerical simulations, and showed why superbubble feedback (from OB associations) work better than feedback from multiple supernovae in general. They have derived the general conditions under which feedback implementations would work in simulations. This work has been reported in a paper submitted to *MNRAS*.

Biswajit Paul's areas of current research interest include X-ray binaries and transients. His astronomy research in the year gone by has been in the investigation of various aspects of compact X-ray sources and Paul has made significant contributions in several studies of X-ray binaries.

Aru Beri (IIT Ropar), Chetna Jain (Hans Raj College), Paul and Harsha Raichur (RRI) investigated the pulse profile evolution of the unique accretion powered X-ray pulsar 4U 1626-67 over the last 40 years since its discovery. This pulsar showed two distinct eras of steady spin-up separated by a steady spin-down episode for about 18 years. In this work, using data from different observatories active during each phase of spin-up and spin-down, they established a clear correlation between the accretion torque acting on this pulsar and its pulse profile. The energy-resolved pulse profiles were found to be identical in both the spin-up eras and quite different in the spin-down era, especially in the low-energy band. This correlation, along with the already known feature of strong quasi-periodic oscillations (QPO) that was present only in the spin-down era, clearly establishes two different accretion modes to the neutron star. The two different accretion modes produce different pulse profiles, only one of which produces the QPOs.

GX 301-2, a bright High Mass X-ray Binary (HMXB) with an orbital period of 41.5 days, exhibits stable, periodic, orbital intensity modulations with a strong pre-periastron X-ray flare. Paul along with Nazma Islam (RRI) carried out exhaustive orbital phase resolved spectroscopic measurements of GX 301-2 using data from the Gas Slit Camera on board the MAXI all sky X-ray instrument of the International Space Station. Using spectroscopic analysis of the MAXI data with unprecedented orbital coverage for many orbits continuously, they have found a strong orbital dependence of the absorption column density and equivalent width of the iron emission line. A very large equivalent width of the iron line along with a small value of the column density in the orbital phase range 0.10-0.30 after the periastron passage indicates presence of high density absorbing matter behind the neutron star in this orbital phase range. A low energy excess was also found in the spectrum at orbital phases around the pre-periastron X-ray flare. The orbital dependence of these parameters was then used to examine the various models about mode of accretion onto the neutron star in GX 301-2.

Aru Beri, Paul and Gulab Dewangan (IUCAA) have carried out a pulse phase resolved spectroscopy of the complex emission lines around 1 keV in the unique accretion powered X-ray pulsar 4U 1626–67 using observations made with the XMM-Newton in 2003. In this source, the red and blue shifted emission lines and the line widths measured earlier with Chandra suggest an accretion disk origin. Another possible signature of lines produced in accretion disk can be a modulation of the line strength with pulse phase. They found the line fluxes to have definite pulse phase dependence. The O VII line at 0.568 keV varied by a factor of ~4, stronger than the continuum variability, which supports its accretion disk origin. The line flux variability may appear due to variable illumination of the accretion disk by the pulsar or more likely, a warp like structure in the accretion disk. In the end they also discuss some further possible diagnostics of the accretion disk in 4U1626-67 with pulse phase resolved emission line spectroscopy.

Along with Pragati Pradhan (St Joseph's College, Darjeeling), Chandreyee Maitra (RRI), Nazma Islam (RRI) and B.C. Paul (North Bengal University), Paul studied the variations in the pulsation and spectral characteristics of the HMXB OAO 1657-415. In this work, they carried out a study of the broadband pulsation and spectral characteristics of the accreting X-ray pulsar OAO 1657-415 with a 2.2 d long Suzaku observation covering its orbital phase range 0.4 to 0.6 with respect to the mid-eclipse. During the last third of the observation, the X-ray count rate in both the XIS and the PIN instruments was found to increase by a factor of more than 10. During this observation, the hardness ratio changed by a factor of more than 5, uncorrelated with the intensity variations. In two segments of the observation, lasting for ~30-50 ks, the hardness ratio was found to be very high. In these segments the spectrum showed a large absorption column density and correspondingly large equivalent widths of the iron fluorescence lines. They also found a dip in the PIN residuals at around 33 keV consistent with the presence of a cyclotron feature around that energy as reported from earlier observations of this source. The pulse profile, especially in the XIS energy band showed evolution with time but not so with energy. In this study, Paul along with his collaborators examined the nature of the intensity variations, and variations of the absorption column density and emission lines during the duration of the observation as against the expected values due to a clumpy stellar wind of the supergiant (SG) companion star.

These results indicate that OAO 1657-415 has characteristics intermediate to the normal supergiant systems and the systems that show fast X-ray transient phenomena.

In a study of the variations of the harmonic components of the X-ray Pulse Profile of PSR B1509-58, the Fourier decomposition technique was used to investigate the stability of the X-ray pulse profile of the young pulsar by studying the relative amplitudes and the phase differences of its harmonic components with respect to the fundamental using data from the Rossi X-Ray Timing Explorer. Like most young rotation powered pulsars, PSR B1509-58 has a high spin down rate. It also has less timing noise allowing accurate measurement of higher order frequency derivatives, which in turn helps in study of the physics of pulsar spin down. The X-ray pulse profile of this source has been analysed for 15 years (1996–2011). Also, the long term average amplitudes and phases of the first, second and third harmonics were measured compared to the fundamental. Significant variation of the harmonic components of the pulse profile in comparison to the fundamental was not found. This work was done by Pragati Pradhan (St Joseph's College, Darjeeling), Biswajit Paul (RRI), Harsha Raichur (RRI) and B.C. Paul (North Bengal University).

Lakshmi Saripalli's areas of current professional research interests lie primarily in radio galaxies, intergalactic medium and large-scale structure surrounding radio galaxies.

In the year 2013-2014 she continued her work related to giant radio galaxies and the large-scale structure surrounding them. Relationships between the galaxy distribution on large scales and giant radio galaxy morphologies were examined both via the overlays as well as dipole and quadrupole Fourier components. This allowed for various interesting conclusions to be drawn on the formation of Giant Radio galaxies and the influence of their environments.

Thereafter she worked on another project with the same radio-optical data on giant radio galaxies to examine the scale-lengths of the distributions of galaxies surrounding giant radio sources using their luminosity functions. Her collaborators in these two studies were Jurek Malarecki (ICRAR, UWA, Australia), Heath Jones (Monash University, Australia), Lister Staveley-Smith (ICRAR, UWA, Australia) and Ravi Subrahmanyan (RRI, India).

With Paola Parma (INAF, Bologna, Italy) Saripalli carried out radio interferometric observations at high frequencies using the Australia Telescope, on a sample of radio galaxies showing signs of restarted activity. This data was analysed and they derived total intensity and polarization maps. The high frequency properties of the radio galaxy sample are being examined in this study. With an aim towards the high frequency study, Saripalli is attempting to model the multi-frequency spectra over the lobes of these galaxies.

In the year gone by, Saripalli also initiated a study of X-shaped radio galaxies in collaboration with Dave Roberts of Brandeis University, USA. High-resolution radio maps were made of a sample of 50 candidate X-shaped radio galaxies. These maps were used to characterize the sources and form subsamples based on radio lobe morphologies. The higher resolution maps allowed a subsample to be formed of strong core AGNs to be further examined with high resolution with an aim of testing formation scenarios for this class of radio galaxies. An observational proposal was made to the European VLBI Network and they are waiting for the schedule of their observations.

Shiv Sethi's areas of current professional research interests are Epoch of Reionization and cosmological implications of primordial magnetic fields.

Over the year gone by his research comprised of mainly 2 themes:
i) HI absorption from the epoch of reionization and primordial magnetic field and ii) observing the EoR using drift scans.

HI absorption from the epoch of reionization and primordial magnetic field: Sethi along with Evgenii O. Vasiliyev have investigated the impact of primordial magnetic fields on the HI absorption from the epoch of reionization (EoR). In particular, they investigated the change in the number of collapsed haloes and heating owing to magnetic field dissipation in these haloes. The results show that the number of haloes in the mass range $10^6 - 10^8 M$ increases by a factor of roughly 100 for magnetic fields with strengths in the range 0:3 – 0:6 nG. The impact of heating is to reduce the observed optical depth in HI absorption by up to 30% but the former effect dominates. They also show that single radio sources of flux 400 mJy in the redshift range 10–14 might suffice to reveal the presence of primordial magnetic fields (Figure 1).

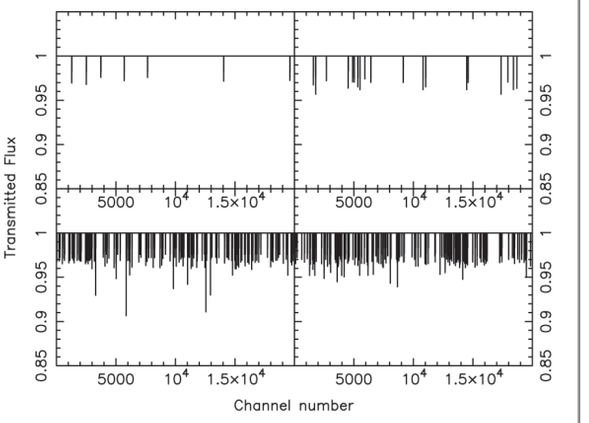
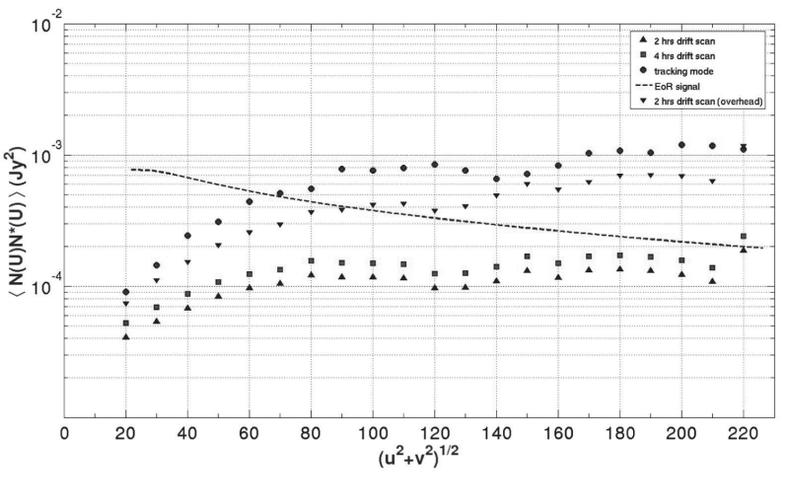


Figure 1

ii) observing the EoR using drift scans: The detection of EoR in the redshifted HI signal remains a challenging task. Sethi along with Paul *et. al.* investigated in detail the efficacy of drift scans to detect this signal using MWA. An advantage of such a strategy is that the system parameters—primary beam, bandpass, etc.–remain fixed during a drift scan. They show that the visibilities measured at two different times could be strongly correlated depending on the region of sky being observed. In particular, they show that for equatorial scans, the visibilities could be correlated for up to an hour. The sensitivity achieved in such a procedure is comparable to the sensitivity in the usual tracking mode (Figure 2).

Figure 2

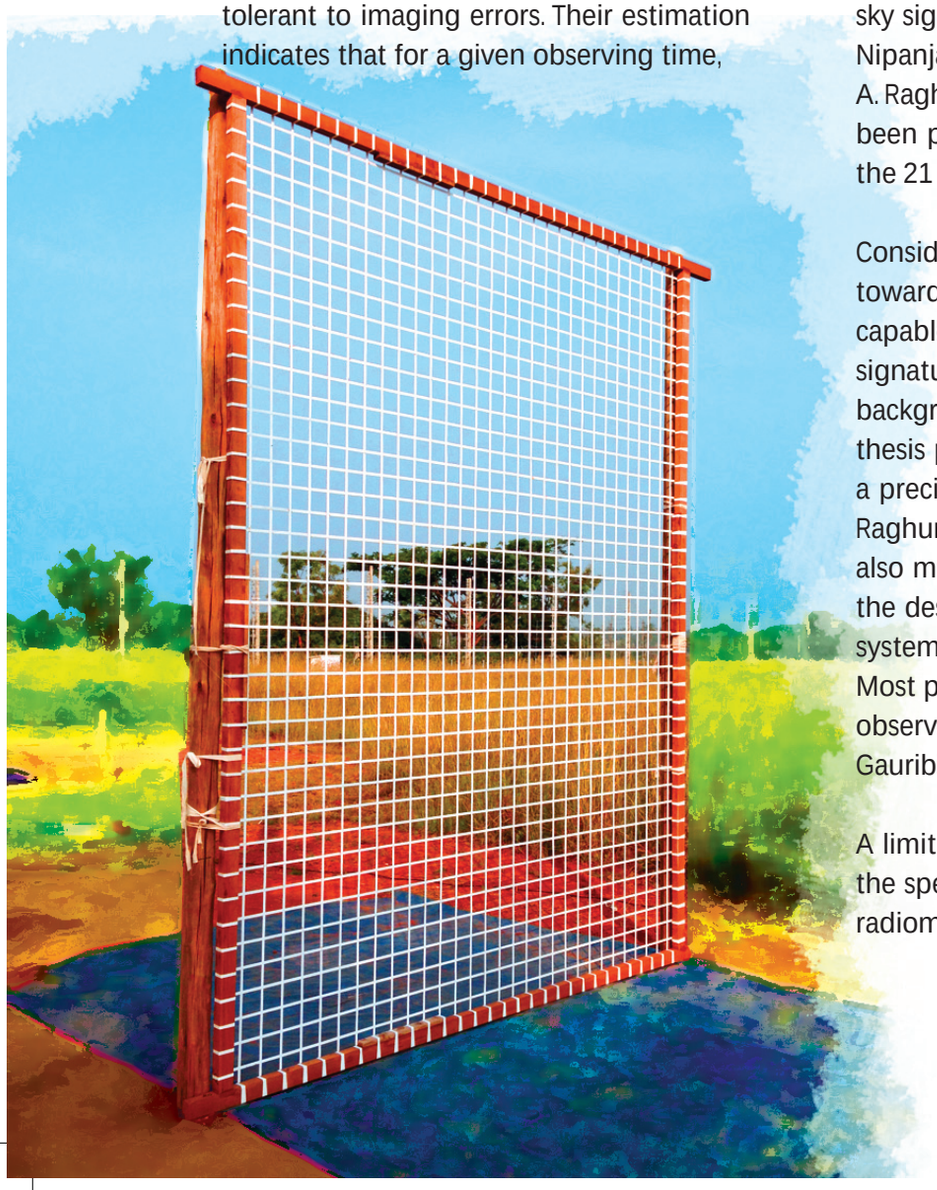


N. Udaya Shankar's areas of current research interests consist of detection of Epoch Of Reionisation (EoR), an array for the detection of Epoch Of Recombination and instrumentation and signal Processing for radio astronomy.

In the period between 2013-2014, in collaboration with Nithyanandan Thyagarajan, Ravi Subrahmanyan and the wider MWA collaboration, Udaya Shankar has worked on the statistical Detection of EoR Signal using Murchison Wide Field Array. The Murchison Wide Field Array (MWA) is a low frequency demonstrator operating in the frequency range 80 MHz to 300 MHz. One of the main scientific goals of this array is to detect signals from the Epoch of Reionisation (EoR). Uday has participated in the investigations of Imaging Modes and strategies for detecting EoR using MWA.

During the last academic year Shankar and his collaborators had initiated work on extending the framework developed earlier by Vedantham, Ravi Subrahmanyan and himself on minimization of foreground contamination in EoR window. As a continuation of this work they explored for the first time the relative magnitudes of three fundamental sources of uncertainty, namely, foreground contamination, thermal noise, and sample variance, in detecting the HI power spectrum from the Epoch of Reionization (EoR). A secondary goal was to understand how these uncertainties compete with each other on different scales in determining the sensitivity of a radio interferometer array. They derived limits on the sensitivity of a Fourier synthesis telescope to detect EoR based on its array configuration and a

statistical representation of images made by the instrument. They used the Murchison Widefield Array (MWA) configuration for their studies. The highlight of this academic year's work has been the development of a unified framework for estimating signal and noise components in the HI power spectrum. Using the framework they have successfully derived an expression for and estimated the contamination from extragalactic point-like sources in three-dimensional power spectrum. They estimated the sensitivity for EoR HI power spectrum detection using different observing modes of MWA. Their results showed that with 1000 hours of observing on a single field using the 128 tiles MWA, EoR detection is feasible. Band-pass shaping and refinements to the EoR window are found to be effective in containing foreground contamination, and also in making it tolerant to imaging errors. Their estimation indicates that for a given observing time, observing many independent fields of view does not offer an advantage over a single field observation when thermal noise dominates over other uncertainties in the derived power spectrum. Estimating the classical source confusion in the images to have been recorded using the MWA from first principles meant that one had to use the source counts known in the literature. When sources above the 5σ classical source confusion threshold were subtracted, the 1σ classical source confusion limit near the zenith was found to be $\simeq$35 mJy for a natural weighting scheme. This work has been published in The Astrophysical Journal and is an MWA collaboration paper that has originated from RRI.



Shankar's second major research theme in the year gone by has been the detection of the all-sky signal from EoR with collaborators Nipanjana Patra (PhD student), Nivedita M., A. Raghunathan and R. Subrahmanyan. RRI has been pursuing an experiment to measure the 21 cm all-sky signal.

Considerable progress was made last year towards the primary goal of building a system capable of a useful measurement of spectral signatures of the EoR in the cosmic radio background. This work constitutes the PhD thesis project of Nipanjana Patra, and developed a precision spectral radiometer called SARAS. Raghunathan, Subrahmanyan and Shankar are also members of the team who participate in the design and development of the receiver system and techniques for the analysis of data. Most part of 2013–14 was used to carry out observations using the system at the Gauribidanur Field Station.

A limiting factor in absolute measurements of the spectrum of the sky with a spectral radiometer is unwanted additive contributions

generated within the receiver electronics. Absolute measurements of the cosmic radio background using a single antenna element as the sensor of the sky radiation will always include emissions from the resistive losses in the antenna and associated balun. Additionally, although switching schemes and correlation receivers do cancel internal sources of receiver noise to a large extent, accuracy in spectral measurements is limited by small magnitude changes in system bandpass, impedance matching and multi-path propagation of internal noise. A way to retain the advantages of interferometers and make absolute measurements of spectral structure in the uniform sky brightness is to construct a space beam splitter that divides and directs the incident sky power into two antennas that form an interferometer pair. The interferometer then responds to and provides a measurement of the common mode power. This concept is called a 'zero-spacing interferometer' and leads to a radiometer concept called ZEBRA. The highlight of this year's work is the design, development and testing of an electromagnetic space beam splitter for this configuration.

The initial investigations have clearly shown that the beam splitter for a zerospacing interferometer requires being lossy and not having 90^{o} phase shift between transmission and reflection coefficients. It was further shown that if the beam splitter sheet has an impedance equal to half the free space impedance (377/2 ohms=1/S; where S is the conductance of the sheet) half the incident power is dissipated in the resistive sheet and the reflected and transmitted waves have half the amplitude (quarter of the power) of the incident EM wave. The change in transmission and reflection coefficients with angle of incidence is exactly what would be expected if the effective conductance of the sheet were assumed to be S/cosine of the angle of incidence. This understanding is important to optimise the performance of the space beam splitter depending on the radiation pattern of the antenna elements used. The resistive sheet beam splitter was constructed as a 10 cm square grid of resistors for proving the concepts developed. Photograph shows the resistor grid, which was constructed using a wooden frame, polypropylene strapping tape and 180 Ohm resistors soldered at the centers of a 10-cm square conductive copper grid. This is a collaborative work with Nivedita M., A. Raghunathan and R. Subrahmanyan, all at RRI.

S. Sridhar's research interests are in stellar and exoplanetary dynamics; dynamo action in turbulent shear flows; magnetohydrodynamic turbulence; Global description of light beams and their geometric phase.

His research work during 2013-2014 includes a theory of the "secular dynamics and statistical mechanics of Keplerian stellar systems bound to supermassive black holes in galactic nuclei." This is a joint work done over many years with Jihad Touma of the American University of Beirut (Lebanon), which is now seeing fruition. They first formulated a theory for collisionless stellar systems, by using a multiple-time-scale analysis to derive a Collisionless Boltzmann Equation for secular, self-consistent dynamics. They presented a "secular Jeans theorem" and explored steady-state stellar distribution functions. Having derived results on linear secular stability of these distribution functions, they turned their attention to collisional processes. The required theory goes well beyond the usual Landau-Chandrasekhar-Spitzer approach, and is based on Gilbert's statistical mechanical treatment of systems with long-range interactions. Sridhar and Touma

have derived a kinetic equation, which they expect will form the basis of an understanding of the process called "resonant relaxation", proposed in 1996 by Rauch and Tremaine. Using this kinetic equation, they have proved an H-theorem on entropy increase, and derived explicit formulae for the fueling rates of mass, energy and angular momentum to the black hole. Three papers are in preparation. Future work in this area aims at a theory of the evolution of star clusters in galactic nuclei, with focus on the Galactic Centre.

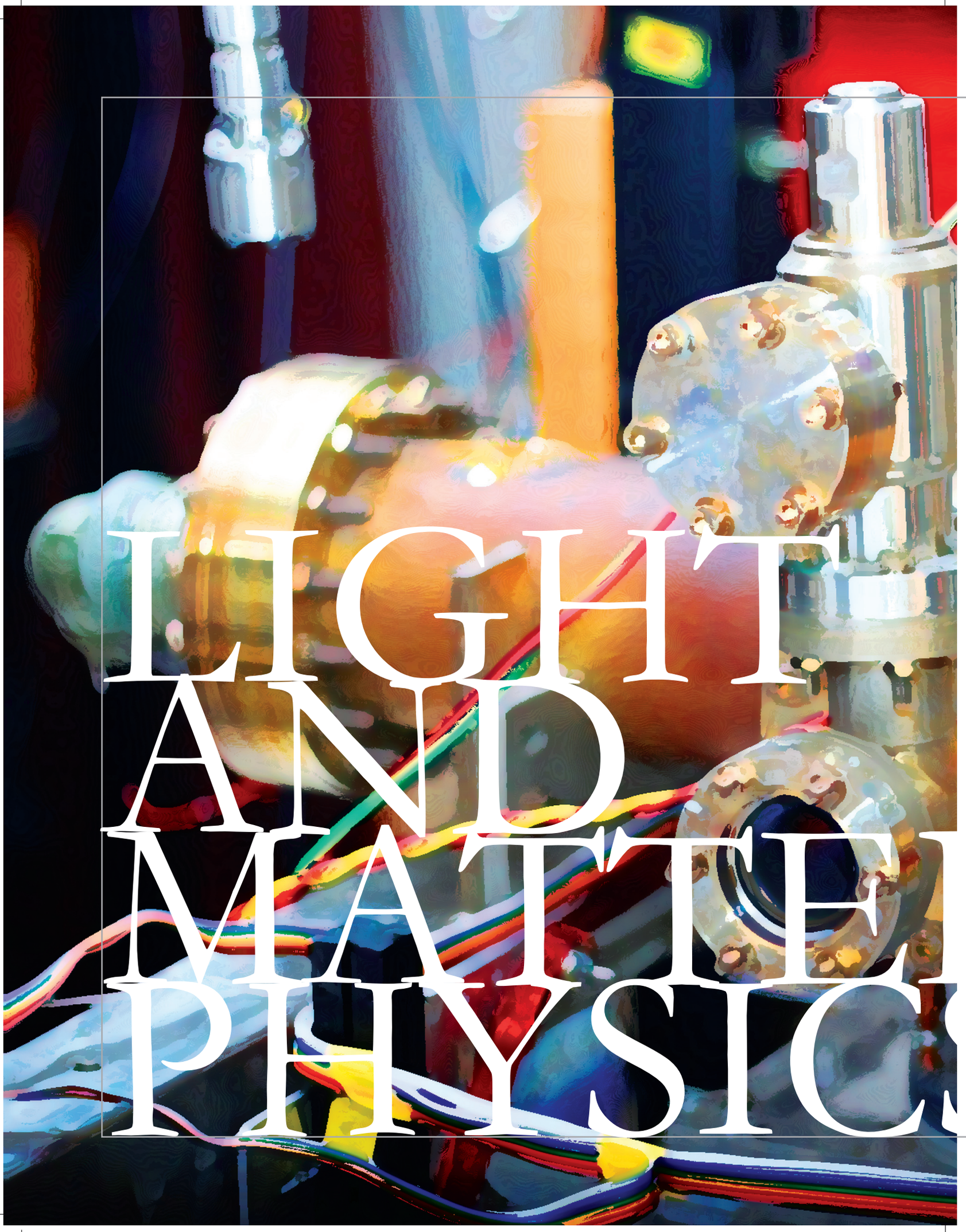
Another major research project for Sridhar during this year has been exoplanetary dynamics, again in collaboration with Jihad Touma. Over the last three years, they have developed a theory for the resonant driving of the secular modes of a multi-planetary system around a primary star, by the orbital motion of its wide-binary stellar companion. Using numerical simulations and analytical calculations, they have demonstrated that this resonant excitation mechanism can induce large eccentricities and inclinations in the planetary system. As evidence they present a phenomenological analysis of the planetary orbital structure observed in the systems Upsilon-Andromedae and 55 Cancri. A paper is in preparation.

With Nishant K. Singh of IUCAA/Nordita, Sridhar has formulated a model of large-scale dynamo action in a shear flow that has stochastic, zero—mean fluctuations of the alpha parameter; this is a minimal extension of the Kraichnan-Moffatt model, to include a background linear shear and Galilean-invariant alpha-statistics. Using the first order smoothing approximation they derived a linear integro-differential equation for the large-scale magnetic field, which is non perturbative in the shearing rate and the alpha-correlation time. Solving the white-noise case exactly, they proved that the necessary condition for dynamo action is identical to the Kraichnan-Moffatt model without shear; this is because white-noise does not allow for memory effects, whereas shear needs time to act. To explore memory effects they reduced the integro-differential equation to a partial differential equation, valid for slowly varying fields and small alpha-correlation time. Seeking exponential modal solutions, they solved the modal dispersion relation and obtained an explicit expression for the growth rate as a function of the six independent parameters of the problem. They demonstrated that memory effects can give rise to new physical scales, and dynamo action is completely different from the white-noise case. Some salient results are (a) even weak alpha fluctuations can give rise to a dynamo, (b) at any wavenumber both Moffatt drift and shear always contribute to increasing the growth rate, (c) a Moffatt drift dynamo in the absence of shear, (d) a shear dynamo in the absence of Moffatt drift. A paper has been submitted to *MNRAS*.

Mayuri S. is interested in the research problem of simulation and feasibility studies to experimentally detect spectral signatures from the Epoch of Recombination. Along with R. Subrahmanyan and N. Udaya Shankar, Mayuri has been working on developing a pipeline to simulate the output of a spectral radiometer system recording sky noise to obtain all-sky spectra. The question that is being pursued is whether it is at all possible to detect faint recombination spectral features with nano-Kelvin brightness temperature variations with frequency in the presence of almost eight orders of magnitude larger foregrounds that constitute the cosmic radio noise from the Galaxy and extragalactic sources.

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.

The feasibility of detection of cosmological recombination lines is examined by modeling the sky spectrum as recorded by an ideal instrument, including calibration. Emphasis is on examining whether it is at all possible to recover the weak signals embedded in the substantially brighter Galactic and extragalactic foregrounds. Methods for fitting to data for the recovery or detection of the faint recombination line spectrum when observed embedded in the substantially brighter cosmic radio background are discussed. Also the optimum observing frequencies for the detection and associated signal-to-noise ratio for detection with realistic receivers and a purpose-built array of spectral radiometers are estimated. Inputs to the simulation include parameters such as the observing location, integration time, antenna characteristics, an all-sky model and a model for the cosmological recombination lines.
The detection of faint spectral features in the cosmic radio background is a more general problem and solutions to the detection of cosmological recombination lines is of relevance to the detection of cosmological features from the epoch of reionization as well. The receiver designs and antenna designs also require similar considerations, although in different parts of the radio band. The entire class of these problems is of interest to RRI members and hence is a collaborative effort of several members of the group.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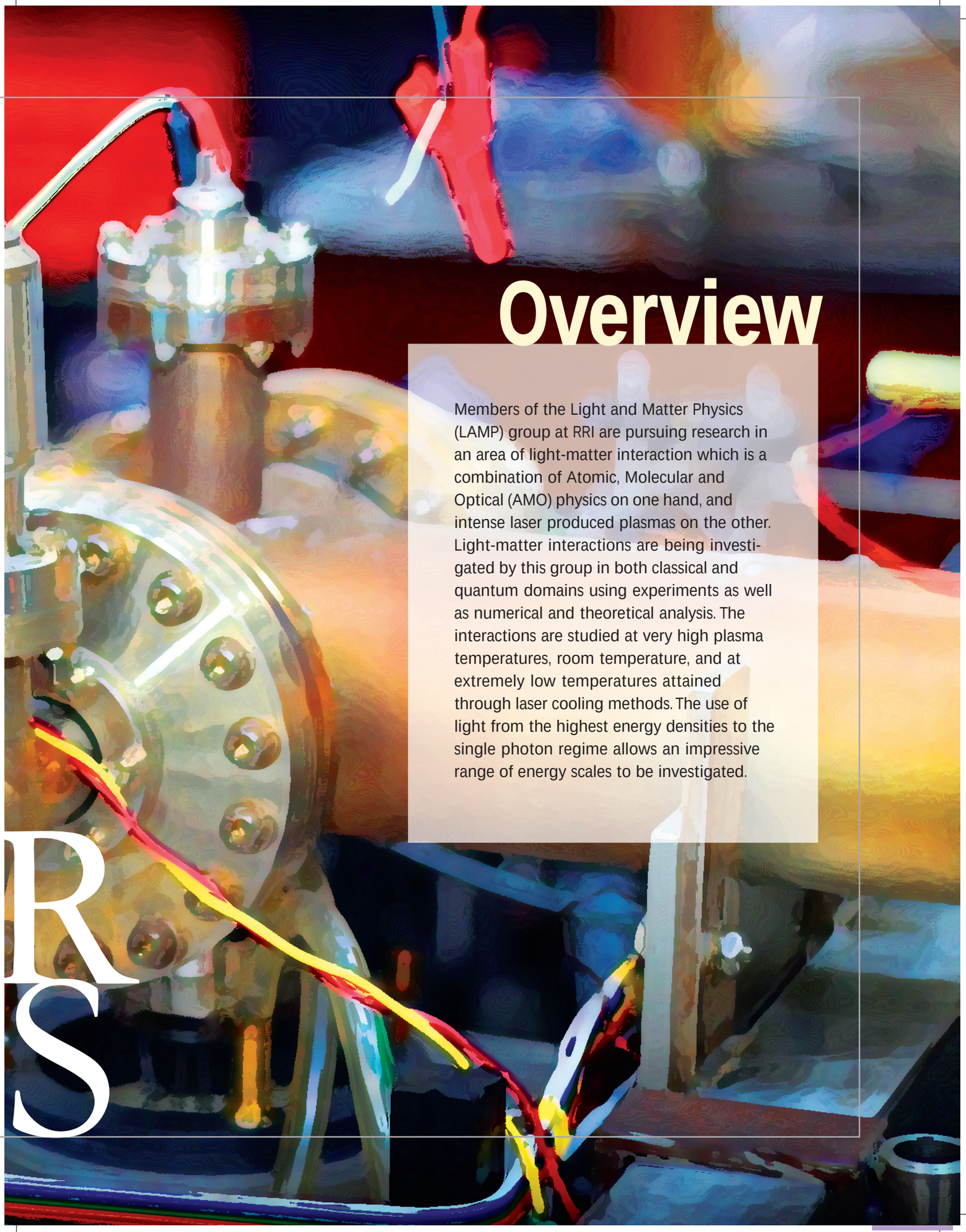

Overview

Members of the Light and Matter Physics (LAMP) group at RRI are pursuing research in an area of light-matter interaction which is a combination of Atomic, Molecular and Optical (AMO) physics on one hand, and intense laser produced plasmas on the other. Light-matter interactions are being investigated by this group in both classical and quantum domains using experiments as well as numerical and theoretical analysis. The interactions are studied at very high plasma temperatures, room temperature, and at extremely low temperatures attained through laser cooling methods. The use of light from the highest energy densities to the single photon regime allows an impressive range of energy scales to be investigated.

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Current Research Interests

The research of the LAMP group stresses on demonstration of quantum logic using ultra-cold atoms loaded in optical lattices and various nano-traps, investigation of transport and localization properties of light in various random media, ultrafast laser induced plasmas from solid targets, nonlinear optical properties of nanomaterials, laser cooling and trapping of atoms, molecular spectroscopy, cold collisions, investigations on spin statistics, ion trapping, atoms in cavities, response of cooled atoms to external fields, quantum optics with neutral atoms and non-classical light sources, quantum walk of light, manufacture of single photon sources based on spontaneous parametric down-conversion and their applications to fundamental tests of quantum mechanics, quantum information and computing and quantum communication, etc. Currently, quantum logical gates are being designed by tailoring the internal degrees of freedom of quantum optical tools in external potentials.

A more detailed picture of the particular research topics currently in focus at the LAMP group can be found below.

Quantum Optics

Quantum optics is a field of study in physics that applies quantum mechanical tools to understand phenomena involving light and its interaction with matter. Major fields of interest in quantum optics include manipulation of elemental particles like atoms, ions and molecules and the use of quantum optics to build further upon our current understanding of quantum information. Quantum coherence transfer between atoms and light and creation of new quantum states of light and matter are some of the other questions being actively pursued at the moment. For this purpose, experiments involving low-intensity probes for atoms prepared in a superposition state and Quantum Non-demolition (QND) measurements of quantum superposition states have been designed.

Another line of quantum optics research in LAMP focuses on the creation and manipulation of quantum correlations, and their transfer from photons to material objects. These material objects range from being in a state which is gaseous, with a dilute collection of loosely bound atoms, to solid state objects which have micrometer dimensions like a micromechanical spring. A comprehensive study of photon-matter interactions with such a dynamic range in sizes and states of matter is carried out to answer how quantum properties are created, stored and retrieved in such diverse systems. This research may also unravel fundamental constraints involved in creating quantum properties in matter with mesoscopic dimensions existing at room temperature. A preoccupation of quantum effects in light and matter has led the LAMP group to naturally explore some foundational questions in quantum mechanics. One such area of current interest is the area of Quantum measurements. The group is studying weak measurements and weak value amplifications in atom-photon interactions both theoretically and experimentally.

Laser cooling and trapping

Laser cooling and trapping is a fairly novel technique that has gained huge popularity throughout the world of physics since the last decade. Presently, atoms can be cooled to extremely low kinetic temperatures (150 microK) and trapped for a time period of the order of seconds. There are some techniques to cool and trap atoms of alkaline elements, the most common one being Doppler cooling. In Doppler cooling, three mutually perpendicular laser beams are made to intersect at the centre of a chamber while a pair of magnetic coils produces a magnetic field that is zero at the centre of the chamber but increases radially outwards. Tuning the wavelength and polarization 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 laser beams and the spatially varying magnetic field. In other words, Doppler cooling involves a Magneto Optical Trap (MOT). Electromagnetically induced transparency and related phenomena and nature of fluctuations in a collection of cold atoms are being studied at the Laser cooling laboratory.

Hybrid trapping of atoms and ions

A hybrid trap experiment is one that combines cold atoms, ions and molecules and studies their interactions to great accuracy. Research at RRI has 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. Ion-molecule processes have also been investigated to show a rich variety of very interesting phenomena.

Cavity physics and Cavity QED

Hybrid trap experiments, as mentioned above, can access the quantum electrodynamic regime for atom-electromagnetic field interactions. Using cold ions, atoms and molecules simultaneously cooled and trapped with photons in a high Q optical cavity, the non-classical nature of atom-field interactions are being tapped. This is the first such experiment of its kind and provides a complete system for the study of cold dilute classical and quantum gases.

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. EIT can be observed when two highly coherent lasers are tuned to interact with three or more quantum states of a material. A concerted effort is on at RRI to understand this phenomenon both from a theoretical and experimental point of view.

Quantum walks of light

Just as the mathematical formulation of a classical random walk is used in search algorithms where the search parameter is random, so also quantum walks, which are the equivalent of random walks in quantum computing, can be mathematically made to be a part of a quantum algorithm. The LAMP group is currently investigating the frequency space of quantum walks.

Light propagation in random media

Multiple scattering of light in random media, like fog, reduces visibility because propagation of light in random media is diffusive rather than ballistic. This in turn leads to some interesting phenomena like mirrorless lasing, Levy statistics and weak and strong localization. Experiments using colloidal suspensions of dielectric or magnetic microspheres, both active and passive, as well as Monte Carlo simulations and theoretical analyses are the different methods being employed to probe this process of light propagation.

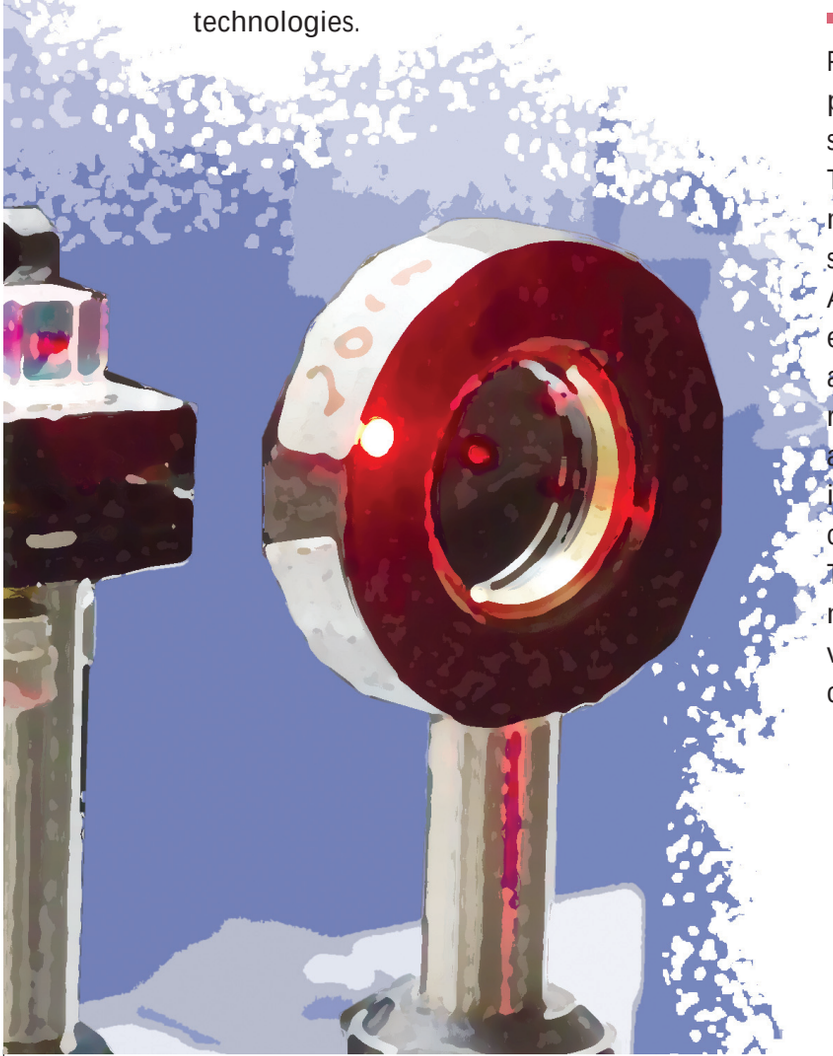
Fundamental tests of quantum mechanics

Quantum mechanics is a cornerstone of modern physics. Just as the 19th century was called the Machine Age and the 20th century the Information Age, the 21st century promises to go down in history as the Quantum Age. However, can we really claim to fully understand quantum mechanical principles? How much do we really believe of what we know? Answers to such questions require us to revisit the fundamental postulates of quantum mechanics and perform precision theoretical and experimental investigations to come up with the right bounds. In the LAMP group, a part of the focus is to attempt such investigations using single light particles, or in other words single photons, as tools. Such tests carry a lot of portent in the current theoretical physics scenario where a lot of importance is being given to unification of quantum mechanics and General Relativity. Such unification attempts would also be benefited if one can have a more precise understanding of the principles involved in at least one of the theories, i.e. quantum mechanics.

Quantum Information and Quantum Computation

The main thrust here is research on aspects of quantum information and quantum computation. The systems of choice are qutrits (three dimensional quantum systems), based on spatial degrees of freedom of the single photon. The LAMP Group is one of the first labs in the country to develop the technology of single photon sources based on spontaneous parametric down conversion in bulk non-linear crystals. The single photons and their various degrees of freedom are used to investigate aspects of quantum optics and quantum information.

Photons are massless, charge-less particles and as such perfect for communication purposes. In the near future, the LAMP Group wishes to enter the domain of quantum communication and develop both terrestrial and satellite based technologies.



Nonlinear optics

Nonlinear optical (NLO) transmission of materials finds applications in optical switches, optical limiters and saturable absorbers. Materials show tunable, enhanced characteristics in the nano phase, which can be very different from their properties in the bulk form. Optical nonlinearities of nanoparticles and nanocomposites are being investigated in the LAMP group. Ultrafast (100 fs) and short (5 ns) laser pulses are employed to identify features of nonlinearity in different time domains. In addition to demonstrating prototype NLO devices like mesoscopic nanocarbon based optical diodes, these investigations have also thrown new light into the role of lattice defects in determining the nonlinear absorption behaviour of materials like Graphene.

Laser induced plasmas

Plasma, the fourth state of matter, is routinely produced in the LAMP labs by irradiating suitable targets with powerful pulsed lasers. These plasmas, which exist only for a few microseconds, can be considered as short-lived stars and their study is often called 'Laboratory Astrophysics'. Ultrafast laser produced plasmas ejected from metal targets irradiated in vacuum are found to contain electrons, ions, visible radiation, and high-energy photons in the soft and hard X-ray regimes. Spectroscopic investigation of the plasma is used to identify constituent elements of an unknown target. Temporal evolution of the plasma studied in the nanosecond regime gives information on the velocity and recombination rates of the constituent ions and electrons.

Ongoing Research

Reji Philip's areas of research interests include nanomaterials for nonlinear optics, and laser produced plasmas.

During the year gone by his research consisted of 3 major pieces of work, one falling under the broad category of nonlinear optical (NLO) materials and the other two under laser-produced plasmas.

With his team of doctoral students and visiting students, Philip has investigated optical nonlinearity in nanostructured and other materials. His collaborators Prof. A. M. Rao (Clemson University, USA) and Prof. Tae Joo Park (Hanyang University, South Korea) synthesized and characterized some of these materials, while their nonlinear optical measurements and analysis were done completely in Philip's lab.

An important work done under the NLO theme led to a publication in *Nano Letters,* which discusses the realization of optical diode action in an all-carbon solid-state device using thin films of Graphene and C_{60} [B. Anand *et. al*., *Nano Letters* **13**, 5771 (2013)]. Another interesting work is the single-scan measurement of the spectral dispersion of ultrafast optical limiting in the laser dye Coumarin-120 using a white light continuum (WLC) as the light source (the conventional method, which is a time-consuming and tedious process, uses a tunable laser) [B. Anand *et. al*., *Appl. Phys. Lett.* **102**, 203302 (2013)]. In addition they have investigated optical nonlinearity in pristine and doped semiconductors (Se, ZnO hybrids, ZnS:Cu), core-shell nanostructures (Se/C, Te/C, Se-Te/C), nanocomposites (Ag:ZrO_2, Ni/NiO, Co/Co_3O_4), nanoferrites, and boron-doped carbon nanotubes. The role of defects in the nonlinear optical absorption behavior of several Carbon and ZnO nanostructures, which they investigated in the recent past, was consolidated and published as a perspective article in *Phys. Chem. Chem. Phys.* [Anand *et. al*., *PCCP* **16**, 8168 (2014)].

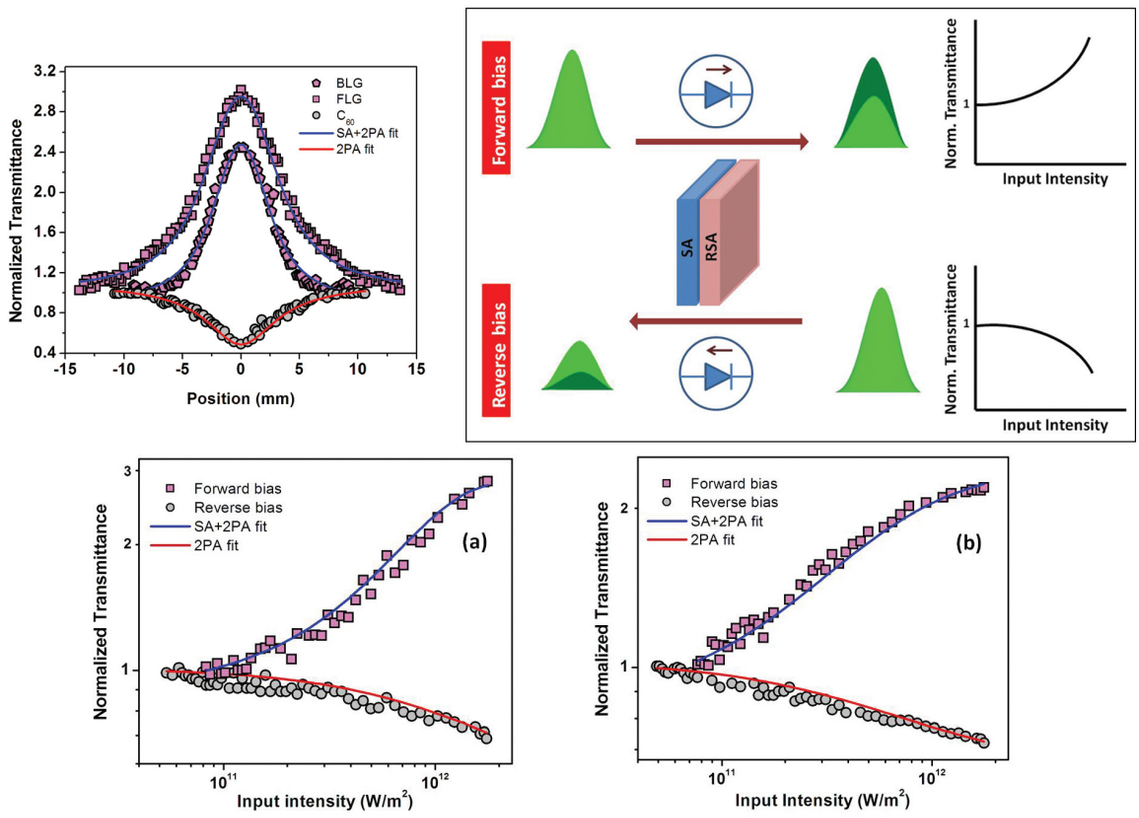


Fig.1 Graphene is a "saturable absorber" (SA) and C_{60} is a "reverse saturable absorber" (RSA). When an SA and RSA are sandwiched it becomes an optical diode, showing unequal transmissions in opposite directions. The degree of nonreciprocity increases with input light intensity. Micron-thick films of Graphene and C_{60} are used to make this all-carbon, solid-state device, which is small in size [from B. Anand et.al, Nano Letters ***13****, 5771* (2013)].

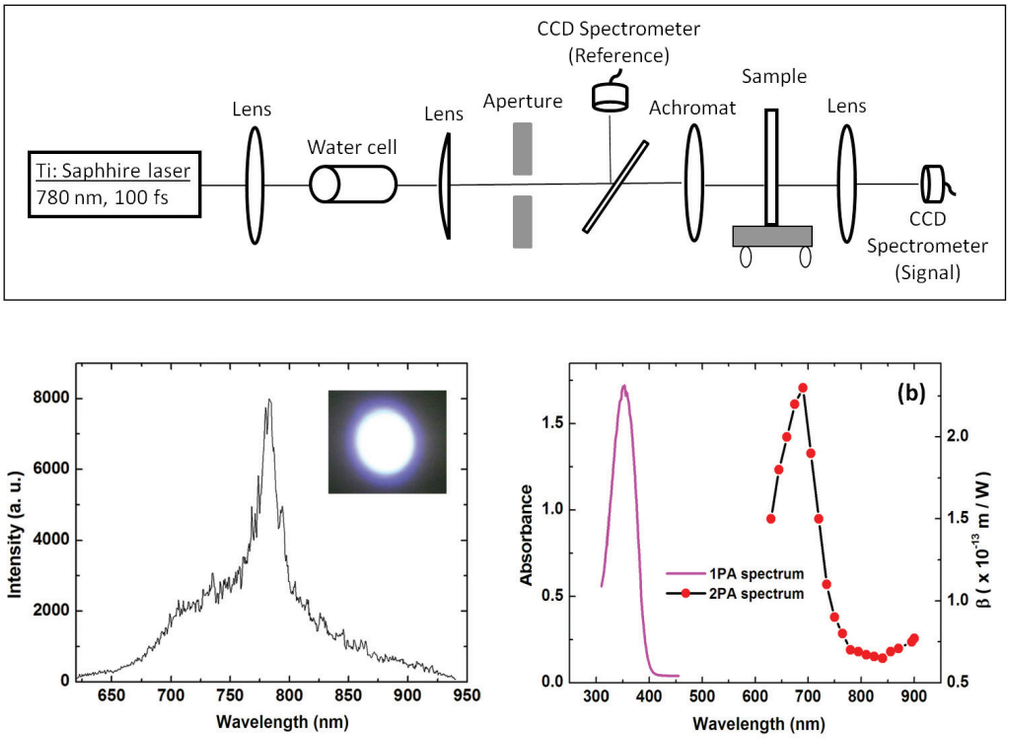


Fig. 2 A "white light continuum" (WLC) can be generated by irradiating media like water by ultrafast laser pulses. The continuum extends from 650 to 900 nm in our case. Here the WLC Z-scan experiment is used to extract the two-photon absorption spectrum of Coumarin-120 molecule from a single measurement. Conventional methods using tunable lasers are time-consuming and tedious in comparison [from B. Anand et.al, Appl. Phys. Lett. ***102****, 203302* (2013)].

Under the second broad research theme of spectroscopic studies of ultrafast laser-induced plasmas, in the year gone by, Philip has worked on plasmas from solid targets and from thin films.

For the case of plasma from a solid target Philip and his team have generated ultrafast (100 fs) and short-pulse (7 ns) laser produced plasmas from a solid nickel target, and compared the temporal features of plume expansion into a nitrogen background (pressure variable from 10^{-6} Torr to 10^{2} Torr). Time of flight (TOF) spectroscopy of emission from neutral nickel (Ni I) at 361.9 nm ($3d^9(^2D)\,4p \rightarrow 3d^9(^2D)\,4s$ transition) reveals two peaks (fast and slow species) in short-pulse excitation and a single peak in ultrafast excitation. The fast and slow peaks represent recombined neutrals and un-ionized neutrals, respectively. TOF emission from singly ionized nickel (Ni II) studied using the 428.5 nm ($3p^63d^8(^3P)\,4s \rightarrow 3p^63d^9\,4s$) transition shows only a single peak for either excitation. Velocities of the neutral and ionic species are determined from TOF measurements carried out at different positions (i.e., at distances of 2 mm and 4 mm respectively from the target surface) on the

plume axis. Measured velocities indicate acceleration of neutrals and ions, which is caused by the Coulomb pull of the electrons enveloping the plume front in the case of ultrafast excitation. Both Coulomb pull and laser-plasma interaction contribute to the acceleration in the case of short-pulse excitation. These investigations provide new information on the pressure dependent temporal behavior of nickel plasmas produced by short-pulse and ultrafast laser pulses, which have potential uses in applications such as pulsed laser deposition (PLD) and laser-induced nanoparticle generation. These results have been accepted for publication.

For the case of plasma from a thin film, in collaboration with Prof. Ajai Kumar of Institute for Plasma Research (IPR), Ahmedabad, Philip and his team investigated plasma plume formation and its expansion into a background gas (1 mbar nitrogen) in a 50 nm thick Ni thin film under the laser blow-off (LBO) geometry, employing 10 ns, 200 ps and 100 fs laser pulses. Plume directionality and splitting are found to depend on the laser pulse width. Plume expansion involves the expulsion of molten matter in jet form where the film thickness and pulse width determine the jet parameters. Plume evolution follows different models at different pulse widths. These investigations have potential applications in pulsed laser deposition and ultrafast laser based nanoparticle generation. Results have been communicated for publication.

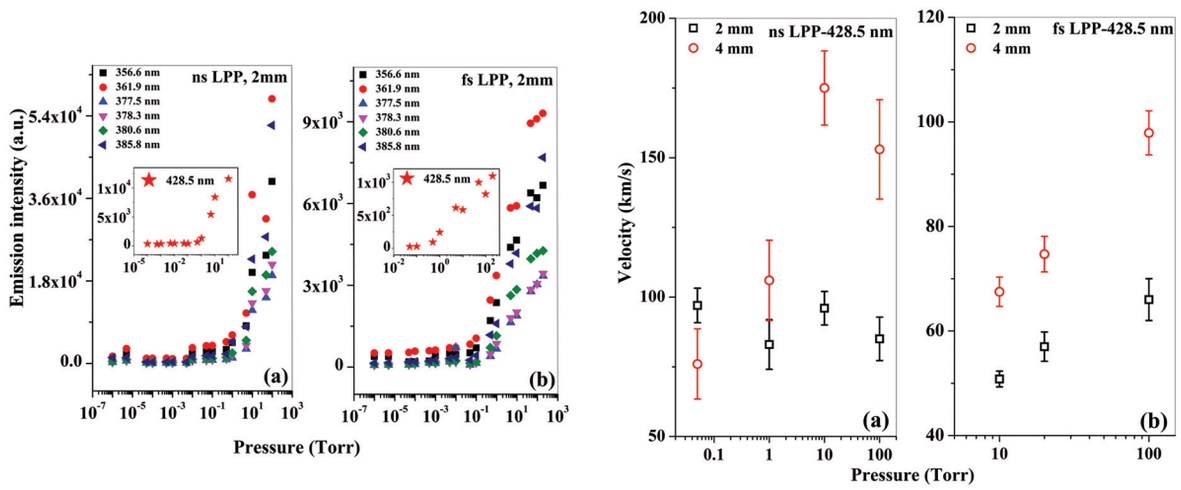


Fig. 3 Intensity of the laser produced plasma (from a solid nickel target) increases with background pressure for short-pulse (5 ns) as well as ultrafast (100 fs) excitations. From time of flight (TOF) measurements done on the plume axis at different positions, velocity of ablated species – neutral as well as ionized – can be determined. Figure shows that for fs excitation the singly ionized nickel species (Ni II) undergoes a field-induced acceleration close to the target surface [from Time of flight emission spectroscopy of laser produced nickel plasma: short-pulse and ultrafast excitations, by N. Smijesh, K. Chandrasekharan, J. C. Joshi, and R. Philip, manuscript accepted for publication in the Journal of Applied Physics].

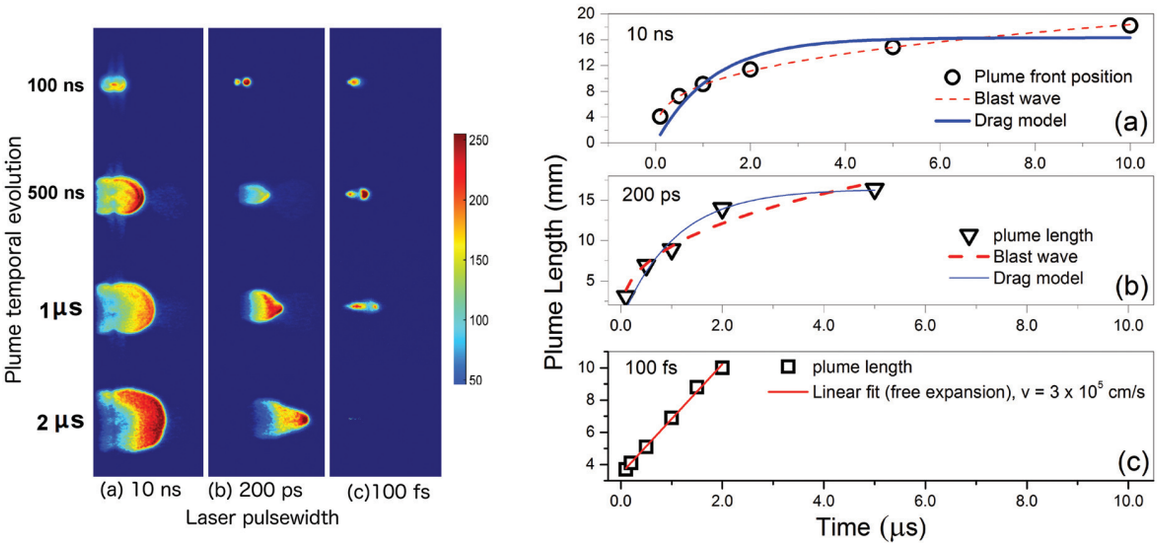


Fig. 4 Time evolution of laser-induced plasma plumes generated in a Ni thin film depends critically on the laser pulse width. While plumes generated by 10 ns and 200 ps pulses can be fitted to blast wave and drag models, that by 100 fs pulses fit to a free expansion model [from Pulse width dependent dynamics of laser-induced plasma from a Ni thin film; by J. Thomas, A. Kumar, T. Priya Rose, and R. Philip, manuscript submitted for publication]

Reji Philip and his team have used the Institute's FESEM a few times for their research. The ultrafast laser system consisting of a 100fs Ti:Sapphire laser was used extensively for spectroscopic studies of ultrafast laser-induced plasmas from a solid nickel target and Ni thin film, ultrafast optical nonlinearities in Selenium allotropes and white light Z-scan measurements in Coumarin-120. On the other hand, the short-pulse laser system consisting of a 5ns Nd:YAG laser was used for optical limiting in several materials, listed in the first research theme he has pursued this year.

Andal Narayanan's current professional research interests are quantum optics and laser cooling of atoms.

An important work for Narayanan in the past year has been slowing down a pulse of light with a room temperature collection of atoms which are in a double Lambda configuration of its internal levels using quantum coherence between the levels.

It is possible to slow down a pulse of light by altering the nature of its refractive index profile. As is well known, around resonant absorption in a medium, a light pulse will undergo anomalous dispersion. In anomalous dispersion, the change in refractive index around resonance for a given positive change in frequency is negative (slope of the refractive index profile is negative.) By making the slope positive one can slow down the group velocity of a pulse of light traveling in

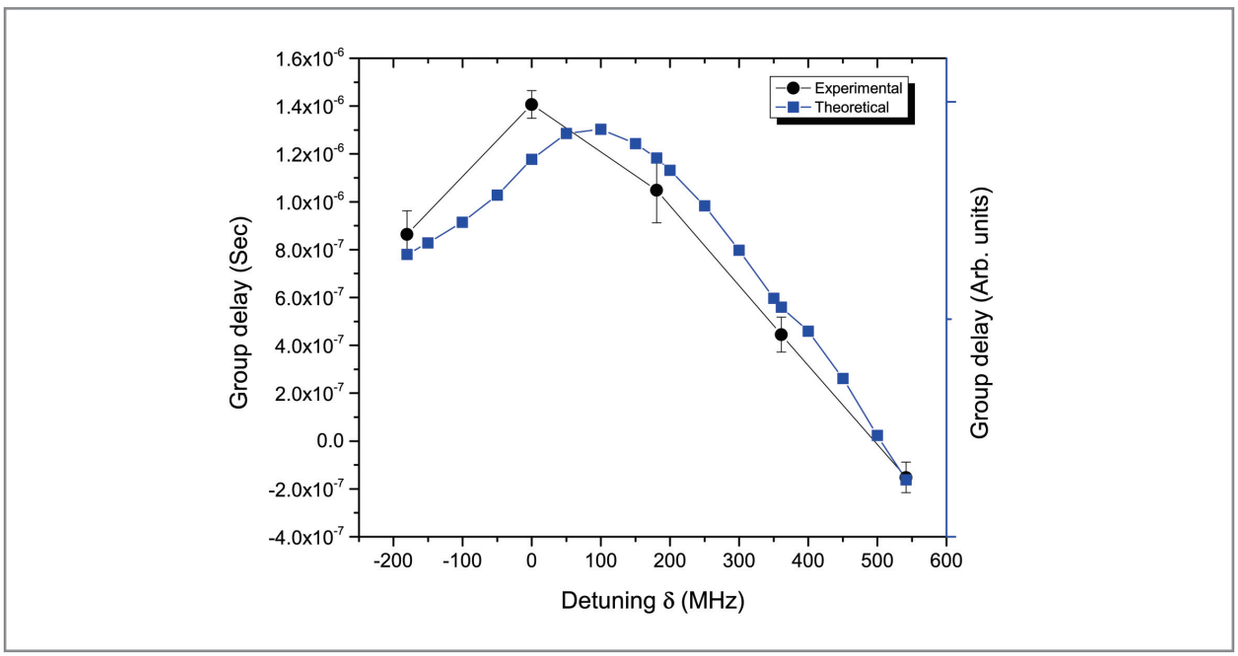
the medium. If there are nearby levels to the pair of levels undergoing resonant transition, then possible Quantum Coherence (QC) between the levels can drastically alter the absorption properties and hence the refractive index seen by the light. As an example, it can make the slope of the refractive index profile positive with a high gradient. Such refractive index profiles slow down a pulse of light traveling in the medium.

Narayanan along with her collaborators Asha K. (Former VSP student), Vineetha N.V. (Project Assistant), Nagendra G.M. (VSP student) and Krishnapriya S.R. (VSP student) have experimentally slowed down a pulse of light in Rubidium vapour at room temperature. This was a continuation of their earlier work in which they had successfully slowed down a pulse from its vacuum counterpart time travel, by about 600 nanoseconds (ns) for a specialized system of levels known as the Double Lambda configuration. The current work was done with a view to understanding and exploring the slowing down of a light pulse in the presence of gradient magnetic fields and Doppler broadening. They have managed to produce a maximum and consistent slowing down of a light pulse by about **one microsecond** in relation to its travel time in vacuum.

They now have experimental data (shown in the figure below with x axis in MHz units) to suggest that one of the Lambda level structures of the double Lambda configuration has an opposing contribution to the slowing down phenomena and that, it looks as if, the light pulse might actually be speeding up at specific detunings of the laser light frequency from the excited states of the double Lambda system. What this speed up actually signifies in terms of relative phases of the interacting double Lambda system is currently being analyzed.

Narayanan's second major area of research this year has been in the field of cavity opto-mechanical systems and their analogy to atom-field interactions.

Cavity opto-mechanical systems are a class of systems whose working principle involves a high finesse cavity coupled to a single mode of



mechanical oscillation, which also has a high Quality (Q) factor. These systems span a huge dynamical range in sizes of cavities and frequencies of mechanical oscillations. They are typically used as sensors to detect extremely weak forces. Applications range from detection of Gravity waves to highly sensitive measurements using an Atomic Force Microscope (AFM). Recently, this system has acquired a quantum regime of operation, with the experimental achievement of cooling the mechanical oscillator down to its quantum ground state of oscillation. It is now possible to transfer quantum light signals from the cavity light field to the mechanical oscillator and back. This enabled cavity optomechanical devices to be potentially looked upon as quantum "macroscopic" devices, in which Quantum Optical phenomena can be realized even in mechanical modes containing many atoms.

Narayanan and her collaborator, Satya Sainadh U. (Research Assistant, RRI) studied a dual cavity and a spring system in the aforementioned quantum regime. In the recent past, these systems have been shown to facilitate transfer of quantum state of one cavity to the other without much dissipation. This was achieved using a dark eigen mode of the dual cavity spring systems. The specific question to be addressed here involved quantifying the vulnerability of this system to unwanted couplings to more than one mechanical mode. A simple case was chosen where the dual cavity coupled to two mechanical springs instead of one. Narayanan has worked out the quantum fidelities of state transfer between the cavities with the additional spring mode present. She showed that even in this very minimal case of coupling to one extra mechanical mode, the fidelity of quantum state transfer fell below 0.5. This is a limit set for practical use of quantum information through practical channels, which suffer both amplitude decay and phase, decoherence. This work appeared in *Physical Review A*.

In the year gone by Narayanan has also investigated the phase sensitive microwave controlled amplification of quantum optical transmission of light.

For the past two years, Narayanan and her collaborators, Satya Sainadh U. (Research Assistant, RRI), Manu Kumar M. (Visiting Student from IQC, Singapore), Prof. Barry Sanders (IQST, Calgary, Canada), Asha K. (Former VSP student, RRI) and Raghunathan A. (RAL), have expanded their research theme based on Electromagnetically Induced Transparency (EIT) effect, to an entirely new area of transfer of quantum correlations from one frequency to another frequency based on EIT effect. This is made possible because, Rubidium atoms with which the bichromatic light fields interact to create the EIT effect have a magnetic dipole transition in the microwave regime. Connecting this transition with a microwave field gives rise to a Delta system. This system has many interesting properties. As a part of the current project they are experimentally investigating amplification of the EIT transmission in an optical field, controlled by the relative phase between the optical and microwave fields. Such amplification processes have far reaching consequences towards transfer of quantum correlations between disparate frequency regimes of the electromagnetic field. With their home built microwave cavity, they have tentative signatures of amplification in the optical field. Studies are on to confirm the precise nature of this amplification in the coming few months.

Hema Ramachandran's research interests lie primarily in few photon-few atom systems, light in random media and brain computer interfaces.

Within the first research theme, few-photon few-atom systems, her research during the year gone by comprises of two major pieces of work.

Ramachandran and her collaborators, Deepak Pandey (Research Student), N. Satapathy (Research Student), B. Suryabrahmam (Research Student) and S. Ivan (Postdoctoral Fellow), who recently developed the technique of imparting phase and intensity fluctuations to light by acousto-optic interaction, have now optimized the technique leading to the creation of several classical states of light having non-Gaussian intensity statistics. The technique allows for the rapid and precise tuning of the correlation of photons by electronic means. They have also proposed the creation of a new non-classical state by this technique – the Single Photon Added Non-Gaussian state (SPANG). This work has been accepted for publication in *European Journal of Physics – Plus*.

Along with D. Pandey, M. Shafi (Research Assistant), B. Suryabrahmam, B.S. Girish and Meena M.S., Ramachandran has also measured the intensity-intensity correlation of light from a collection of cold atoms in a magneto-optical trap. Thermal sources of light are known to emit photons in bunches, such that the correlation the intensity of light received at two detectors (g2) shows a peak at zero delay, that falls off with increase in time delay (t). Thus, one may theoretically show that g2(0) = 2, for a thermal source while g2(t) = 1 for all t for a coherent source. For the purposes of this study, with light from a collection of cold atoms in a magneto-optic trap, they obtain g2(0) = 2 +/- 0.2. They have also studied the variation of g2(t) vs t as function of the detuning of the cooling laser, and find a systematic variation, that is being interpreted in terms of temperature of the collection of the atoms.

Under her second broad research theme, light in random media, Ramachandran's research consisted of the following four major problems.

The need to image a light source at a distance of about a kilometer is frequently encountered in airborne, maritime or terrestrial navigation. This problem was addressed by conducting field experiments, with a source of light atop a tower, 1.5km away from the laboratory. A large volume of data was acquired under various visibility conditions, and analysed using a variety of polarisation-based quantifiers. It was shown that a significant improvement in the contrast could be achieved by the use of a polarized source and a polarimetric camera, especially in the presence of high background illumination levels, as is the case in daytime (due to sunlight), or in night-time (due to scattering of unpolarized ambient light by the atmosphere). Ramachandran's collaborators in this project were Julien Fade, Swapnesh Panigrahi, A. Caræ, L. Frein, C. Hamel and Mehdi Alouini (all from University of Rennes) and Fabien Bretenaker (from University of Paris). This work has been accepted for publication in *Applied Optics*. A patent for this technique of using long range imaging under poor visibility has been applied for.

An alternate technique of imaging through diffuse media utilises an intensity or polarisation modulated source, and a lock-in detection at the receiver. Along with James Mathew (Research Assistant), Sriram Sudarsanam (Visiting Student), Julien Fade, Swapnesh Panigrahi and Mehdi Alouini, Ramachandran's current efforts are directed

towards obtaining images in realtime, using a CCD camera and software-based frequency determination. They have evaluated several techniques, and find fastest imaging capabilities with a matched filter technique. This is being quantified under various visibility conditions. This work has been carried out as part of the Indo-French project – RITFOLD funded by CEFIPRA.

Ferrofluids are known to exhibit several counter-intuitive transmission features under application of external magnetic fields; no single picture explains all features. Ramachandran, Madhuri Kumari (Research Student), Archana Malavalli (Visiting Student) and Vishnu Nair (Visiting Student) have undertaken a systematic study of the magneto-optic effects of the ferrofluid, as a function of its various physical properties. The observed dependence of optical transmission on the relative orientation of the applied field and the polarisation vector, the strong viscosity dependent behaviour, and the variation of the critical field with the saturation magnetisation have shed some light on the underlying processes. The data is being analysed in the light of two models, to ascertain whether either one can explain all observations.

Solutions of laser dyes are typically pumped close to the peak of their absorption. They emit at longer wavelengths. Addition of random point-like scatterers to the dye is known to increase the intensity of emission due to multiple scattering that enhances the path length of the emitted photons and hence the stimulated emission in the system. In the process of up-conversion emission, however, the dye is pumped at the long wavelength tail of its absorption, and emission occurs at shorter wavelengths. In the past one year, Ramachandran in collaboration with Madhuri Kumari (Research Student), Rithika Kumble (Visiting Student) and Ashvini Purohit (Visiting Student) has examined whether a similar enhancement of up-conversion emission takes place upon addition of scatterers. It was observed that in contrast to the earlier case of usual dye emission, the addition of particles was found detrimental to up-conversion emission. Monte-Carlo simulations of light transport through this system are underway to understand the difference in the underlying mechanisms in the two cases.

Brain Computer interfaces constitute the third research theme for Ramachandran during the past year. More details on this are given in the Facilites section under the Electronics Lab.

Sadiq Rangwala's areas of current professional research interests include ultra-cold molecules and ultra-cold dipolar molecules and their quantum interactions.

During the year gone by his research included a measurement of the collision-rate coefficient in collisions between ions and ultra-cold atoms in a magneto-optical trap. This study performed along with collaborators Seunghyun Lee and K. Ravi was aimed at measuring 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. 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 ionization and ion-atom collisions, and an expression for the ion-atom collision-rate coefficient is derived. 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. Finally, the scope of the experimental technique developed is discussed in the publication in *Phys. Rev. A* that resulted on the basis of this work.

Trapped dilute gas systems at ultra-cold temperatures allow for specific state preparations 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, realized in recent times, can be potentially used to probe chemical processes like never before. In Rangwala's study, he along with his collaborators, Lee, Jyothi S. and Krishna Rai Dastidar of Indian Association for the Cultivation of Science investigate the creation and the dissociation of an ultracold molecule, in trapped mixtures of ions and neutrals. Highly excited vibrational states of ultra cold rubidium (Rb_2) molecules are created by photoassociation (PA) of magneto optically trapped (MOT) Rb atoms, which overlap with the trapped Rb^+ ions. The molecules exhibit signatures consistent with dissociation in the mixture and the "product" free atoms are recaptured by the MOT resulting in enhancement of the MOT fluorescence. The mechanism for dissociation of the vibrationally highly excited molecule in collision with an ion is understood by a first principles model, which accounts well for the experimental value of their inelastic collision rate coefficient. This manuscript is under revision.

During the past year Rangwala in collaboration with Tridib Ray, S. Jyothi and N. Bhargava Ram, worked on the design and implementation of a thin wire ion trap meant for studying ion-atom collisions within a Fabry Perot cavity. The thin wire Paul trap with tungsten wire electrodes traps ions. The ion trap geometry, though compact, allows large optical access enabling a moderate finesse Fabry–Perot cavity to be built along the ion trap axis. The design allows a vapor-loaded magneto-optical trap of alkali atoms to be overlapped with trapped atomic or molecular ions. The construction and design of the trap have been reported, and its operating parameters have been determined, both experimentally and numerically, for rubidium Rb. The macromotion frequencies of the ion trap for ^{85}Rb are determined to be f_r = 43 kHz for the radial and f_z = 54 kHz for the axial frequencies, for the experimentally determined optimal operating parameters. The destructive off axis ion extraction

and detection by ion counting has been demonstrated. Finally, evidence for the stabilization and cooling of trapped ions, due to ion–atom interactions, was presented in this work by studying the ion-atom mixture as a function of interaction time. The utility and flexibility of the whole apparatus, for a variety of atomic physics experiments, were discussed in conclusion. This was published in *Applied Phys. B*.

In the year gone by Rangwala along with Tridib Ray, S. Jyothi and N. Bhargava Ram also devised a unique experimental arrangement that allows for simultaneous trapping and cooling of ions and neutral atoms within a Fabry Perot (FP) cavity. The versatility of this hybrid trap experiment enables a variety of studies with trapped mixtures. The article based on this work contains the motivation behind the design of such a hybrid trap system, followed by details of how the experiment is put together. Several experiments that have been performed with this system are presented and the opportunities of further experiments using this system are discussed. However the primary emphasis of the article is focussed on the aspects that pertain to the trapped ions, in this hybrid system. It has been accepted for publication in *Neuvo Cimento* in the book series of Enrico Fermi Schools titled Ion Traps for Future Applications

Rangwala was also involved in the transverse extraction and mass spectrometry of trapped ions from a modified Paul trap. This work included S. Jyothi and Tridib Ray and is in preparation for publication. In this study, the detection of ions by extraction, from the thin-wire modified spherical ion trap (MSIT) is discussed in detail. It is experimentally demonstrated that the arrival times of a single, trapped ion species from MSIT, is strongly affected by the phase of the trapping field, at the time of ion extraction. The experimental results are compared with numerical simulations of the entire trapping and extraction process and they are able to show excellent agreement between these. Mass spectrometry with multiple ion species has been demonstrated and the temporal dispersion of ions in extractions is shown. Some scenarios where the phase dependent extraction can be used for significant experimental advantage have also been constructed.

The next major research problem that Rangwala has explored in the last year has been the control of resonant light transmission through a cavity for an atom-cavity system. This work has been done in collaboration with Arijit Sharma, Tridib Ray, Rahul V. Sawant, and G. Sheikholeslami of Raman Research Institute and Byung Kyu Park and D. Budker of University of California, Berkeley. They demonstrate the manipulation of transmitted light through an optical Fabry-Perot (FP) cavity, built around a spectroscopy cell containing Rubidium (Rb) vapor. Light resonant with the ^{87}Rb D2(F=2 or F=1) to F' transition, is controlled by transverse intersection of the cavity mode by another resonant light beam. The cavity transmission can be suppressed or enhanced depending on the frequency of the transverse intersecting beam with respect to the atomic transitions. The extreme manifestation of cavity mode control is the complete extinction (negative logic) or creation (positive logic) of the transmitted light intensity, when the transverse beam intersecting the cavity mode is on. Both the steady state and transient response for the process are experimentally investigated. The mechanism behind the change in cavity transmission is discussed qualitatively within the atom-cavity coupled system framework. The discussion anticipates a detailed and general theoretical analysis for the observed phenomenon, which is described in another related work.

The details of the above light control in cavity mode have been theoretically studied by Rahul Sawant along with Rangwala. This work investigates the steady state and transient response of the cavity mode intensity. It has provided detailed insights into the experimental work of the above paragraph. The formulation is very general and can be applied to a variety of atom cavity studies that are of interest. It is also applicable to cold atoms in cavity. A manuscript for this work is under preparation.

Over the past year Rangwala has also been working on the following research problems, which are under various stages of progress.

Molecular ion creation, trapping and detection in the atom cavity experiment –
In this study, resonant 2 photon processes have created molecular ions. The trapping and detection of these have been established and the manuscript is in preparation. Now the lifetime of these molecular ions is under investigation so that the nature of molecular ion – cold atom interaction can be understood. There is a lot of uncertainty in the field about the interactions of molecular ions in such mixtures and his experiments would serve to systematically address a number of points and clear up several issues.

The quantum limit of ion-atom interactions –
Theoretical investigations have been undertaken where the collisions of the atoms and ions are treated using quantum scattering theory. The implications of this work are such that it is now understood how to build a next generation experiment, which should allow this regime to be accessed. The work is performed by Niranjan Myneni and Rangwala. A new ion confinement strategy has been developed so that the quantum regime for ion-atom interactions can be accessed. This is one of the most important open problems of the system. The above studies are ongoing and when finished should set the parameters for future experimental development.

Higher order atom-cavity coupling –
Niranjan Myneni and Rangwala have performed a theoretical analysis of the ion-cavity coupling in complex field modes. It is very important to understand how to exploit the strong coupling of atoms to the cavity mode. The calculations have led to a better understanding of the parameters for optimal performance of the ion-atom coupled system. The experiment shall be performed in the near future.

Urbasi Sinha's areas of current professional research interests are quantum information and quantum computation using single photons. She is also interested in experiments that aim to test the foundations of quantum theory.

During the year gone by the research completed by her included 3 major pieces of work that are described below.

The Feynman's path integral formalism has been used to propose experimental tests of the correction term, which arises due to the often incorrect application of the superposition principle in, for instance, the double slit experiment. The naive application superposes solutions to wave equations, which satisfy different boundary conditions to claim that the sum of component wave functions is the same as the composite wave function. In this theoretical study, for the very first time the correction has been bounded within the framework of quantum mechanics. This work was done in collaboration with R. Sawant,

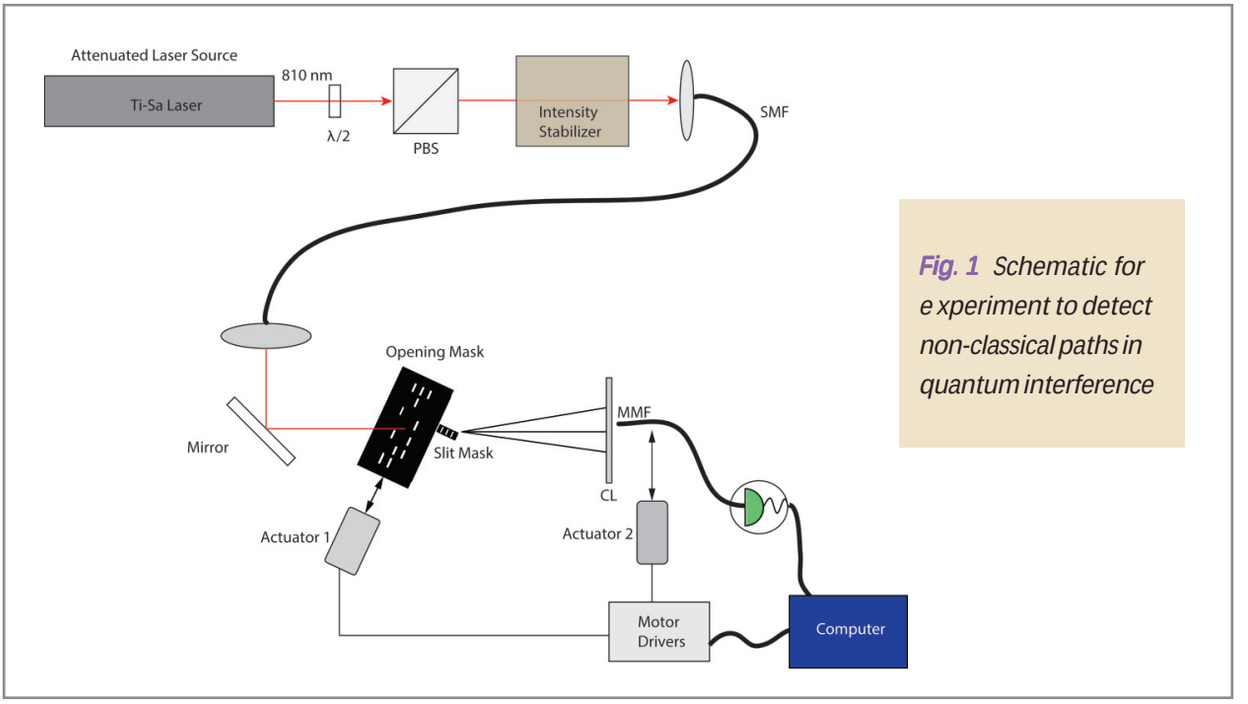


Fig. 1 *Schematic for e xperiment to detect non-classical paths in quantum interference*

J. Samuel and S. Sinha at RRI and A. Sinha at IISc, Bangalore. This work is under review in PRL.

Sinha's second major project involved a theoretical study based on the use of the no-signalling condition to propose limitations in Sorkin's Quantum Measure Theory. This work was done in collaboration with R. Srikanth and K. Joshi at RRI. It is under review at *New Journal of Physics*.

She has also participated in a theoretical investigation of the effect of environmental coupling on the tunnelling of quasi-particles in Josephson junctions. This work was done in collaboration with M.H. Ansari and F. Wilhelm at the Institute for Quantum Computing, University of Waterloo and A. Sinha at IISc, Bangalore. It was published in *Superconductor Science and Technology*.

As far as experiments are concerned Urbasi has successfully set up the Quantum Information and Computing lab at RRI, which involved setting up for the first time in India, an optics lab that has a 'clean room' environment. Her optics lab has a class 10000 clean room environment which involves control of temperature, humidity and dust–level through precision air handling systems. This is ensured so as to enable precision experiments based on interferometry and the production and application of designated single photon sources. Part of the academic year 2013-2014 was spent in finishing the establishment of the lab and the procurement of components.

She and her group have recently acquired a tunable Ti-Sapphire laser system that is currently being used for their experiment on detecting non-classical paths of photons, which is an experimental test of the theory that was developed to correct certain incorrect applications of the Superposition Principle as described above. A schematic of the experiment is shown above. Sinha has been doing this experiment along with project assistant Debadrita Ghosh and VSP students Animesh Aaryan and Pradeep N.

The other major experiment that Sinha has undertaken this year involves collaboration with the radio-astronomy laboratory of R. Subrahmanyan and N. Udaya Shankar. This is a microwave version of the above experiment and involves usage of horn antennas, spectrum analyzers and home built slots and slot stands. The students involved in this experiment are Anjali P.S., a VSP student, Ashutosh Singh, a first year PhD student and for the preliminary set-up Shreya Ray who was a VSP student.

M. Anil Kumar's research focuses on areas of Quantum Optics, Optomechanics and Foundations of Quantum Mechanics.

During the year gone by his primary research theme has been an analytical investigation of optical bistability in a cavity optomechanical system. Recently, the bistable behavior of the mean intra cavity photon number in optomechanical systems with a Bose-Einstein condensate (BEC), ultracold atoms and a quantum well has been extensively studied under linear optomechanical coupling. Producing such phenomena at very low photon number is desirable for applications from optical communication to quantum computation. To date, the theoretical literature has focused on using the quadratic coupling to detect phonon Fock states only, but other possible uses of this form of optomechanical coupling are largely unknown. The main theme of the project is to study the effect of higher order nonlinear or quadratic coupling on optical bistability and multi stability phenomena. This work carried out with U. Sainadh and Andal Narayanan of Raman Research Institute, considers both linear and quadratic coupling effects and the analysis is carried out in steady state.

Kumar has first written down the Hamiltonian for the optomechanical system and then solving the equations of motion under steady state condition arrived at an expression for the mean number of photons in the cavity. He plots 3 graphs corresponding to the behavior of intra-cavity photon number with respect to the detuning of the pump and the input power.

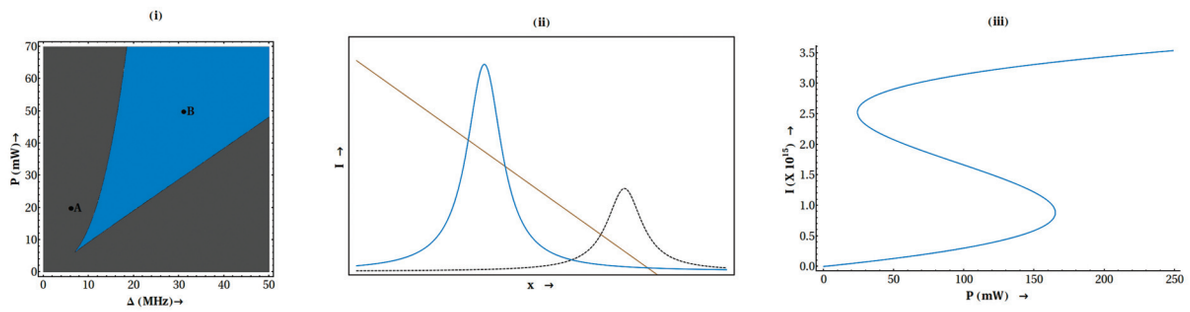


Fig. 1 (i) shows a region plot which specifies the region of 5 real solutions (red colour region inscribed with C), 3 real solutions (blue colour region inscribed with B) and 1 real solution (grey colour region inscribed with A); (ii) the mean photon number I varies as displacement x. The intersection points represent the number of real solutions. The three curves represent different values of pump power and detuning; (iii) indicates mean intra cavity photon number varied as a function of input power (P) for a fixed detuning.

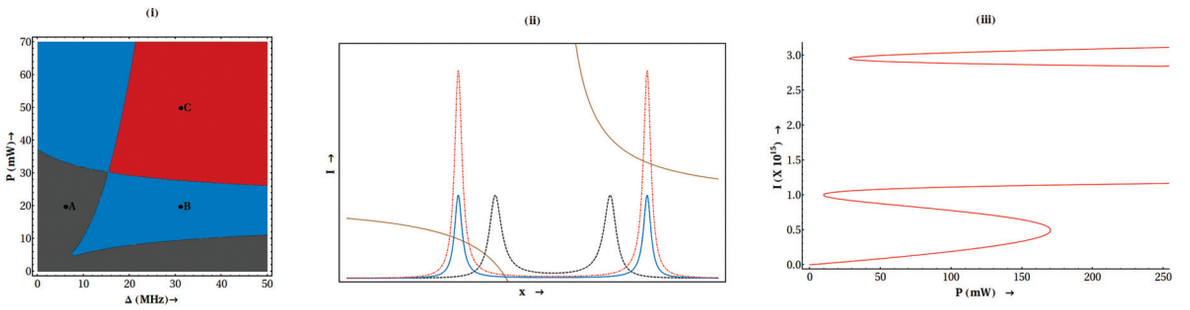


Fig. 2 (i) shows the region plot; (ii) & (iii) show the mean intra cavity photon number as function of displacement (X) and input pump Power (P) as depicted in Figure 1, by setting the quadratic coupling g_2=0.

Figure 2 shows the normal bistable behavior with all the parameters being same except that one of the parameters, the quadratic coupling, is set $g_2 = 0$. When the same set of parameters is considered again but with the above parameter $g_2 > 0$, it is observed that multistability and bistability natures are absent in the system. The nonlinear interaction effect of optomechanical coupling of the linear and quadratic displacement of the mechanical oscillator interacting with a single mode optical field is clearly evident from the result. The main result shows that the multistable behavior is sensitive to the sign of the quadratic coupling in optomechanical system. A paper on this work is in preparation.

Sourav Dutta's current professional research interests are in trapping and cooling of ultracold atoms, ions and molecules and optical manipulation of atoms, ions and molecules. Over the year gone by his research has focused on the following themes; the first four are in collaboration with Sadiq Rangwala at RRI.

Photoassociation (PA) of Rb_2 molecules – Dutta has worked on correcting the assignment of PA spectra previously recorded in Rangwala's lab and contributed to the understanding of PA line shape, crucial to the ensuing research. Predissociation of molecules, previously ignored by the group, has now been factored into the results and this has had a substantial impact on the understanding of the ion-molecule collision data previously produced in the lab. This has also led the group to invest in a new laser system (near 795 nm), which will allow PA to electronic states that do not have a predissociation channel.

Collisions between ions and cold molecules – Dutta is working on understanding and modeling the data on collisions of ions with vibrationally excited cold molecules. It appears that such collisions lead to the dissociation of

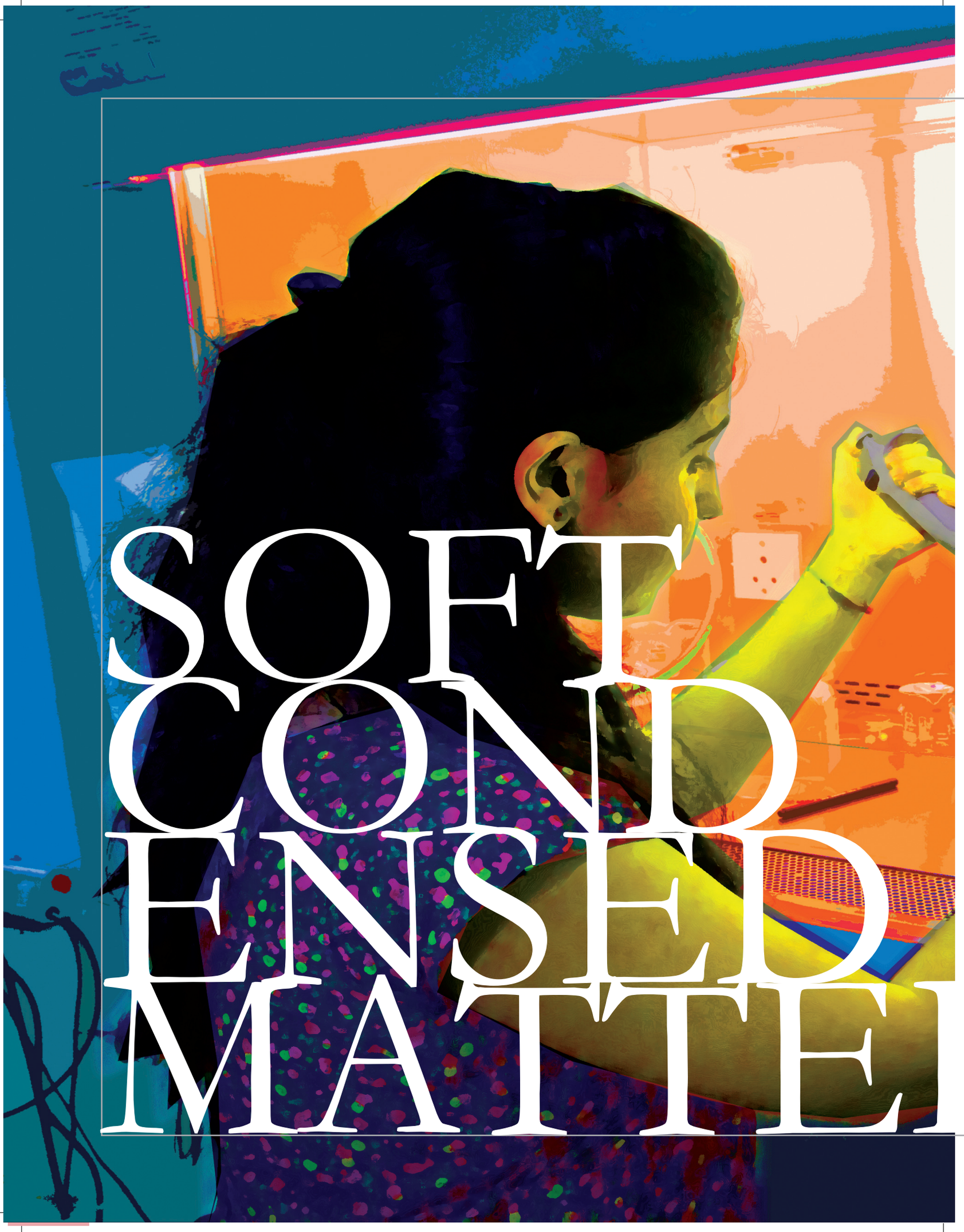
the cold molecules. A manuscript reporting these results is currently under preparation.

Production of cold Rb_2+ by Resonance Enhanced Multi Photon Ionization (REMPI) – This work involved providing the precise wavelength to which the pulsed laser should be tuned for efficient production of cold ions by REMPI of Rb_2 molecules available in a *Rb* Magneto-optical trap (MOT). This allowed ions to be produced and detected for the first time at RRI.

Atom-cavity, ion-cavity and molecule-cavity interaction – During the year gone by, Dutta has also been working towards stabilizing a high finesse optical cavity by locking to a laser. Although technically challenging, once attained this stabilization will allow the study of interaction between atoms and cavity, ions and cavity, and molecules and cavity.

External cavity diode laser (ECDL) – Dutta has designed an ECDL, which should be tunable without mode hops for 100 GHz or more. This is at least a factor of 5 better than any commercial ECDL available in the market today. The RRI workshop has already machined the parts based on his design. Once all the necessary parts have been acquired, the laser will be assembled.

Two-photon PA of *LiRb* – In collaboration with Jesús Pérez-Ríos, Yong P. Chen, Daniel S. Elliott, and Chris Greene from Purdue University, Dutta had experimentally demonstrated two-photon PA of *LiRb* molecules in his previous lab at Purdue University. This was the first such demonstration of two-photon PA in heteronuclear alkali molecules with dipole moment. He has, since then, analysed the data and is currently working on the interpretation and assignment of PA lines.


SOFT
CONDENSED
MATTE

Overview

Soft materials, constituted by macromolecules that are held together by weak inter-macromolecular forces, are characterized by complex structures and phase behaviors. Colloidal suspensions such as milk and paint, polymeric and biological materials, foam and liquid crystals are some common examples. The sizes of the macromolecules that constitute these materials are typically between a few nanometers and a few micrometers. In contrast to atomic systems whose relaxation times are of the order of picoseconds, soft materials relax on time scales that usually lie between 10^{-8} and 10^{3} seconds, which gives rise to long-lived metastable states. The structure and dynamics of these materials can therefore be easily studied using available laboratory techniques. Usually characterized by elastic constants that are many decades lower than those of traditional atomic fluids, soft materials are viscoelastic and easily deformable and can be used in the study of a variety of non-equilibrium phenomena. Inter-constituent interactions can also be easily modified in soft materials, making it very easy to engineer new materials with interesting and useful properties. Their structural complexity and mechanical flexibility make soft materials ideal model systems for the application of ideas from statistical physics and condensed matter theory in general.

The soft condensed matter group at RRI is engaged in research on the synthesis, characterization and physical studies of liquid crystals and also colloids, polymers, nano-composites, amphiphilic systems, complex fluids and other exciting new areas such as biological physics and surface physics.

Current Research Interests

Liquid crystals, nanocomposites, polycrystallites and polyelectrolytes

Experimental and theoretical studies are undertaken to deal with the structure property relations of 'soft' materials, which are easily deformable by external stresses, electric, and magnetic fields. Among these soft materials thermotropic liquid crystals consisting of highly anisotropic organic molecules, nano-composite materials, polymers and biomaterials are studied using a variety of experimental techniques. The interplay between the different degrees of freedom and various constraints present in these systems often give rise to rich and complex behaviour, which can be exploited for potential technological applications. Understanding their properties based on the experimental results involves an interdisciplinary approach using both physics and chemistry.

In theoretical investigations, the SCM group is primarily interested in the broad area of the theory of elasticity and topological defects in soft matter. Orientational (such as nematic, vector, hexatic) tangent-plane order on two-dimensional membranes deformable in three dimensions suffers frustration on curved membranes. This is also the case for certain smectic liquid crystals and thin crystalline lamellae. For example, solution- and melt grown polymer crystallites grow in the form of lamellae exhibiting diverse morphologies such as helicoidal, tent and scroll structures. Attempts are being made to formulate a phenomenological theory based upon the interplay between elasticity and topological defects to explain the stability of the observed morphologies.

The chemistry wing of the Soft Condensed Matter Group is involved in the design, synthesis and characterisation of novel liquid crystalline materials that exhibit remarkable electronic and optoelectronic properties. A number of monomeric, oligomeric, polymeric, and ionic liquid crystalline materials have been synthesized. The synthesis of liquid crystalline materials using microwave heating has also been carried out with a view to finding quick and environment-friendly synthetic routes.

The incorporation of nanomaterials like metal-nanoparticles, quantum dots, carbon nanotubes and graphene in the supramolecular order of liquid crystals is likely to lead to novel materials for many applications. With this view, a research program has been initiated to prepare and functionalize these nanomaterials with discotic as well as other molecules and disperse them in monomeric, oligomeric and polymeric discotic liquid crystals. The dispersion of such functionalized nanomaterials in columnar matrix significantly enhances their physical properties such as conductivity, photoconductivity, absorbance, etc.

One of the present research interests of the SCM group is in investigating electric-field induced chiral symmetry breaking in liquid crystals made up of achiral molecules. The structure and properties of novel field induced dark mesophases composed of electro optically switchable macroscopic chiral domains are

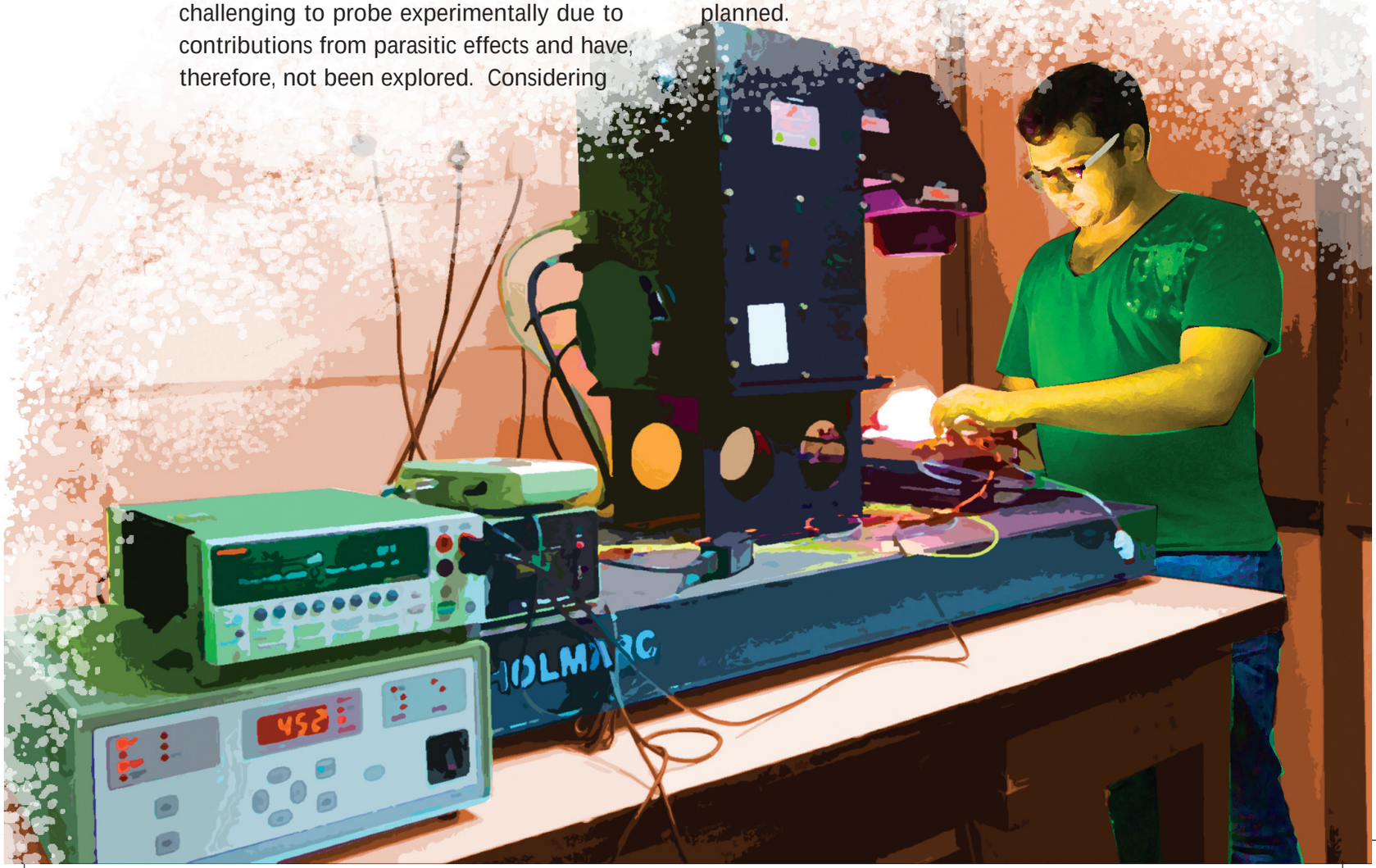
being studied, using a variety of techniques like optical microscopy, dielectric spectroscopy and X-ray diffraction. Field dependent shape transitions exhibited by the nucleating chiral domains, which form these mesophases, are also being studied in order to understand the observed enantioselectivity. The role of growth morphology in coarsening and scaling hypotheses is being looked into to get a physical insight into the effects of chiral and electrostatic interactions. Such chiral thin films possessing tunable enantioselectivity can also be interesting from a technological point of view as they have a potential for chiroptical and NLO applications.

Another area of interest is in understanding the structure and dynamics of polyelectrolytes using dielectric spectroscopy. Very low frequency relaxation modes arising from polarization mechanisms involving counter ions and polar side chains are usually quite challenging to probe experimentally due to contributions from parasitic effects and have, therefore, not been explored. Considering these factors,detailed dielectric studies have now been undertaken on some aqueous polyelectrolytes, some of which also exhibit coacervation.

Options to help reduce power dissipation and hardware complexity of drive electronics in passive matrix liquid crystal displays (LCDs) are being explored as well.

Phase behaviour of ionic surfactants

The effect of adsorbing counterions and polyelectrolytes on the phase behavior of ionic surfactants is being investigated using a variety of experimental techniques. The main objective of these studies is to find conditions under which novel aggregate morphologies and phases can be stabilized in these systems. Theoretical modeling of these systems is also planned.



Structure of DNA-surfactant complexes

Structure of DNA-cationic surfactant complexes is being investigated using X-ray diffraction. The main focus of the study is to stabilize different structures of these complexes by changing parameters such as the size of the surfactant molecule and the nature of its counterion.

Organization of sterols in membranes

The phase behaviour of lipid membranes containing different sterol molecules is being studied, with a view to understand the organization of these biologically important molecules in the membrane. Further, experiments are underway to probe the orientation of these molecules in the membrane.

Colloids and complex fluids

This group's experimental research predominantly investigates the following: the structure, dynamics and rheology of non-Newtonian fluids and aging suspensions, soft glassy rheology, flow-structure correlations in complex fluids, rheological chaos and the nonlinear dynamics of shear flows, interfacial instabilities, the design of viscometers to measure complex flows, the stability of colloidal suspensions, the sedimentation of colloidal gels, micellar packings, controlled, targeted drug delivery using copolymer micelles as vehicles for drug delivery, and the physics of granular media.

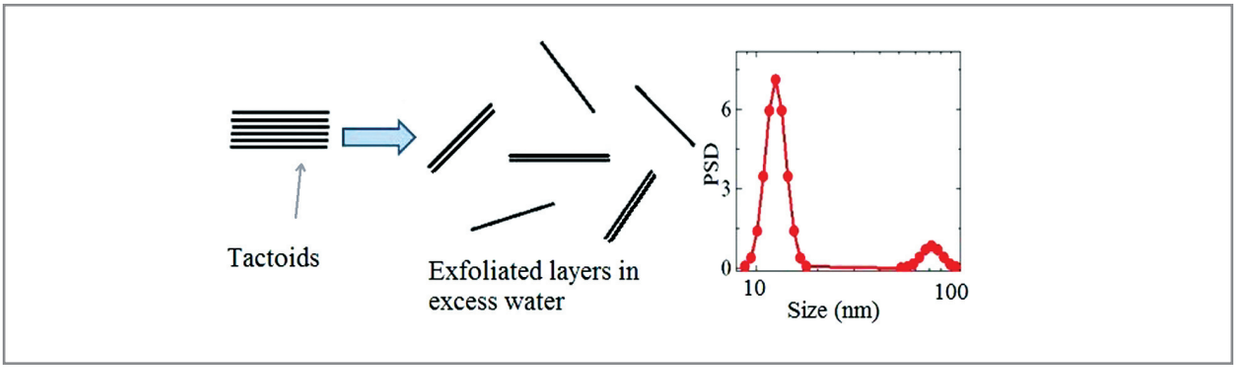
Experimental tools such as static and dynamic light scattering, rheology, ultrasound attenuation spectroscopy and high-speed imaging are being used extensively for these studies. Additionally, the group often collaborates with engineers and theoretical physicists working in areas of statistical mechanics and materials science.

Biophysics

The Biophysics group at RRI encompasses experimental, theoretical and computational studies of various biological systems. A physicist's approach to biological systems provides a novel perspective on how living machinery inside a cellular factory works. The group aims at achieving a quantitative physical description of dynamical phenomena occurring in cells at various levels. They are interested in nanoscale molecular structures that dominate interactions in DNA, proteins segregation and signaling at cell membrane aided by active cellular dynamics. They also investigate dynamical phenomena in neuronal cells leading to shape transitions and active mechanical responses. To quantify these studies, they develop novel state-of-the-art techniques in-house: for example, single molecule resolution nano-devices which help in deciphering secrets of biological nano-world and ultra-sensitive force measurement methods to probe mechanical responses of single cells. Theoretical and computational approach is aimed at not only deciphering quantitative experiments but also to predict novel mechanisms. This is a rapidly expanding area of research at RRI and overlaps with other traditional topics like statistical mechanics, membrane and polymer physics.

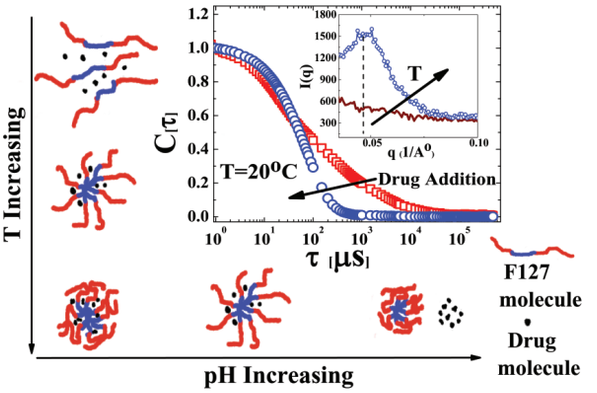
Ongoing Research

Ranjini Bandyopadhyay's areas of current professional research interests are the structure, dynamics and rheology of non-Newtonian fluids, aging and soft glassy rheology, flow-structure correlations in complex fluids, micellar packings, controlled, targeted drug delivery using copolymer micelles as vehicles for drug delivery, interfacial instabilities, designing viscometers to measure complex flows, the stability of colloidal suspensions and the physics of granular media.

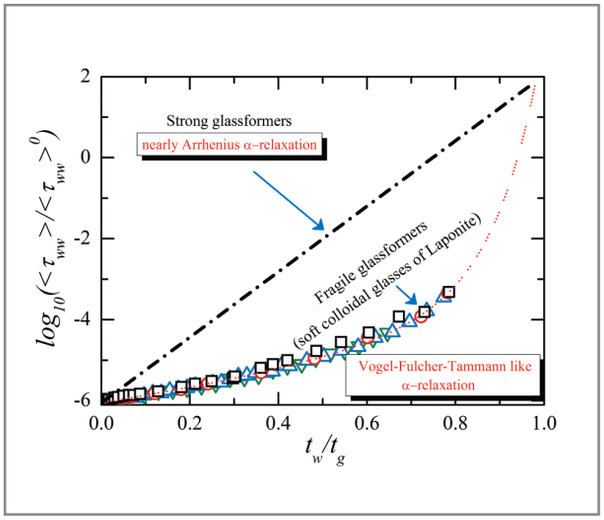


During the previous year she explored the use of ultrasound attenuation spectroscopy to determine the size distribution of clay tactoids (aggregates) in aqueous suspensions along with Samim Ali, PhD student, RRI. As a part of this study, they investigated the exfoliation of single clay platelets from clay tactoids. The attenuation spectra that are acquired in the frequency range 10-100 MHz are used to determine the particle size distributions (PSDs) for different concentrations and ages of the clay suspensions. Their analysis, using equivalent spherical diameter (ESD) for circular discs under Stokes drag in samples of concentrations greater than 1.5% w/v, shows that a substantial fraction of the aggregates in suspension are actually tactoids that are composed of more than one platelet. This is in contrast to the general belief that clay disperses into individual platelets in the concentration range where their suspensions exhibit glassy behavior. They conclude that the incomplete fragmentation of the clay tactoids arises from the rapid enhancement of the inter-tactoid Coulombic repulsion. Also using the same experimental technique, Bandyopadhyay and Ali have evaluated the dispersibility and stability of clay colloids in aqueous suspensions. The effect of clay dispersibility on the suspension stability of arrested phases at different concentrations of clay and added electrolyte are studied by measuring the ultrasound induced colloidal vibration current (CVI) in a suitable experimental setup. It is found that gels, which have been formed by dispersing clay in brine solutions, are far more stable than those where salt is added after dispersing clay in water.

Ranjini Bandyopadhyay also worked on encapsulation of hydrophobic drugs in Pluronic

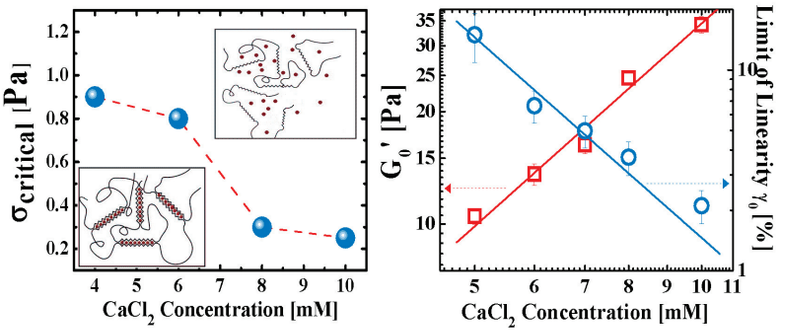


Copolymers form micelles that encapsulate drugs with increasing temperature. The drugs are released into the medium as the pH of the latter is raised.



F127 micelles, where she investigated the effects of drug hydrophobicity, solution temperature, and pH in collaboration with Rajib Basak, PhD student, RRI. Three drugs, ibuprofen, aspirin, and erythromycin, are encapsulated in spherical Pluronic F127 micelles. The shapes and the size distributions of the micelles in dilute, aqueous solutions, with and without drugs, are first ascertained using cryo-scanning electron microscopy and dynamic light scattering (DLS) experiments, respectively. Uptake of drugs above a threshold concentration is seen to reduce the critical micellization temperature of the solution. The mean hydrodynamic radii and polydispersities of the micelles are found to increase with decrease in temperature in the presence of drug molecules. The hydration of the micellar core at lower temperatures is verified using fluorescence measurements. Increasing solution pH at this juncture leads to the ionization of the drugs incorporated in the micellar cores. This causes rupture of the micelles and release of the drugs into the solution at the highest solution pH value of 11.36 investigated here. This work can have extensive biomedical applications.

The third broad research theme for Ranjini Bandyopadhyay in this past year has been the investigation of the dynamical slowing down process in soft glassy colloidal suspensions and its comparison with supercooled liquids. The collaborators in this work were Debasish Saha, PhD student, RRI and Yogesh M. Joshi, Department of Chemical Engineering, IIT Kanpur. The primary and secondary relaxation timescales of aging colloidal suspensions of Laponite are estimated from intensity autocorrelation functions obtained in dynamic light scattering (DLS) experiments. The dynamical slowing down of these relaxation processes are compared with observations in fragile supercooled liquids by establishing a one-to-one mapping between the waiting time since filtration of a Laponite suspension and the inverse of the temperature of a supercooled liquid that is rapidly quenched towards its glass transition temperature. New timescales associated with primary and secondary relaxation processes, such as the characteristic timescale associated with the slowdown of the secondary relaxation process and glass transition time, are extracted to describe the phenomenon of dynamical arrest in Laponite suspensions. In results that are strongly reminiscent of those extracted from supercooled liquids approaching their glass transitions, it is demonstrated that a strong coupling exists between the primary and secondary relaxation processes of aging Laponite suspensions in the cage-forming regime. Furthermore, the experimental data obtained clearly demonstrates the self-similar nature of the aging dynamics of Laponite suspensions within a range of sample concentrations. Related to the same research theme is a study of the physicochemical effects in aging aqueous Laponite suspensions. The



Elastic modulus G' and the limit of linearity γ versus CaCl2 concentration

effects of clay concentration, the concentration of externally added salt and temperature on the microscopic dynamics of clay suspensions are studied using the same method as above – dynamic light scattering. The fast and slow relaxation times of suspensions of Laponite, a synthetic clay and a model glass former, were extracted from intensity autocorrelation functions measured at different waiting times since sample preparation. Comprehensive overlaps of both the fast and the slow relaxation timescales are obtained with changing clay concentration, waiting time, salt concentration and temperature. These results highlight the self-similar nature of the energy landscape of Laponite suspensions when Laponite concentration, the concentration of externally added salt and sample temperature are changed within the range studied here. Conductivity measurements are performed to measure the evolution of the sodium ion concentration with waiting time. The evolution of free energy is calculated using the DLVO theory. The fragility parameters, extracted from fits to the experimental data, are used to uncover the observed self-similar evolutions of the relaxation timescales of Laponite suspensions.

Bandyopadhyay in collaboration with Rajib Basak, PhD student, RRI, studied the formation and rupture of Ca^{2+} induced pectin biopolymer gels. When calcium salts are added to an aqueous solution of polysaccharide pectin, ionic cross-links form between pectin chains, giving rise to a gel network in dilute solution. In this work, dynamic light scattering (DLS) is employed to study the microscopic dynamics of the fractal aggregates (flocs) that constitute the gels, while rheological measurements are performed to study the process of gel rupture. As calcium salt concentration is increased, DLS experiments reveal that the polydispersities of the flocs increase simultaneously with the characteristic relaxation times of the gel network. Above a critical salt concentration, the flocs become interlinked to form a reaction-limited fractal gel network. Rheological studies demonstrate that the limits of the linear rheological response and the critical stresses required to rupture these networks both decrease with increase in salt concentration. These features indicate that the ion-mediated pectin gels studied here lie in a 'strong link' regime that is characterised by inter-floc links that are stronger than intra-floc links. A scaling analysis of the experimental data presented here demonstrates that the elasticities of the

individual fractal flocs exhibit power-law dependences on the added salt concentration. It is concluded that when pectin and salt concentrations are both increased appropriately, the number of fractal flocs of pectin increases simultaneously with the density of crosslinks, giving rise to very large values of the bulk elastic modulus.

Yashodhan Hatwalne's areas of research interests include phenomenological theories of liquid crystals, membranes, and polymer crystallization.

During the past year he studied the morphology of polymer crystallites with Jaya Kumar A. (PhD student at RRI), and M. Muthukumar (University of Massachusetts), who is an Adjunct Professor at RRI.

Polymer crystallites are known to exhibit diverse morphologies. Melt-grown crystallites of achiral polymers such as polyethylene have spherulitic structure comprising helicoidal lamellae that break chiral symmetry. Polymer crystallites also grow in the form of tents, chairs, and scrolls. The stability of these structures has not yet been understood, and no theoretical framework explaining the morphologies exists. This has been a long-standing problem in polymer physics (see, for example, B. Lotz and S. Cheng, *Polymer* **46**, 577 (2005) and references therein). Hatwalne's work has been directed towards formulating a phenomenological theory that explains all the observed morphologies. Using a theory based upon the interplay between elasticity and topological defects Hatwalne and his collaborators have made significant progress in understanding tent structures exhibited by polymer crystallites.

The other research theme for Hatwalne in the previous year has been the elasticity of fluid membranes with tangent-plane order. This work is being done with Jaya Kumar A. (RRI). Orientational (such as nematic, vector, hexatic), tangent-plane order (TPO) on two dimensional membranes deformable in three dimensions leads to frustration of the TPO on curved membranes. Nelson and Peliti (*J. Physique* **48**, 1085 (1987)) formulated the covariant elasticity theory of such membranes. This theory brings out the connection between geometry of the membrane and topology of the TPO embedded in it. Equations of equilibrium (together with boundary conditions) for membranes with TPO have been obtained using this formulation.

Sandeep Kumar of the SCM group at RRI is primarily interested in the synthesis and physical studies of liquid crystalline materials and their properties. During the year gone by Sandeep Kumar has worked on liquid crystal nanoscience and design, synthesis and physical studies of liquid crystalline materials.

Under the ambit of liquid crystal nanoscience, his research concentrated on the following problems:

Mutually ordered self-assembly of discotic liquid crystal-graphene nanocomposites in collaboration with V. Lakshminarayanan – Discotic liquid crystals (DLCs) are nanomaterials with sizes ranging from 2 to 6 nm, and they are presently emerging as an important one-dimensional organic semiconducting material. Recently, hybridization of these materials with various metallic and semiconducting nanoparticles (NPs) to alter and improve their properties has been realized. This work provides

an example of the developments in this newly emerging field of discotic nanoscience, a sub-field of liquid crystal (LC) nanoscience. In this study, it was found that the room temperature anthraquinone discotic 1,5-dihydroxy-2,3,6,7-tetrakis (3,7-dimethyloctyloxy)-9,10-anthraquinone (RTAQ) self-assembles in the presence of octadecylamine functionalized graphene into an ordered sandwich like structure, where the discotic molecules form columnar structures on graphene sheets. Cryo-SEM and SEM images provide evidence for this ordering. Polarizing optical microscopy, differential scanning calorimetry, X-ray diffraction and conductivity studies of nanocomposites also support this behaviour.

Effect of dispersion of gold nanoparticles on the optical and electrical Properties of Discotic Liquid Crystal in conjunction with Pratibha and Kuldeep Raina – In this work, dispersion of gold nanoparticles (GNPs) in a mononitro-substituted triphenylene-based DLC was studied by differential scanning calorimetry, polarising optical microscopy, X-ray diffraction, dielectric spectroscopy, visible absorbance spectroscopy and IR dichroic technique. The experimental results show that inclusion of GNPs in the DLC matrix strains the columnar matrix. The more ordered Colp phase which possesses high charge carrier mobility because of the three-dimensional positional order is still preserved even by insertion of GNPs into the columnar matrix. However, a decrease in orientational order parameter (S) and increase in relaxation time (τ) for disc motion with GNPs in Colp phase was observed. An enhancement in dc electrical conductivity by several orders of magnitude in ambient conditions was observed.

Sandeep Kumar has also worked on the dispersion of various other nanoparticles in the supramolecular order of discotic liquid crystals – This work summarizes the effects of the dispersion of various functionalised nanoparticles such as gold nanoparticles, cadmium selenide quantum dots, single-wall carbon nanotubes and gold nanorods in the supramolecular order of columnar mesophases of DLCs. Dispersion of such nanomaterials in small concentration has negligible effect on the mesomorphic properties of the DLCs but improves the physical properties like conductivity of the system significantly. Nanoparticles embedded discotic nanoribbons can be prepared via simple solution processing. It is expected that such nanocomposites will emerge as advanced semiconducting materials for many device applications.

Under design and synthesis of novel liquid crystalline materials, Sandeep Kumar was involved in the following research projects this year:

Effects of chain branching and lateral fluorine substitution on mesomorphism of cholesteryl benzoates in collaboration with M. C. Varia – In this work, the mesogenic cholesteryl 4'-alkoxyphenyl-4-carboxylate possessing terminal normal/branched saturated/unsaturated alkyl chains with laterally ortho/meta substituted electronegative fluorine atom was investigated. All the homologues exhibited enantiotropic mesomorphism. Smectic A phase, chiral nematic blue phase (BP) and TGBA phases were observed in different homologues. The effects of the various terminal normal/branched saturated/unsaturated alkyl chains and the position of the substituted fluorine atom with its structurally related compounds were also looked into.

New perylene-based non-conventional discotic liquid crystals in collaboration with Dr. S.K. Pal – As a part of this research problem, the synthesis, optical properties and thermal behaviour of three novel non-conventional 3,4,9,10-tetrasubstituted perylene-based discotic oligomers consisting of a perylene core attached to which are four 4-cyanobiphenyl, triphenylene and cholesteryl units via flexible alkyl spacers were reported for the first time. All the oligomers self-assemble into a mesophase and exhibit excellent fluorescence emission properties making them suitable for various opto-electronic applications.

New pyrimidine-based photo-switchable bent-core liquid crystals in collaboration with Dr. Md. Lutfor Rahman group – This study involved the synthesis and characterization of liquid crystalline pyrimidine-based photo-switchable bent-core monomers incorporating azobenzene as side arms linked with terminal double bonds as polymerizable functional groups. The lower homologues are crystalline in nature whereas higher homologues display the stable enantiotropic B6 phase. They exhibit fast photoisomerization effects in solution and relatively slow photoisomerization effects in liquid crystal cells. These are some of the first examples of azobenzene liquid crystals, which exhibit very fast switching properties in solutions.

High-temperature chiral nematic phase in naphthalene and cholesterol derivative liquid crystal – A characterisation and dielectric relaxation study with M. C. Varia and Dr. Rajiv Manohar's group – In this article, Sandeep Kumar and his collaborators report the synthesis of the naphthalene and cholesterol derivative 2-(cholesterol-n-decanoate)-6-(heptyloxy benzoate) naphthalene liquid crystal having chiral nematic (N*) mesophase. The mesophase has been characterised using polarising optical microscopy (POM) and differential scanning calorimetric (DSC) study. The presence of the rigid and less polarisable cores causes a higher N*-Iso transition temperature. The relaxation time of the LC sample follows the first-order exponential decay–type equation.

Superlattice structures observed in the extraordinary phase sequence and analyzed by the phenomenological Landau model and the partially molecular model –
This work was done with Prof. J.K. Vij. In this work, several electric-field–temperature (*E*–*T*) phase diagrams with electric-field-induced birefringence contours in the *n*OHFBBB1M7 (*n* = 10) and *n*OTBBB1M7 (*n* = 11) (C11) mixture system is obtained by changing the C11 concentration carefully; some of the mixtures show the unusual extraordinary phase sequence where subphases with the four-, five-, and six-layer super lattice structures emerge above the smectic-*C** main phase. The results are explained in terms of two complementary models that have so far been proposed: the phenomenological Landau model of phase transitions by Dolganov *et al.* [P. V. Dolganov *et al.*, *Phys. Rev. E* **86**, 020701(R) (2012)] and the partially molecular Emelyanenko-Osipov model [A. V. Emelyanenko and M. A. Osipov, *Phys. Rev. E* **68**, 051703 (2003)]. The observed *E*–*T* phase diagram can be well reproduced by the phenomenological model. An emergence of the subphase with the four-layer superlattice structure above smectic-*C** is also understandable in terms of the partially molecular model.

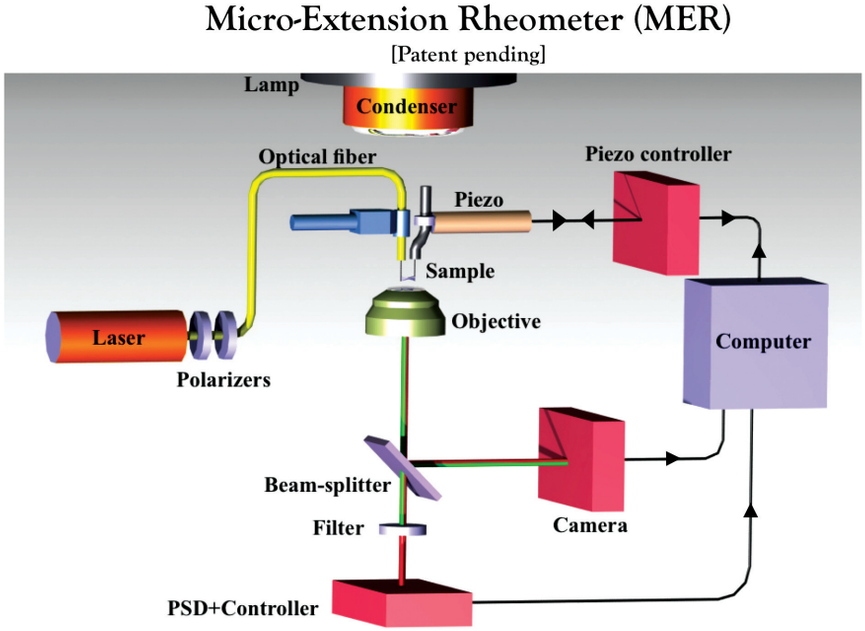
Synthesis and characterization of liquid crystalline azobenzene chromophores with fluorobenzene terminal – This project was pursued in collaboration with Md. Lutfor Rahman. Two series of fluorine-substituted benzoate ester type rod-shaped liquid crystals incorporating the azobenzene as a side arm linked with terminal double bonds as polymerizable functional groups were synthesized and characterized by polarized-light optical microscopy (POM), differential scanning calorimetry (DSC) and UV–visible spectroscopy investigations. Rod-shaped monomers, namely 4a and 4b having odd and even number of carbon in the terminal group exhibited nematic phase while SmA type phase was found at lower temperatures. Compound 5 showed nematic phase whereas compound 6 showed SmA phase. These rod-shaped molecules exhibit strong photoisomerization behaviour in solution. The photoswitching properties of the compounds showed trans to cis isomerization in about 10 s, whereas the reverse process takes place in about 120 min in solutions. Proposed materials may have potential to use it in optical storage devices.

Synthesis of symmetrical and unsymmetrical triphenylene discotic liquid crystals using Antimony (V) chloride under Scholl oxidation – Triphenylene-based discotic liquid crystals, useful in studying the energy and charge migration in self-organized systems, are the most widely synthesized and studied discotic liquid crystals. In this work, an efficient synthetic procedure for the preparation of symmetrical and unsymmetrical triphenylene discotic liquid crystals using antimony pentachloride as a novel reagent was studied. Scholl oxidative trimerization of 1, 2-dialkoxybenzenes with SbCl5 gives hexa alkoxy-triphenylenes with a good yield, while the oxidative coupling of a 3, 3', 4, 4' tetra alkoxy-biphenyl with a 1, 2, 3-trialkoxybenzene affords an unsymmetrically substituted hepta alkoxy-triphenylene derivative. The potential of this new reagent was compared with other known reagents for the synthesis of alkoxy-triphenylenes.

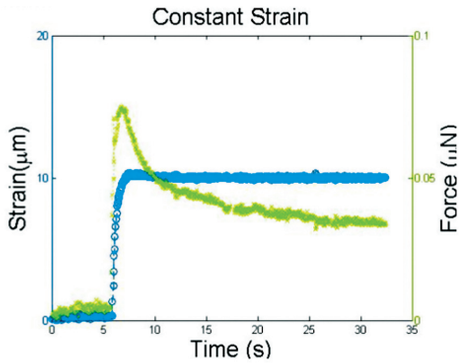
Pramod Pullarkat is primarily interested in the mechanical properties of axon, axonal shape instabilities and pattern formation during stem cell differentiation.

Axons are thin tubular extensions produced by neuronal cells in order to conduct electrical signals. In a human body they can be anything between a few tens of microns (in the brain) up to a meter long (in nerves extending into lower limbs). The diameter of the axon is only about a micron and in normal cells it is almost constant for the entire length. This robustness may be because the diameter is set by interplay between opposing physical factors like axonal membrane tension and internal pressure due to the polymer gel that fills the interior (cytoskeleton). Moreover, maintenance of axonal plasticity requires that the neuronal cell should be able to retract and reform connections. Here it is suspected that molecular motors are at work as they can generate active stresses. The questions that Pullarkat and his collaborators are trying to address are: How do axons maintain this constant diameter over such long lengths? What determines the generation and redistribution of components during axonal growth? What drives the retraction of axons during axonal rewiring? The approach of the group includes development of simple assays, image analysis techniques and fluorescence microscopy methods to study shape stability, probing the response of axons to laser induced ablation, and building of novel force measurement devices and use of optical tweezers to probe the mechanical responses of axons. This is an interdisciplinary approach involving active collaborations with neurobiologists and theoretical physicists.

The biophysics laboratory has designed and built an optical fiber based force apparatus with pico-Newton force sensitivity, nano-meter position resolution and feedback control. The new force apparatus uses an etched optical fiber attached to a piezo drive to apply or measure forces while the sample can be imaged using Phase contrast or fluorescence microscopy during force measurements. A feedback loop allows independent control of



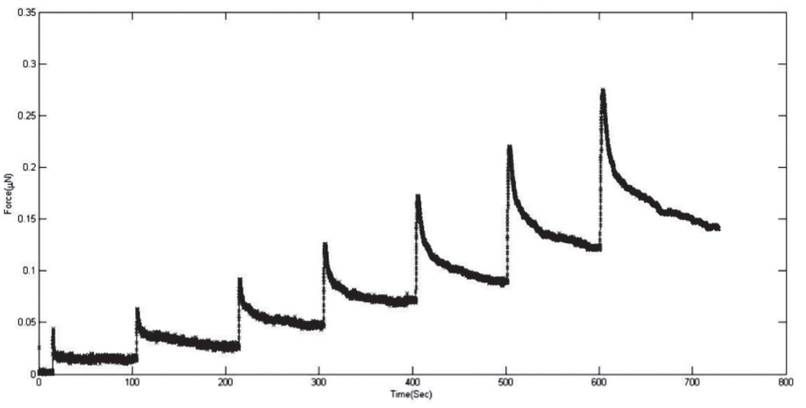
A schematic diagram of the force apparatus that uses an etched optical fiber as force sensor. Pico-Newton force sensitivity and nano-Newton spatial resolution can be achieved by this technique.



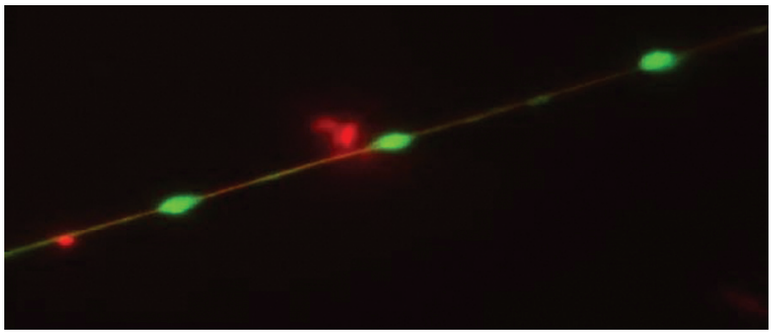
Force relaxation response of a polymer melt to a step-like elongation applied using the constant strain mode.

force or extension. An article has been published in Review of Scientific Instruments and a patent has been filed together with collaborators from NCL Pune. As further improvement, Sushil Dubey (PhD Student, RRI) and Sampada Mutalik (PhD Student, IISER-Pune) have added a motorised X-Y-Z control for easy manipulation of the fiber position and a new sample chamber with temperature control for neuron experiments. Seshagiri Rao (PhD Student, RRI) worked on improving the detection method by adding a Quadrant Photodiode. The calibration of this device and computer interfacing via a DAQ card are also complete. The setup was first used to explore the viscoelastic properties of axons under stretch. Jagruti Pattadkal (project student from IISER-Pune) had observed non-linear viscoelastic effects that depend on the applied force. Multiple experiments suggest that this arises due to a force-dependent dissociation rate for cytoskeletal cross-linking proteins. After Jagruti left, Sushil Dubey has been working on the same experiment with collaborators Aurnab Ghose at IISER-Pune and Andrew Callan Jones of University of Paris, Diderot. To further explore the non-linear viscoelastic effect Sushil has used a modified setup, which allows the application of strain steps with well-defined strain values. This was essential to characterize the viscoelastic nature of the response.

In collaboration with Anagha Datar (PhD Student, RRI) and Roli Srivastava (Project Assistant, RRI), Pullarkat has also performed a series of experiments to understand shape instabilities of axons. Specific biochemical agents are first used to depolymerise actin-



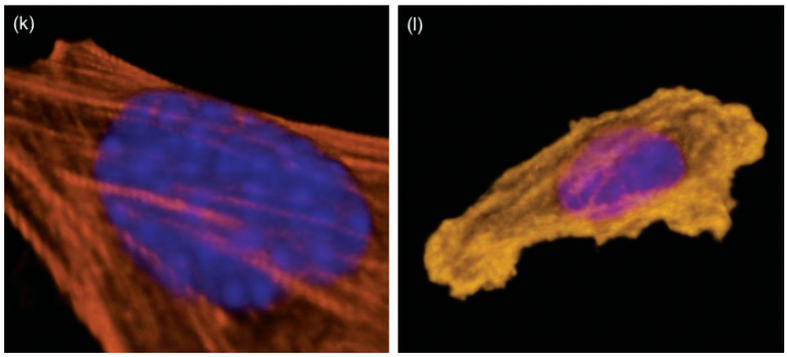
An example of the force relaxation in axons of neuronal cells seen in response to the application of successive step strain using the force apparatus. The plots show non-linear visoelastic behaviour.



An image of the radius modulations seen in axons after the disruption of microtubules. Tubulin is marked using green fluorescence label and actin using red.

filaments inside the axon and then the resulting shape evolution is observed. Two distinct responses are seen: (i) After microtubule depolymerisation the axon develops peristaltic radius modulations; (ii) When actin filaments are disrupted the axon exhibits a dynamic retraction front, which separates a thin region largely devoid of cytoskeletal components from a thick region into which these components are displaced. Interestingly, they have shown that both these shape dynamics can be also induced by a local ablation of the axon using a nano-second laser pulse.

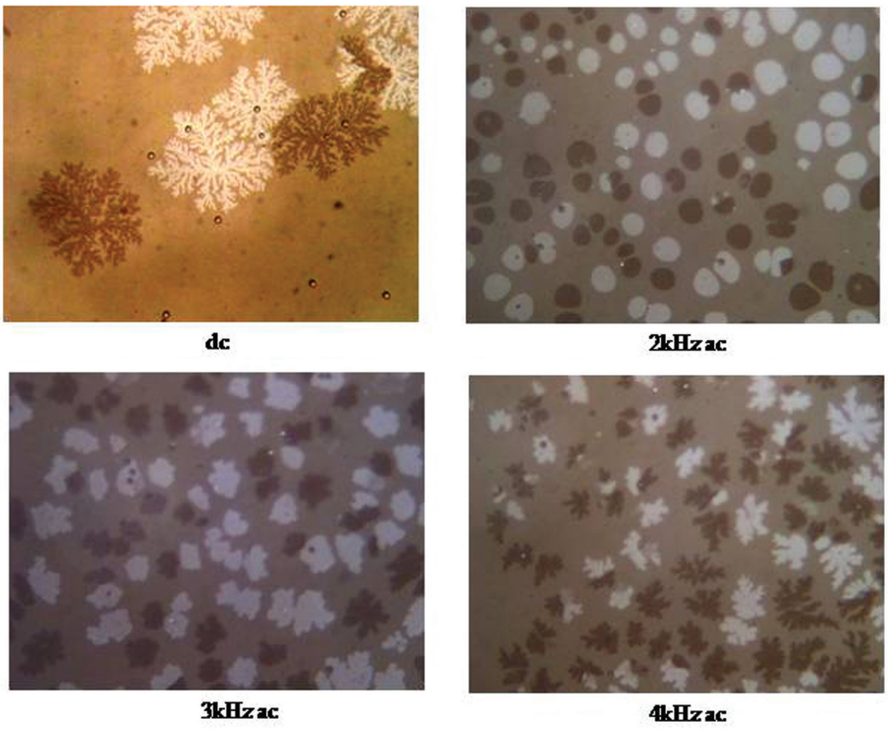
Renu Vishavkarma (PhD Student, RRI) and Pramod Pullarkat are together involved in investigating stem-cell mechanics with the aim of understanding the role of physical forces in regulating cell geometry and cell substrate interaction through substrate properties such as stiffness or adhesivity. It has been shown that actin cables running over the cell nucleus plays an important role in dictating cell shape and can explain the changes in cell shape as a function of substrate properties like stiffness or adhesivity. Pramod Pullarkat's collaborators in this project are Abhijit Majumdar (NCBS) and Jyotsna Dhawan (NCBS). Renu along with a project student Nidhi P. has also developed a shear device for studying the effect of shear stress on cells along with fluorescence microscopy. The setup development is complete and preliminary data on cell detachment as a function of shear stress has been obtained. This data should allow for a characterization of the adhesion forces that regulate cell-substrate adhesion and an exploration of how the cell regulates this when subjected to a shear stress by reorganizing focal adhesion complexes.



Confocal images of cell spread on stiff (k) and soft (l) substrates showing different distribution of the actin cytoskeleton

R. Pratibha's research interests mainly include chiral liquid crystals, polyelectrolytes and nanocomposites.

In the year gone by, she has worked on chiral symmetry breaking under applied electric fields along with G. B. Deepa. In this particular project the primary interest was in understanding chiral symmetry breaking induced by electric fields in bent-core liquid crystals made of achiral molecules. Detailed experimental studies show that, if the dark conglomerate (DC) liquid crystalline phase characterized by macroscopic chiral domains, is formed from the isotropic phase under a dc or ac field, chiral segregation can be controlled and the chiral domains become electro-optically switchable. Consequently the enantioselectivity, dielectric parameters and switching polarization in the DC phase become tunable. Such switchable chiral domains with enhanced optical contrast have a high potential for novel electro-optic applications. Another interesting aspect is that the nucleating conglomerate domains formed under ac fields exhibit frequency dependent shape transitions which have a striking resemblance to domain shape changes observed in 2D monolayers. This is probably the first observation of such frequency dependent shape changes in conglomerate chiral domains. The domain shapes which range from fractal structures under dc fields to nearly circular and highly branched structures under ac fields can be used to get a physical insight into the effects of chiral and electrostatic interactions on domain growth and interface



Shape transitions exhibited by nucleating chiral domains of the dark conglomerate liquid crystal formed under electric fields

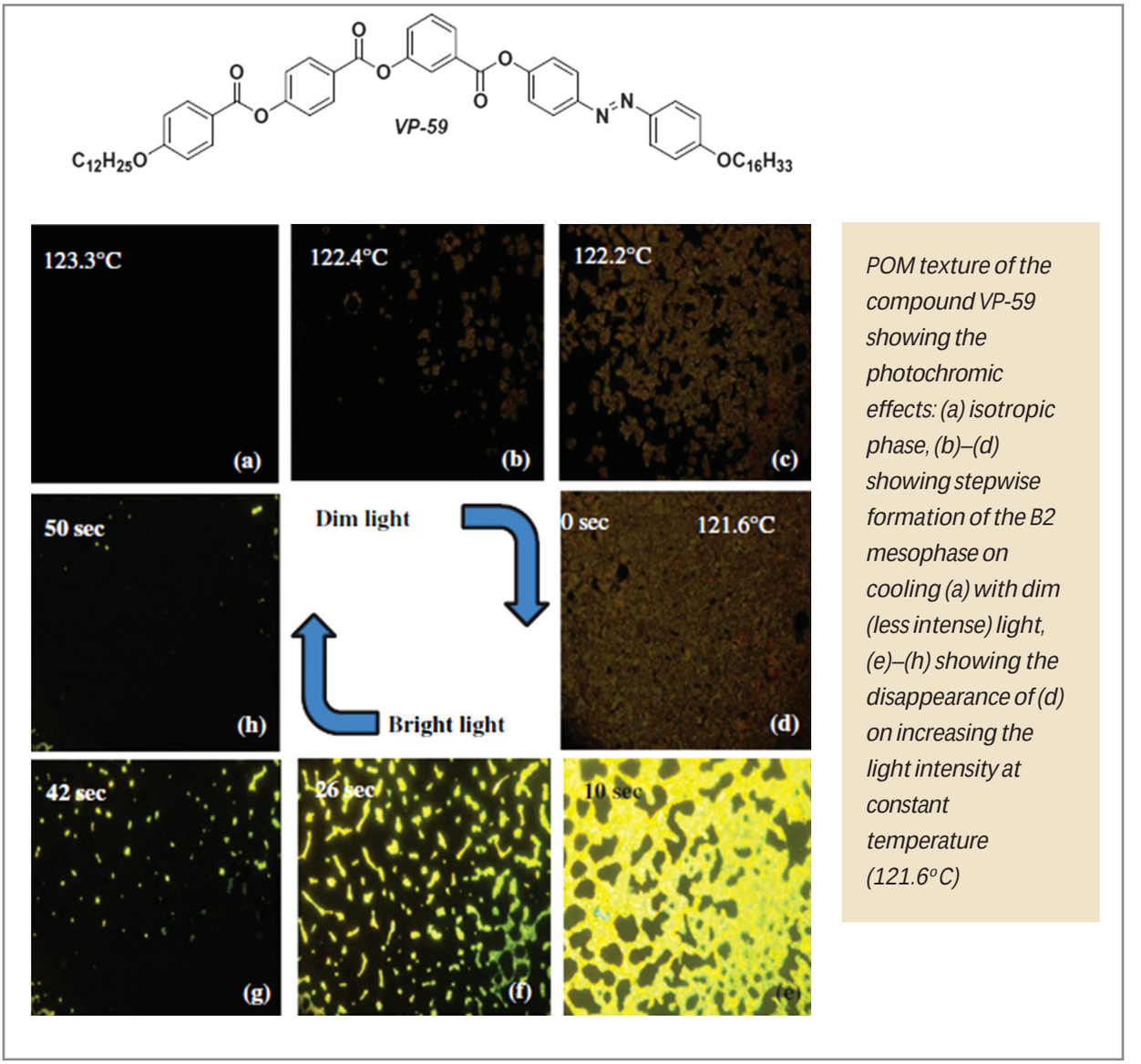
structures. These can also be used to investigate the role of growth morphology in coarsening and scaling hypotheses. From a technological point of view this opens up the possibility of obtaining chiral thin films with preferential sense of chirality which can be useful in chiroptical and NLO applications.

Apart from a single observation that indicated the presence of birefringence in normal human red blood cells (RBCs) way back in 1969, a quantitative measure of the birefringence associated with such RBCs had hitherto not been clearly revealed. More recently a model, based on experiments in an optical trap, had attributed the optical property to form birefringence arising from folding of the RBCs. However more recent experiments by researchers at the Physics Department of Bangalore University, did not find any evidence for such a folding. It was also observed that the RBC aligns its slow axis to the plane of polarization of an optical tweezer and reorients about an axis parallel to the polarization direction indicating the presence of birefringence. In order to verify this, a quantitative measurement of the birefringence in healthy human RBCs in the absence of an optical trap, was undertaken at the Raman Institute. The birefringence was measured under a polarizing microscope using freely suspended RBCs in an appropriate buffer solution. After proper identification of the slow axis of the RBCs using a full wave retardation plate, the birefringence was measured using the Sénarmont technique. R. Pratibha together with Nagesh B.V., Yogesha, Praveen P., Sarbari Bhattacharya and Sharath Ananthamurthy (Bangalore University) showed that the birefringence is confined to the dimpled region of the RBC suggesting that it probably owes its origin to the RBC membrane rather than haemoglobin or other constituents of the cytoplasm which would be expected, if present in excess at the rim rather than at the dimple region.

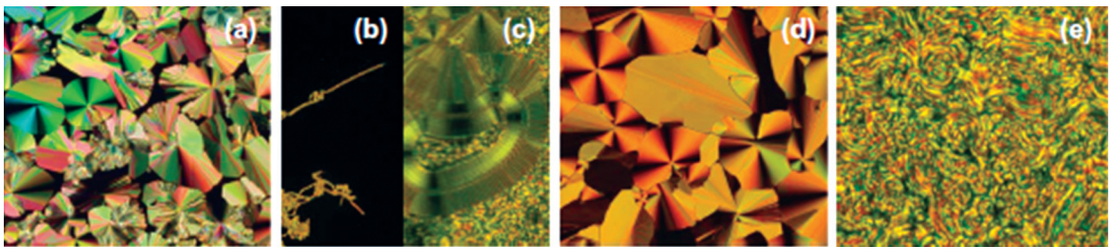
R. Pratibha has also been working on dielectric spectroscopy of polyelectrolytes in collaboration with Pramod Tadapatri and M. Muthu Kumar (University of Massachusetts). Dielectric spectroscopy is a convenient technique for investigating relaxation processes that provide an insight into the structure and dynamics of polyelectrolytes. However, investigating dielectric properties of aqueous polyelectrolyte solutions over a wide frequency domain can be quite challenging. Various contributions like polyion dipolar orientation relaxation, solvent-solute interactions and orientational polarization of water molecules results in very complex behavior. The effect of counter ions leads to further complications. As some of these features are not yet very well understood, a detailed experimental study of the dielectric parameters of some polyelectrolytes, especially at very low frequencies has been undertaken as a part of this project. While optical studies carried out on two polyelectrolytes, viz. Poly(allylamine hydrochloride) (PAH) and Poly(acrylic acid) (PAA) showed evidence for coacervation it could not be observed with an aqueous solution of Poly (Sodium 4-styrene sulphonate) (NaPSS). Both these systems are now being investigated using dielectric spectroscopy.

Arun Roy's areas of current professional research interests are phase transitions and electro-optics of liquid crystals, liquid crystals nano-particle composites, micro Raman spectroscopy and phenomenological theories of liquid crystals.

During the previous year Roy has worked on Azo functionalised photosensitive achiral bent-core liquid crystals along with N. G. Nagaveni (Student CSMR, Bangalore), Dr. Veena Prasad (CSMR, Bangalore) and Prashant Raghuvanshi (Research Assistant, RRI). The design, synthesis and liquid crystalline properties of four new homologous series of photochromic bent-core liquid crystals have been reported. Roy and his collaborators have also investigated the effect of the presence of –N=N–linkage at different locations of the molecular architecture, on the mesomorphic properties. For example, the molecular structures of all the newly synthesised compounds are established using the organic spectroscopic methods while the liquid crystalline properties are investigated using polarising optical microscopy (POM), differential scanning calorimetry (DSC), X-ray



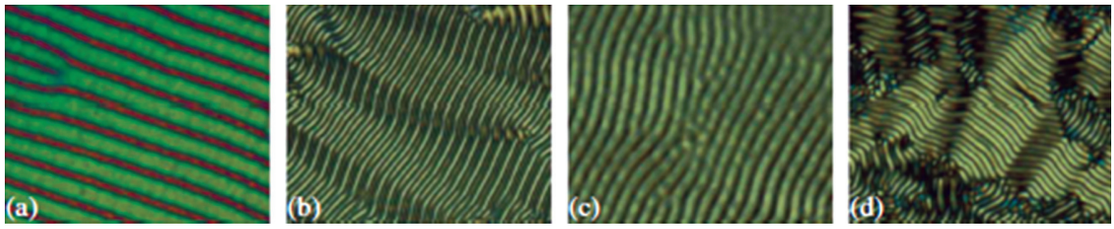
POM texture of the compound VP-59 showing the photochromic effects: (a) isotropic phase, (b)–(d) showing stepwise formation of the B2 mesophase on cooling (a) with dim (less intense) light, (e)–(h) showing the disappearance of (d) on increasing the light intensity at constant temperature (121.6°C)



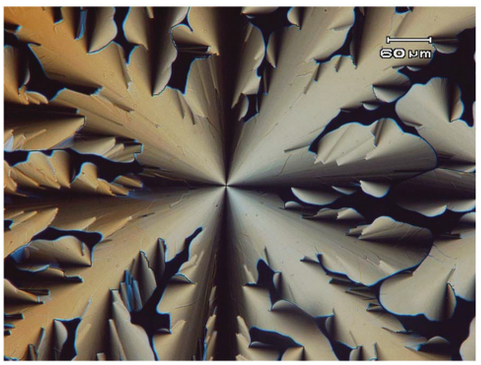
POM textures obtained on cooling from the isotropic liquid:
(a) B1 mesophase (150°C) exhibited by the compound A-5,
(b) formation of the spiral texture of B7 mesophase (163.2°C) by the compound A-12,
(c) checker-board texture of B7 mesophase (155°C) of the compound A-12,
(d) B1 mesophase (120°C) of the compound B-7 and
(e) B2 mesophase (145°C) of the compound B-12

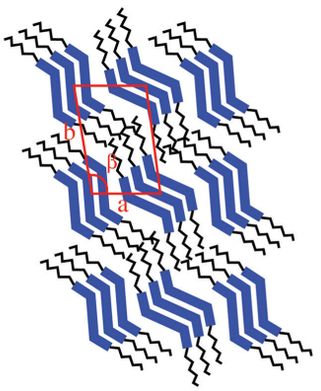
diffraction and electro-optical studies. They are found to exhibit B1 (colr) and B2 (SmCAPA) mesophases. The presence of the –N=N– linkage at different locations in the molecular architecture does not seem to have much effect on the mesogenic behaviour of such compounds. However, the location of the –N=N– linkage is found to have a profound effect on the photo-induced electro-optical properties of these compounds.

Roy and collaborators also investigated three other structural variants of azo substituted achiral bent-core compounds. By way of structural variance, it was the effect of symmetrical and non-symmetrical arms at 1,3-positions of the central phenyl ring on the mesogenic properties of the resulting compounds that was studied. It was found that the nonsymmetrical molecules are more conducive to mesomorphism than the symmetrical ones. The observed mesophases in these compounds were B1 (Colr), B2 (SmCAPA) and B7. The B7 mesophase was found to have a modulated layer structure. Interestingly, a reversible field-induced transition from the B7-like structure to the racemic SmCAPF was also observed. On making a comparative study of photo-induced effects in the B2 and B7 mesophases, it was found that photo-induction was more pronounced in B7 rather than in B2.



Field-induced textural changes of the nematic phase of dimer A-6
(a) 6 V/µm, 120 Hz; (b) 20 V/µm, 1KHz at 145°C; (c) 6 V/µm, 120 Hz and (d) 16 V/µm, 500 Hz at 161°C





POM texture and molecular organization in columnar oblique phase

In another study, three new series of Azo-functionalized dimers composed of banana (bent-core) and rod-like moieties connected via flexible alkylene spacers were synthesized and characterized. Here, the molecular structure and the allied liquid crystalline property of the dimers has been studied, mainly by varying the spacer chain length in addition to the effect of polar –CN end group. A variety of mesophases in these dimers, namely, N, SmA, SmC, SmX, SmY, Colx and Coly were observed. In addition, a re-entrant phenomenon of the mesophases in one of these dimers was also observed. The nematic phases of some of these dimers exhibited electric field induced textural patterns. The dimers were also found to be photosensitive and the T_{NI} was seen to decrease as the illuminated light intensity was increased.

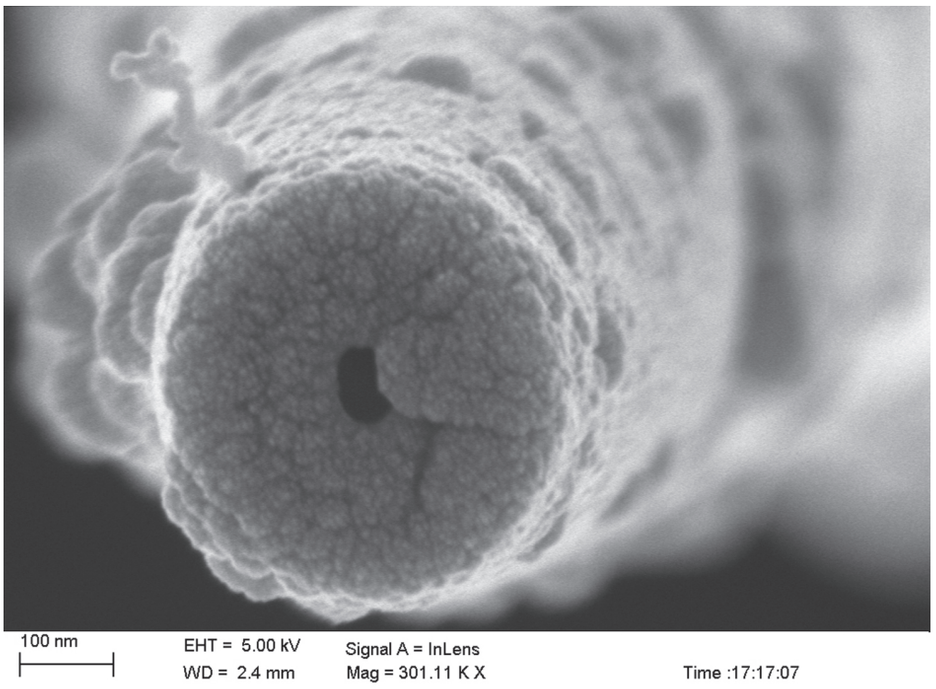
The other major area of research for Arun Roy during the last year has been that of novel zigzag-shaped compounds exhibiting apolar columnar mesophases for which he collaborated with S. Radhika (Student, RRI), M. Monika (VSP student, RRI) and B.K. Sadashiva (RRI). The design, synthesis and characterization of a total of eight different series of compounds whose constituent molecules have a completely new zigzag-shape have been carried out. Two types liquid crystalline phases exhibited by these compounds were characterized as a columnar phase with either a rectangular or an oblique lattice using polarising optical microscopy, differential scanning calorimetry, X-ray diffraction and electro-optical studies. Perhaps, these represent the first examples of a rigid zigzag-shaped compound exhibiting a mesophase.

Besides these broad areas of research, during the last year Arun Roy in conjunction with Anu Renjith (PhD Student, RRI) and V. Lakshminarayanan (RRI) was involved in an *in situ* fabrication of electrochemically grown mesoporous metallic substrate by anodic dissolution in deep eutectic solvents. In this project, a simple electro-deposition process of forming thin films of noble metallic nanoparticles in deep eutectic solvents (DES) was developed. The proposed method utilizes the inherent ability of DES medium to act as a reducing medium and also stabilizing the nanoparticles that are formed. The mesoporous metal films were then characterized by SEM, XRD and electrochemical techniques. The potential application of these substrates in Surface Enhanced Raman Spectroscopy (SERS) has also been investigated. Substantial enhancement of the Raman signal of analytical substance was achieved on this mesoporous silver substrate.

Gautam Vivek Soni is interested in physical & engineering aspects of biological systems. His current professional research interests lie in the nanoscale biophysics of chromatin and its resulting control on biological function. Chromatin is the way any eukaryotic cell engineers the packaging of DNA inside the cell nucleus while keeping the DNA dynamically accessible for information to be read out as necessary for cell function. By the virtue of its dynamic structure, genes on the packaged chromatin can be turned ON or OFF. Gene silencing features in cells that depend on the packaging features of chromatin fibers constitute the core of his research interests.

His research is primarily guided by the intriguing synergy of structures in biological systems and their functional dynamics. He uses, as well as develops, novel nano-technological tools to decipher biophysical principles governing self-assembly of proteins and DNA-protein complexes such as chromatin fibers with collaborators like Prof. Cees Dekker, Kavli Institute of NanoScience, Department of Bionanoscience, TU Delft and Prof. Don Cleveland at Ludwig Institute for Cancer Research, La Jolla CA.

Since joining RRI in January 2014, he has used the RRI mechanical workshop to construct a low-noise enclosure box, which will be extensively used for very sensitive nanopore-based measurements. In a separate project, he fabricated glass nanopores using quartz capillaries and used the SEM facility (a common use facility of the SCM group) to image these glass nanopores.



Example of a quartz nano-pipette with a 35nm aperture designed and built in G.V. Soni's lab

V. Lakshminarayanan's areas of current professional research interests lie in the study of deep eutectic solvents and Silane modified ITO surfaces.

In the year gone by, the work on deep eutectic solvents (DES) started during the previous year has been continued with specific attention to their application in the preparation of nanomaterials. The DES has the advantage of a larger electrochemical potential window compared to usual electrolytes used for nanomaterial deposition, which overcomes the problem of hydrogen/oxygen evolution processes occurring at extremities of the potential. This provides a clear advantage as it prevents the blocking of the surface sites during the nanoparticles depositions.

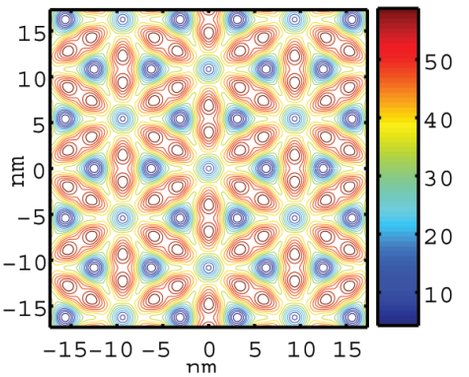
Lakshminarayanan carried the following studies on DES along with RRI Ph.D student Anu Renjith. Using Deep Eutectic Solvent (DES) as a medium, a method of preparation of mesoporous silver substrates has been developed. Since silver nanoparticles are excellent Raman enhancers, they have explored the application of this substrate in surface enhanced Raman spectroscopy in collaboration with Dr. Arun Roy. A huge SERS enhancement of Raman signal of analytes such as Methylene blue and Rhodamine B was observed on the mesoporous silver substrate after removing all the stabilizer molecules from the surface by the method of high temperature calcination. It is estimated that the mesoporous silver film shows an enhancement by a factor of 10^5 for Methylene Blue which suggests its excellent potential for using in ultra trace detection of analytes.

DES as an electrolytic medium for the preparation of noble metal and core-shell alloy nanoparticles has been explored during this period. For example, the gold nanoparticles modified graphite substrate prepared in this medium has been studied for its electrocatalytic application as an anode catalyst for direct ethanol and methanol fuel cells. The studies show that the electrodeposited nanoparticle films provide superior electro catalytic properties for methanol electro-oxidation reaction with lower activation energy making them useful even at ambient temperatures. They also studied the DES medium for the electrochemical synthesis of core–shell nanostructures comprising of Au core and Pd shells and deposition on graphite substrate. The method used is the first report of a single step preparation and deposition of core–shell nanoparticles on a solid substrate. The mesoporous film was examined in detail for its electrocatalytic applications and was found to be a very good catalyst for methanol oxidation and hydrogen evolution reactions. In all the above cases, they have characterized the modified surfaces using FESEM, EDAX and electro-analytical techniques.

A novel non-polymeric gel electrolyte was prepared from a predetermined composition of tetra butyl ammonium salt and ethylene glycol (HBD). Using the already existing concept of a mixture of quaternary ammonium salt and ethylene glycol, they prepared a non-polymeric gel electrolyte, which exhibits some unique electrochemical and rheological properties. They have used the ionic conductivity of the gel as a measure of the progress of the enzyme-substrate reaction. When the gel containing a constant amount of enzyme was allowed to react with different concentrations of substrate, they found that the reaction rate obeys the Michaelis - Menten kinetics. The electrochemical method developed here is quite simple and robust enough to follow enzymatic reactions in a medium that mimics the biological environment.

During the year gone by Lakshminarayanan, along with RRI PhD student Jagadeesh, has been studying the silane modified surfaces for their electrochemical redox response. While organic thiol modified surfaces are very well studied, the corresponding reports on the electrochemical behavior of silane self-assembled films on ITO surfaces are quite few. Lakshminarayanan and his collaborator have explored the 3-amino propyl trimethoxy silane (APTMS) modified Indium tin oxide (ITO) surface for the adsorption of lipids and proteins. The terminal hydrophilic amino group of APTMS has a good anchoring ability to bind many of the biomolecules. The adsorption of phospholipid molecules on the silane modified surfaces show that they undergo physical adsorption through electrostatic interactions. Morphological images analyzed through Atomic Force Microscopy (AFM), Scanning Electron Microscopy (SEM) and Scanning Tunneling Microscopy (STM) confirms that APTMS adsorbs on ITO as dense clusters of polymeric film rather than as a simple monomeric film. The silane-modified substrate has been demonstrated as an effective platform for immobilizing bio-molecules, nano structures, etc. Studies show that redox active molecules such as ferrocyanide and hexammino ruthenium tend to irreversibly adsorb on the surface of the silane modified electrodes. This provides a route for using the redox species as potential mediators in biomolecular reactions, an aspect which is currently being explored in the laboratory.

The SCM group facilities such as FESEM and Raman microscope have been extensively used for characterizing and studying the surface morphology and adsorption properties of the silver, palladium and Au/Pd (core-shell) nanoparticles and for establishing their chemical composition (using EDAX). The FESEM is also being used for imaging the silane and lipid modified surfaces. Using the Raman microscope, the SERS studies of methylene blue and Rhodamine–B adsorption on silver nanoparticles and discotic liquid crystal modified graphene oxide surfaces were performed. The AFM has been made use of for the study of the electrochemically generated graphene oxide and the adsorption of lipid molecules on the silane surfaces.

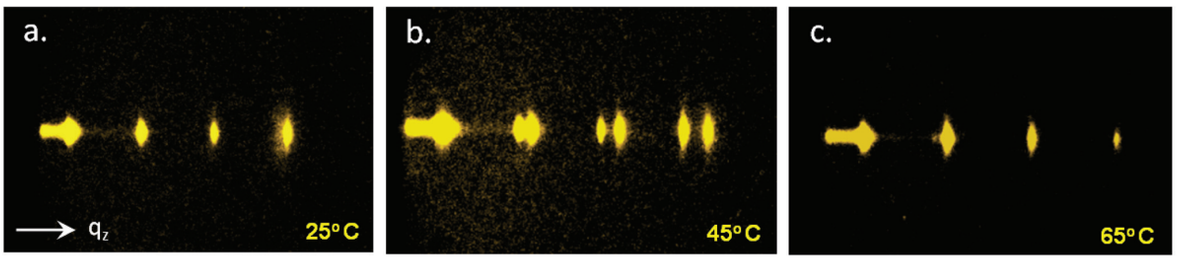


Electron density map of the two-dimensional super-hexagonal phase of DNA-surfactant complex. Red discs denote cross-sections of DNA and blue ones those of the cylindrical micelles.

V. A. Raghunathan pursued research in two major problems during the previous year – structural transformations of DNA-surfactant complexes along with S. Madhukar (PhD Student, RRI) and phase behaviour of lipid-sterol membranes in collaboration with P.K. Shabeeb (PhD Student, RRI).

DNA forms complexes with cationic surfactants that self-assemble into cylindrical micelles. These complexes are analogues to two-dimensional ionic crystals. Structural transformations of these complexes driven by salt and osmotic pressure have been studied using x-ray diffraction techniques. Effect of the micellar size on the stability of different structures has also been probed. Work is in progress to understand the formation of different structures observed in these systems in terms of the interactions between the two macro-ions.

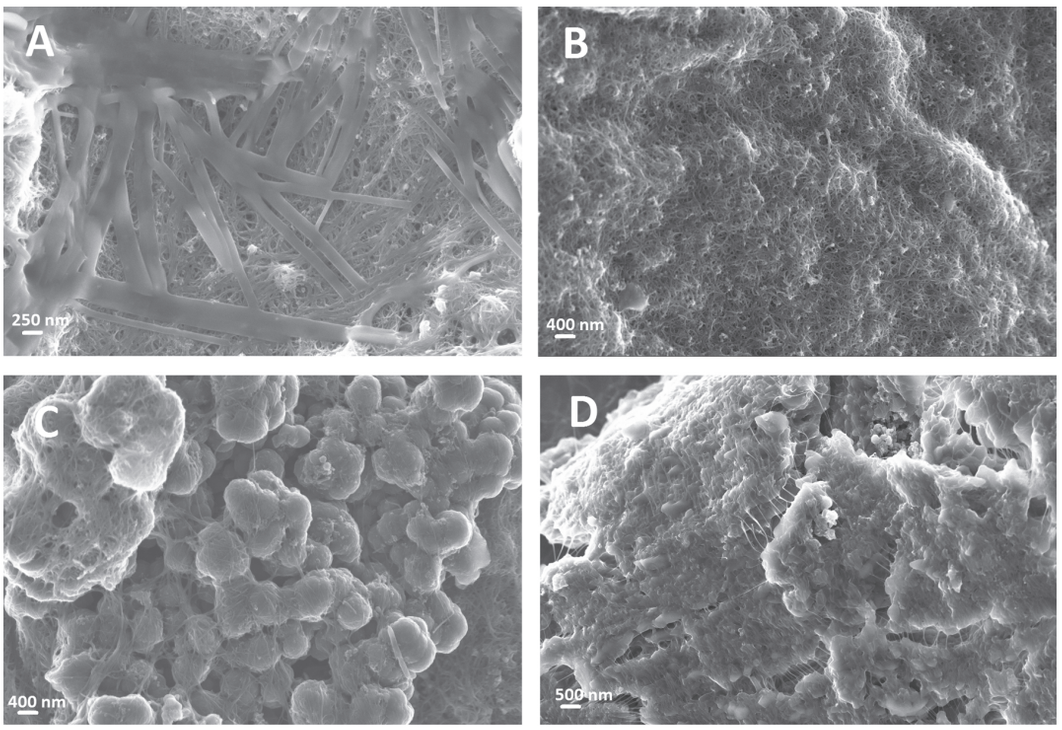
Sterols, such as cholesterol, are major components of biomembranes, and their effect on the phase behaviour of lipid membranes has been studied extensively. Although some of the early studies indicated that cholesterol induces fluid-fluid phase separation in lipid bilayers, later experiments have conclusively ruled out this possibility. The group has recently discovered that some derivatives of cholesterol induce fluid-fluid coexistence in lipid membranes. These results are interesting since such phase coexistence has been proposed to be important for the functioning of biomembranes. Work is underway to understand the microscopic origin of this unusual behaviour.



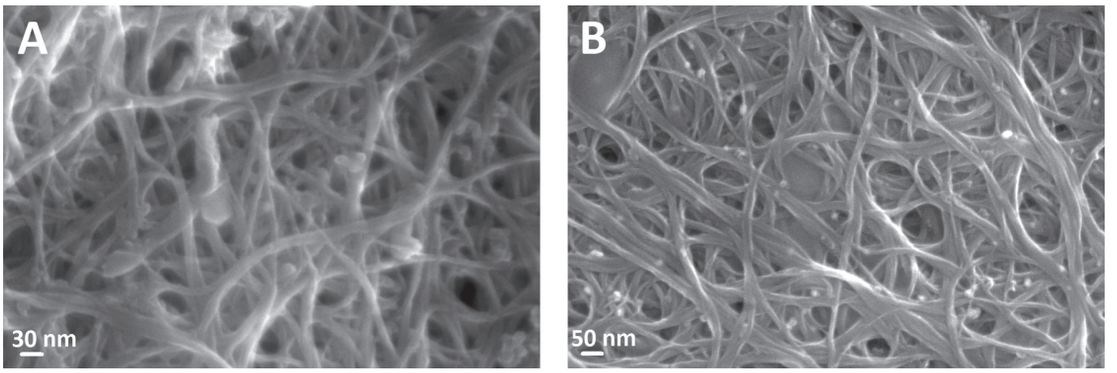
X-ray diffraction patterns of lipid-sterol membranes revealing the coexistence of two phases at intermediate temperatures.

D. Vijayaraghavan is interested in the electrical, optical and diamagnetic properties of nanoparticles dispersed lyotropic liquid crystals and surfactant solutions. He is also carrying out high resolution proton NMR studies on these systems.

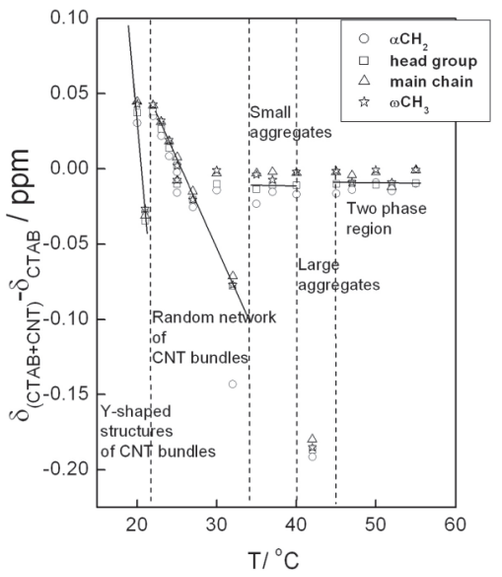
In recent work, he has dispersed a small amount of single walled carbon nanotubes (SWCNTs) bundles in a dilute aqueous solution of cetyltrimethylammonium bromide (CTAB) and found interesting self-assembled structures of carbon nanotube bundles. As seen from the scanning electron microscopy images this SWCNTs-CTAB system exhibits Y-shaped CNT structures, random network of CNT bundles, and small and large aggregates of CNT structures on heating. His high-magnification SEM images showed some bright regions in association with the self-assembled structures of CNTs (Fig. 2). It is believed that these bright regions are related to the aggregation of CTAB molecules associated with the CNT structures. He has also analyzed the association of CTAB molecules with these CNT structures using high-resolution proton NMR chemical shifts of the molecular groups of CTAB as a function of temperature. The results of the NMR study suggest a correlation between the association of CTAB molecules with the CNT structures and the chemical shifts of molecular groups of CTAB. For example, when the CTAB molecules are adsorbed on the outer surface of CNT structures, the chemical shifts of the molecular groups of CTAB in the composite



SEM images of self-assembled CNT structures of 0.1 wt% single-walled carbon nanotubes dispersed in a dilute aqueous CTAB solution as a function of temperatures A) Y-shaped CNT structures (T=22°C), B) random network of CNT structures (T=28°C), C) small spherical CNT aggregates (T=36°C) and D) large irregularly shaped CNT aggregates (T=42°C).



High–magnification SEM images of self-assembled CNT structures with the associated CTAB molecules (bright regions) in SWCNT-CTAB-water system at various temperatures in the temperature range 23 to 35°C. A) CTAB molecules adsorbed on the outer surface of the random network of CNT bundles (T= 24°C), B) small number of CTAB molecules in the pores of random network of CNT bundles (28°C), C) large number of CTAB molecules in the pores of the random network of CNT bundles (T=33°C).



Temperature dependence of the difference in chemical shifts ($\delta_{CTAB+CNT}$ - δ_{CTB}) of the molecular groups of CTAB.

shift downfield and when the CTAB molecules are trapped in the pores of the CNT structures the chemical shifts of the molecular groups of CTAB in the composite shift upfield with respect to those in the pure CTAB solution. Vijayaraghavan has found discontinuous changes at the nanotubes structural transition temperatures. It is also inferred that the observed downfield shift of CTAB molecular groups in the CNT composite with respect to those in the pure CTAB solution are due to the adsorption of CTAB molecules on the outer surface of CNT bundles and the upfield shift of CTAB molecules in the composite with respect to the pure CTAB solution are due to the trapping of CTAB molecules in the pores of the CNT structures.

T.N. Ruckmongathan's areas of current professional research interests include display devices and the application of signal processing to driving LCDs. During the year gone by, Ruckmongathan's research themes included exploring the application of compressive sensing to driving displays and the potential of micro-pulse width modulation for grey scales in display devices and for driving Matrix LCDs.

Harsha Mohan Paroor's areas of current professional research interests are in experimental Soft Matter Physics; to be more specific, in dynamics at interfaces, phase separation, surfactant systems, microemulsion and rheology of colloids. Over the year gone by, Paroor has been conducting experiments on birefringence studies of the interface induced anisotropy observed in aqueous clay suspensions in collaboration with Ranjini Bandyopadhyay and Arun Roy (RRI).

She has set up an experimental arrangement to study the birefringent property of the sample [Fig. 1]. Data has been collected [Fig. 2] and analysed. The time required for the clay suspensions to show birefringence as well as the strength of the birefringence is studied using this setup.

Also, using Dynamic Light Scattering set up in Ranjini Bandyopadhyay's lab, she has made some preliminary measurements to investigate the dynamics of the orientational ordering in aqueous clay suspensions.

However, Paroor has made further improvements in the birefringence measurement by using a novel method. Previous investigations on the birefringence have only considered transmitted intensity of light through crossed polarisers and the sample as a measure of birefringence. During the period between 2013-2014, Paroor has set up an improved arrangement, based on lock in detection, to measure even mild birefringence and hence the order in clay suspensions. This is achieved using a photo elastic modulator, whose retardation axis defines the 0^{o} for the coordinate system of the setup [Fig 3]. The modulated light passes through the sample to a second polariser, then to a detector. The detector output is split with one branch going to a lock-in amplifier for detection of the 1f AC signal and the other branch goes to a DC

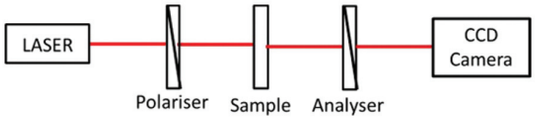


Fig. 1: Experimental setup for the birefringence study

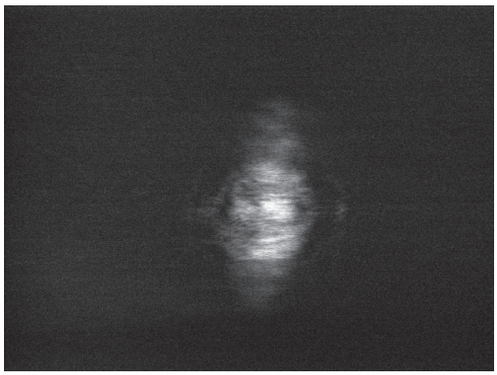


Fig. 2: Sample data of the birefringent-Laponite suspensions captured in the CCD camera.

voltmeter. The ratio of V_{1f} to V_{DC} gives quantity R_{1f}. Later the sample retardation is calculated as

$$\delta = \sin^{-1}\left[\frac{R_{1f}}{\sqrt{2}J_1(A)}\right]$$

where $\sqrt{2}$ is a correction factor and $J_1(A)$ is a Bessel function of the PEM retardation A. Birefringence can be calculated from the sample retardation as $\Delta n = \delta\lambda/2\pi d$; where λ is the wavelength of the laser and d is the sample thickness.

The rotational stages on the vertical bench have been designed and made in RRI Mechanical Engineering workshop. This vertical optical bench is recommended since the sample may be supported on a shelf with a hole for the light to pass through. Movement along the length of the sample is achieved using a translational stage with an accuracy of 0.01 millimetres.

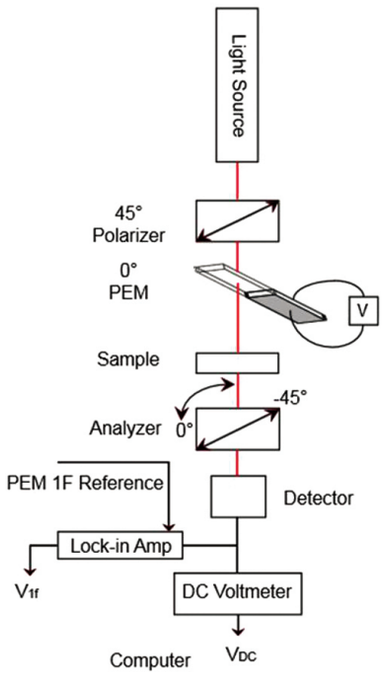


Fig 3: Schematic Diagram of the setup to study the height dependent extension of the orientational ordering in aqueous Laponite suspensions.

Aqueous Laponite suspensions have been prepared to investigate the aforementioned questions. The influences on the orientational ordering by the different cluster size, different pH and dissolution of air in the sample are also being investigated now using this improved set up.

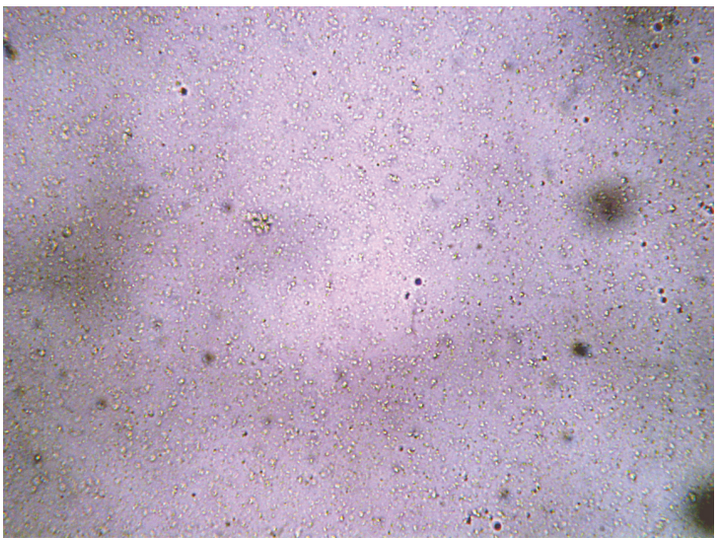
Pramod Tadapatri's areas of current professional research interests are dielectric properties of polyelectrolytes and electric field induced phases in bent core liquid crystals.

During the year gone by his research comprised primarily of optical and dielectric studies on polyelectrolytes. Polyelectrolyte aqueous solutions when mixed in a proper ratio undergo liquid-liquid phase separation and can lead to polyelectrolyte complexes. This phenomenon is called "Coacervation". Depending on the process that leads to coacervation these are classified into simple and complex. Addition of salt can bring about simple coacervation whereas the complex category is brought about only by the interaction of two oppositely charged macromolecules. The basic process that leads to coacervation is yet to be understood. Understanding it is useful because there are many potential applications of coacervates starting from protein purification, drug encapsulation to treatment of organic plumes. Probing the system with dielectric spectroscopy more information on the interaction between the counterion released in the aqueous solution and the polyelectrolyte chains can be obtained.

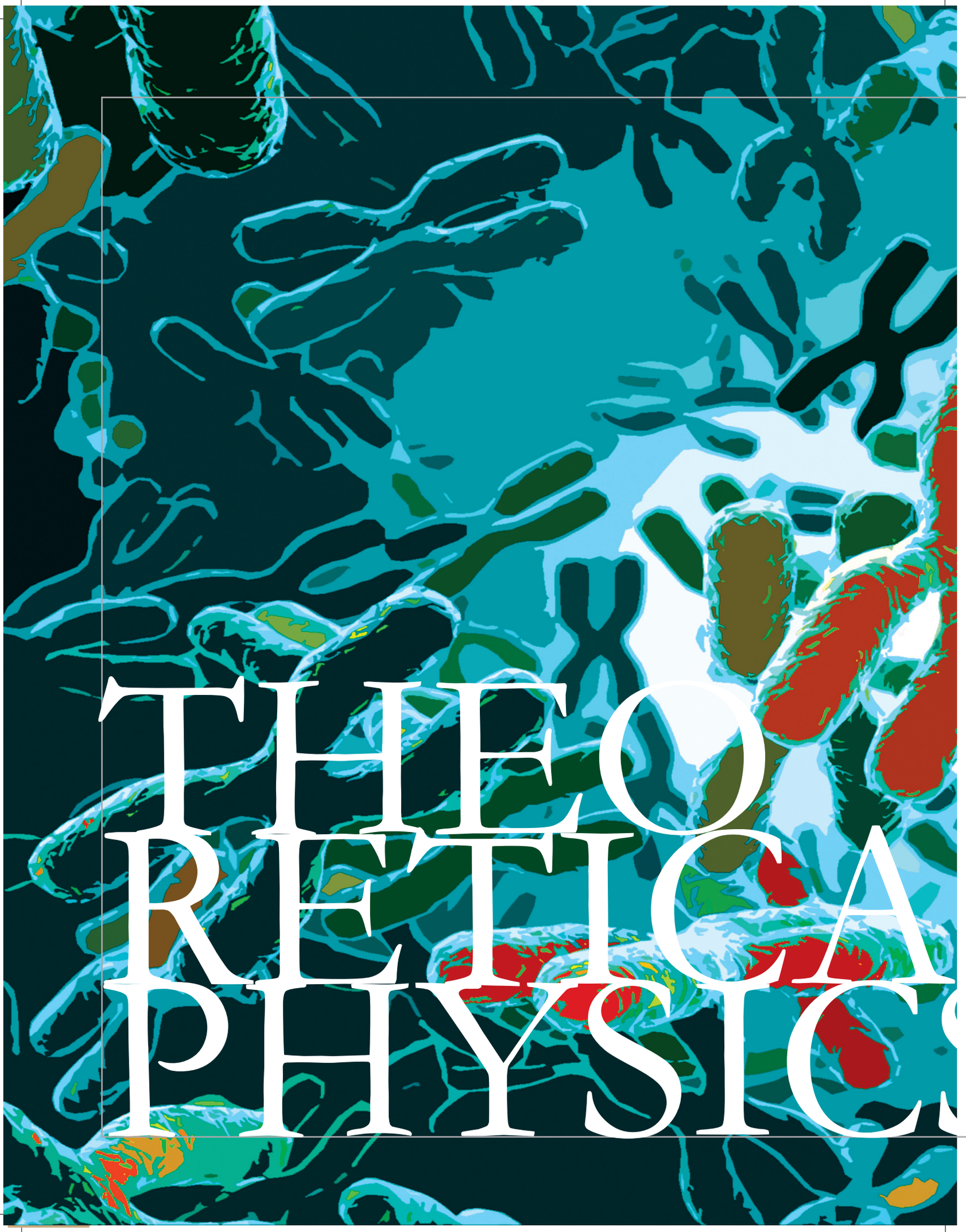
Optical studies were done on two polyelectrolytes namely Poly(allylamine hydrochloride) (PAH, $(C_3H_4O_2)_n$ Mw~50000) and Poly(acrylic acid) (PAA, $(C_3H_7N)_n$ Mw~58000). The two stock solutions of 2wt% PAA and 2wt% PAH were prepared using deionised Millipore water. Polyelectrolyte complexes (PECs) of different polyion mixing ratios (from 1/9 to 9/1 w/w) were prepared. The solution undergoes liquid-liquid phase separation with a supernatant liquid. Then, the solution was centrifuged at 1000RPM for 5 min. The turbid solution was observed under the microscope and found to be in the polymer-rich 'coacervation phase' as shown in the Figure 1 below. There was no change in this phase with increasing temperature. Another system studied was the aqueous solution of Poly (Sodium 4-styrene sulphonate) (NaPSS, $(C_8H_7NaO_3S)_n$ Mw~70000). Various concentrations were prepared but no coacervation phase was formed.

To conduct dielectric experiments, a custom designed cell was used. The liquid dielectric cell was a parallel plate capacitor with two Platinum electrodes separated by a definite distance (~10mm) having Teflon insulation. The polarization effects of the electrodes were taken care by introducing a third reference electrode (Ag/AgCl electrode). Dielectric spectra were recorded using Novocontrol Alpha-A analyzer connected with ZG4 interface. To be accurate in obtaining data, dielectric spectra were obtained first for tap, distilled and Millipore water; they were found to fit the literature data. The cell was then filled with polyelectrolyte solutions to get their dielectric spectroscopy. Dielectric experiments were conducted on 1/9, 2/8 solutions of the PECs and 2 wt% NaPSS solution. Interestingly, experiments on PECs reveal new relaxation modes especially at low frequencies. Apart from this, some preliminary turbidity measurements were also conducted.

Most importantly, a relaxation mode in micro Hz (~200 μHz) frequencies for water has been found. This result can be reproduced and has not been observed so far. His collaborators in this work have been R. Pratibha (RRI, Bangalore) and Prof. M. Muthukumar (Department of Polymer Science and Engineering, Conte Research Center, University of Massachusetts Amherst).



Coacervation phase found in 1/9 (w/w) solution of PAH and PAA. Single polarizer along horizontal direction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Overview

The major areas of research pursued by the Theoretical Physics (TP) group include statistical physics, soft matter physics (including physics in biology), gravitation and general relativity and foundations of quantum mechanics. Within statistical physics, the research interests lie mainly in the areas of mesoscopic physics and non-equilibrium statistical mechanics together with biophysics and soft condensed matter. Within general relativity, the problems currently being explored include gravitational waves and quantum gravity. There is also an interface with the LAMP group and some joint work in the area of foundational questions in quantum physics.

Current Research Interests

Statistical Physics

A theoretical and experimental understanding of heat and electron transport processes in systems of mesoscopic (a few microns to the size of a single atom) scale are fundamentally important to improve the performance of nano-devices and their applications. To this end research is carried out by the TP group on the transport of heat and electricity using the Langevin equation and scattering approaches. The role of disorder, nonlinearity and dissipation on the transport properties of such systems are also under investigation.

Non-equilibrium statistical mechanics is another field of interest for the TP group. Large deviations, probability and statistics of rare and extreme events are some of the problems being explored currently. Fast algorithms from a physical point of view are being developed for this purpose and they are expected to have applications in interdisciplinary problems like finance and cellular processes in biology. That apart, issues pertaining to jamming of granular matter and onset of shear waves in a bacterial bath are being addressed using techniques typical to non-equilibrium statistical physics.

The equilibrium and dynamical properties of polymers is another area of soft condensed matter research that the TP group is currently engaged in. In this area, there are several experimental groups, which can bend and twist DNA molecules to study their elastic properties. The packaging of DNA in the cell nucleus is one of the motivations for the study. The work from the TP group addresses elastic properties of semiflexible polymers over the range of stiffness, using the worm-like chain model. This study can be viewed as an application of the methods of theoretical physics to biology.

Biological Physics

Scientists from the SCM group and the TP group are together involved in the work being done on various topics in the field of biophysics that include vesicle formation and their transport in cells, mitochondrial distribution dynamics and DNA stretching and twisting. Research in biophysics involves active collaborations not only within the Institute but also with the National Centre for Biological Sciences.

Quantum Gravity

The TP group at RRI carries out research on quantum gravity from at least two viewpoints, Loop Quantum Gravity (LQG) and Causal Set Theory (CST).

LQG is a method where standard Hamiltonian ways of quantization are applied to the classical gravitational field without resorting to perturbation theory. The consequent absence of a spatial geometry in LQG has been addressed through some new ideas and tools by the TP group, while the absence of a background time and an overall recovery of the space-time continuum in the classical limit are the two issues being looked into currently. Also applications of LQG ideas to solve a truncated space of homogeneous and isotropic (cosmological) gravitational fields are being actively pursued through studying simpler covariant toy models.

In the CST approach to quantum gravity, on the other hand, one replaces continuum spacetime by a discrete substructure, which is a locally finite, partially ordered set, the Causal Set. While the partial order represents the underlying causal structure of a causal Lorentzian spacetime, the local finiteness encodes the hypothesis of a covariant discrete cut-off. In the CST approach the continuum arises as an approximation, rather than as a limit since the cut-off is a physical input rather than a mathematical convenience as in other discrete approaches. At RRI a broad range of directions in causal set theory have been pursued. These include a close examination of causal set kinematics in which continuum quantities like topology, dimension, curvature and geometry are reconstructed from purely order theoretic considerations. There has also been active work on quantum dynamics, both using numerical MCMC methods as well as the quantum measure approach. In both cases, the construction of quantum observables rests on previous work on causal set kinematics. An important result in numerical simulations for full 2D causal set quantum gravity using the RRI cluster is that the spacetime continuum is emergent.

Another line of investigation motivated by causal sets and quantum cosmology considerations is the quantum measure approach to quantum foundations. Here, one places quantum theory in parallel with stochastic physics with its attendant interpretational generalisations. Work is on at RRI to understand how this framework can be used to obtain covariant observables in quantum gravity.

As an example of the multi-faceted research being carried out by the TP group we have a research problem that explores in detail the analogy between quantum gravity effects that cost too high an energy and are thus unfeasible to test out in a standard laboratory, with the fluctuating surface tension of micron sized fluid membranes. The background to the problem involves the smallness of the cosmological constant, or the dark energy that drives the expanding universe. It has been suggested that quantum gravity fluctuations could lead to this smallness and thus the need to probe more closely quantum gravity effects experimentally. This makes the aforementioned analogous study of surface tension a topic of fundamental importance in the field.

General Relativity

Laser interferometer gravitational wave detectors like LIGO and VIRGO with their remarkable sensitivity to wave signals from distant astrophysical sources have sparked off dedicated research in the calculation of gravitational waveforms from inspiralling binaries. The wave signals received by LIGO and VIRGO are, however, weak and heavily noise-ridden, which in turn intensifies the need for accurate templates to compare and cross-correlate with the data. The TP group at RRI examines this signal detection using future space based gravity-wave detectors like LISA and performs a complete and detailed study of the entire waveform. Taking into account the entire waveform ensures improved angular resolution for super massive black hole binaries and the data obtained is able to achieve a consistency with the dark energy equation of state to within a few percent.

Research is also being carried out on the physical applications of the Ricci flow in general relativity. The latter is a heat equation for metrics and smoothens out geometries and also wipes out memory of initial conditions. Thus Ricci flow and the attainment of thermal equilibrium by a physical system are analogous. This analogy paves the way for the final aim of this study, which is to have a theoretical understanding of black hole entropy.

Ongoing Research

Bala Iyer's current professional research interests lie in gravitational waves and general relativity.

In the year gone by, Iyer studied non-linear multipole interactions in gravitational waves to third and a half post-Newtonian order. His collaborators in this work are Faye G (Institut d'Astrophysique de Paris, Paris, France) and Blanchet L (Institut d'Astrophysique de Paris, Paris, France).

The current project is to extend the computation of GW from inspiralling compact binaries and to obtain the waveform complete at order 3.5PN for all the modes (l, m) in a spin-weighted spherical harmonic decomposition of the waveform. This entails (i) Controlling all non-linear couplings between multipole moments up to order 3.5PN, which involves the important contributions of tails, tails-of-tails and the non-linear memory effect, and the contributions due to the use of specific definitions of source multipole moments; (ii) Obtaining the source multipole moments of (non-spinning) compact binaries compatible up to 3.5PN order, which means essentially, computing firstly the mass octupole moments to order 3PN, since the mass quadrupole moment is already known to that order. This permits the computation of (3, 3) and (3, 1) modes at 3.5PN order.

Narendra Kumar's research interests are generally in Anderson localization, superconductivity, randomness and complexity, fluctuation-dissipation, and decoherence in condensed matter – quantum as well as classical.

During the year gone by, he (along with V. Ranjith) studied light transmission through an ultra-slow-wave optical medium and its resulting complete stoppage. As part of this study, light-wave transmission – its compression, amplification, and the optical energy storage – in an Ultra Slow Wave Medium (USWM) has been studied analytically. A phenomenological treatment based entirely on the continuity equation for the optical energy flux, and the well known distribution-product property of Dirac delta-function has been applied to the problem at hand. The results so obtained provide a clear understanding of some recent experiments on light transmission and its complete stoppage in an USWM.

Ranjith and Kumar also worked on tight-binding models that render 'Quantum First Passage Time' speakable. The calculation of First Passage Time (and its Probability Density) has been generally viewed as an ill-posed problem in the domain of Quantum Mechanics (QM). The reasons for this have been often summarily attributed to the violation of the Kolmogorov Sum rule for probabilities in QM: The probability for entering and non-entering Feynman paths into a given region of space-time does not, in general, add up owing to the interference effects between the two. Here, we present a family of quantum systems, namely the 1D tight-binding Hamiltonian systems, wherein this interference terms dropout, rendering thus the first-passage time problem "speakable". With this premise, we have suitably used a method, due originally to Schroedinger (in 1915), to calculate first-passage time distribution exactly for our model system. This seems very interesting, especially given the fact that the tight-binding models are extensively used to describe real phenomena in condensed matter.

Along with Santanu Das, Kumar has looked into the discrete, the continuous and the "concrete" aspects of classical harmonic dynamics. An elementary treatment of classical harmonic dynamics of a linear (1D) array of identical point-like masses with equal couplings (elastic spring constants) is re-considered in three distinct limits – the discrete, where the mass-points are identical and equi-spaced while the springs are massless; the continuous, where the points are mass-full and uniformly distributed in the 1D elastic medium; and the "concrete" lattice that comprises continuously distributed *elastic couplings with non-zero mass-density* (per unit length) and embedded with equi-spaced identical mass-points – all along the 1D system. Analytical expressions are obtained for some elementary but rather subtle quantities of

physical interest – specially, the mechanical power transported across any arbitrarily chosen site, and the associated mechanical momentum along such an apparently simple purely oscillating 1D harmonic system. This classroom exercise concludes with a suggestion for the possibility that the "concrete" case may well correspond to the hard nanoparticulate crystallites embedded in a 1D elastic continuum, *e.g.*, a spider dragline silk, which is known for its exceptionally fast vibrational energy transport, comparable to that of a diamond.

Madan Rao's areas of research interests include nonequilibrium statistical mechanics and its applications in soft matter and biological physics. That apart, he is also interested in information theory and control theory.

His research focuses on broadly two areas:
i) Understanding the mechanical behaviour of elastic media (amorphous and crystalline solids) from first principles.
ii) Understanding the mechanics of living systems (cells and tissues) at different scales, how this helps in organizing molecules, and their implications for the management of information and homeostatic control.

During the year gone by he has worked on understanding the mechanical response of amorphous and crystalline medium to large deformations and nucleation dynamics and dynamics of solid-solid transformations. This study was undertaken in collaboration with Surajit Sengupta, TCIS-TIFR, Hyderabad.

Under the second broad research theme, Rao has studied molecular transport through the secretory pathway in cells (with Pierre Sens at ESPCI, Paris); the biogenesis of organelles using nonequilibrium physics models (with Mustansir Barma at TIFR, Mumbai); the dynamics of morphology of organelles driven out of equilibrium by active processes of fission and fusion (this includes work done by his group and separate collaborations with Sunil Kumar, IIT-Madras and Pierre Sens, ESPCI, Paris); active mechanics of membranes, polymers, fluids, solids etc. (again this includes work done by his group and separate collaborations with Sriram Ramaswamy, TCIS-TIFR, Hyderabad, Nir Gov, Weizmann Institute, Israel); a study of the active composite cell surface (with Satyajit Mayor, NCBS); cell mechanics, information processing and computation (in collaboration with Garud Iyengar, Columbia University, USA, Sandeep Krishna, NCBS, Satyajit Mayor, NCBS); and finally active tissue mechanics (with Thomas Lecuit, University of Marseilles, France).

Madan Rao and his research group have used the RRI computing cluster to do atomistic MD simulation of a multicomponent membrane to test some of their ideas on the Active Composite Cell surface Model. The RRI computing facility has also been used extensively to study transport problems in crowded cellular environments (Monte Carlo simulations) and in solving partial differential equations that arise in the dynamics of active fluids and active elastomers.

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

During the year gone by he studied the high-energy tail of the velocity distribution of driven inelastic Maxwell gases along with V. V. Prasad of RRI and A. Dhar of ICTS, TIFR, Bangalore.

In this work, a model homogeneously driven dissipative system, consisting of a collection of N particles that are characterized by only their velocities, has been considered. Adopting a discrete time dynamics, at each time step, a pair of velocities is randomly selected. They undergo inelastic collision with probability p. With probability (1-p), energy of the system is changed by changing the velocities of both the particles independently according to v —> a v + x, where x is a Gaussian noise drawn independently for each particle as well as at each time steps. For the case a= -1, although the energy of the system seems to saturate (indicating a steady state) after time steps of O(N), it grows linearly with time after time steps of $O(N^2)$, indicating the absence of a eventual steady state. For -1 < a <1, the system reaches a steady state, where the average energy per particle and the correlation of velocities are obtained exactly. In the thermodynamic limit of large N, an exact equation is obtained for the moment generating function. In the limit of nearly elastic collisions and weak energy injection, the velocity distribution is shown to be a Gaussian. Otherwise, for |a|< 1, the high-energy tail of the velocity distribution is Gaussian, with a different variance, while for a=+1 the velocity distribution has an exponential tail.

Joseph Samuel's current professional research interests are in General Relativity, Statistical mechanics and Elasticity of Semiflexible polymers, and Quantum information theory. A consistent theme throughout his work is the use of geometric and topological ideas in physics. In General Relativity his interest is in understanding how the theory meshes with quantum physics. In this area, an analogy between the statistical mechanics of membranes and quantum aspects of spacetime was developed, leading to connections between surface tension and the cosmological constant. In the area of statistical mechanics of semiflexible polymers, an approach using the geometric phase has led to a solution of a simple theoretical model that captures a range of molecular elastic properties, from DNA to Actin. Samuel is also interested in the physics of information, especially in its quantum aspects and the way it relates to black holes and their entropy.

During the year gone by Samuel's research consisted primarily of two broad themes – i) Three slit experiments and beyond from a path integral perspective in collaboration with Rahul Sawant, Urbasi Sinha and Supurna Sinha of Raman Research Institute and Aninda Sinha of Centre for High Energy Physics, Indian Institute of Science and ii) Quantum limits on the stability of clocks in a gravitational field in collaboration with Supurna Sinha of RRI.

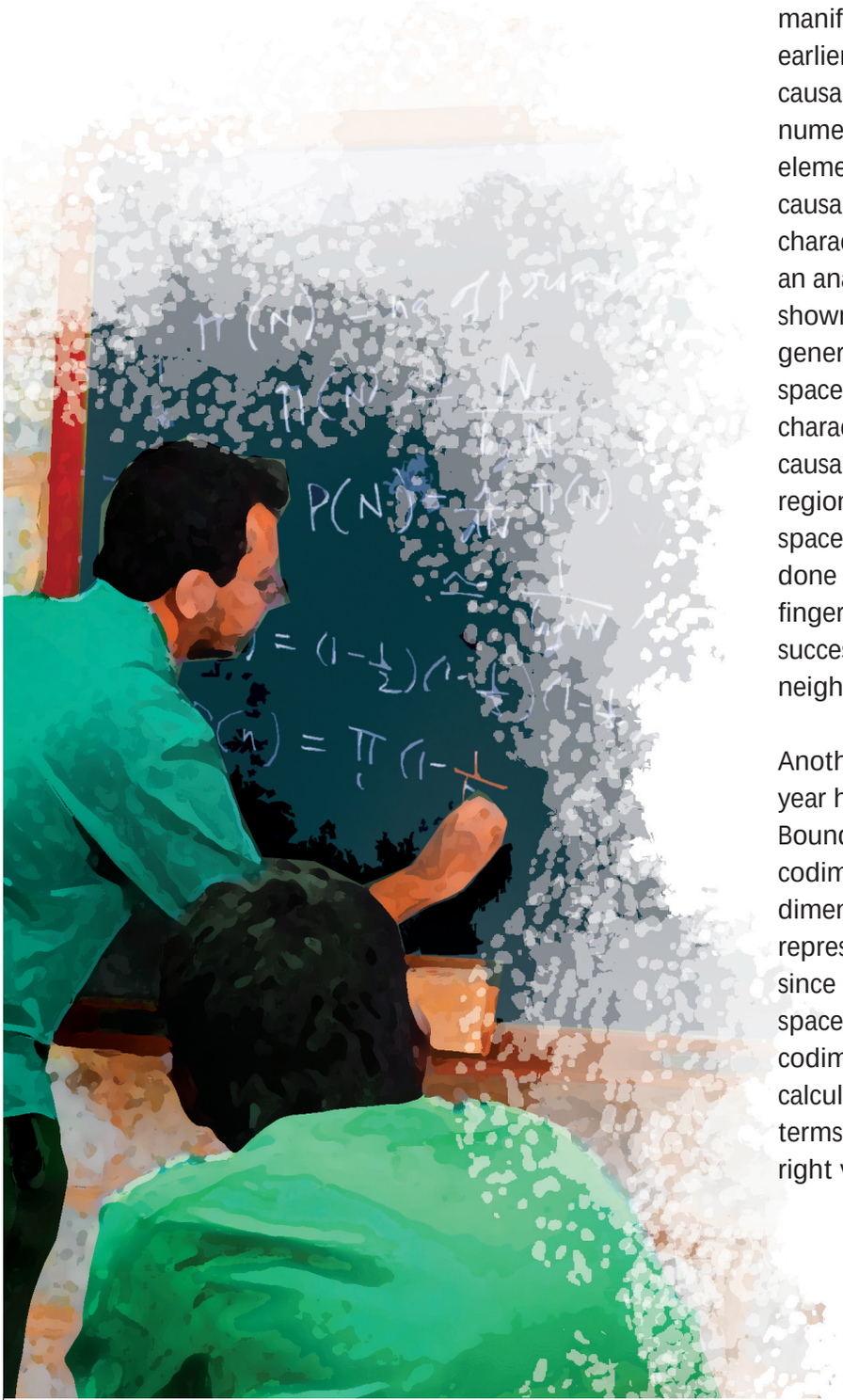
In an n-slit experiment where each slit may be open or closed there are (2^n)-1 configurations possible. From the Schrodinger point of view there is no connection between the outcomes of these experiments since they correspond to different boundary conditions. However, the Feynman path integral form suggests that in an approximate sense these outcomes may be related. This study looks at the extent to which this approximation holds in a 3-slit experiment.

Samuel's study on the stability of clocks, explores the fundamental limits on time keeping due to quantum mechanical and gravitational effects on the stability of clocks. Good clocks are of importance both to fundamental physics and for applications in astronomy, metrology and global positioning systems. In a recent technological breakthrough, researchers at NIST have been able to achieve a stability of 1 part in 10^8 using an Ytterbium clock. This naturally raises the question of whether there are fundamental limits to the stability of clocks. In this work Samuel and his collaborator have pointed out that gravity and quantum mechanics set a fundamental limit on the stability of clocks. This limit comes from a combination of the uncertainty relation, the gravitational redshift and the relativistic time dilation effect. For example, a single ion Aluminium clock in a terrestrial gravitational field cannot achieve a stability better than one part in 10^{22}. This observation has implications for laboratory experiments involving both gravity and quantum theory.

Supurna Sinha's areas of research interest are, generally speaking, in theoretical physics and in equilibrium and non-equlibrium statistical mechanics and soft condensed matter in particular. Over the year gone by Sinha has been pursuing research in the following problems.

Statistical Mechanics of bent twisted ribbons (in collaboration with Joseph Samuel, RRI). The study involves the formulation of an analytical study of bent twisted ribbons. First the elastic response of a ribbon within a purely mechanical framework is described. Thereafter Sinha and her collaborator have studied the role of thermal fluctuations in modifying its elastic response. The results led them to predict 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.

Apart from the problem stated above, Sinha has also worked on a study involving three slit experiments and beyond from a path integral perspective (in collaboration with Rahul Sawant, Joseph Samuel, Urbasi Sinha of RRI and Aninda Sinha of Center for High Energy Physics, Indian Institute of Science) and the quantum limit on stability of a clock in a gravitational field (in collaboration with Joseph Samuel). Details on the last two problems are to be found in the research summary of Joseph Samuel.



Sumati Surya's research interests lie in classical and quantum aspects of gravity. The main focus of her research in the year gone by has been geared towards arriving at a definition of locality in a manifold-like Causal Set – a work that she collaborated on with Lisa Glaser of the Neils Bohr Institute, Copenhagen.

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 this means that there are local regions that are approximately like flat spacetime. 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.

Another project for Surya during the past one year has been that of Gibbons Hawking Boundary Terms for a Causal Set. Any codimension $k < n$ surface in a spacetime of dimension n does not have a faithful representation in the underlying causal set, since any such surface has measure zero in a spacetime Poisson sprinkling. However, codimension 1 and 2 surfaces are important for calculating the boundary Gibbons Hawking (GH) terms, which in turn are crucial to (a) giving the right variational principal in GR and (b) making

the action additive. Analytic results from previous work made it possible to show that the Benincasa-Dowker action for causal sets reduces, in the continuum limit, to the volume of the codimension 2 spatial boundary of a causal interval in flat spacetime in any dimension. In the continuum calculations for null-boundary the terms are notoriously difficult and lead to divergent answers. One may therefore speculate that this prescription *is* the GH term for such boundaries. In addition, Surya along with Michael Buck, Fay Dowker and Ian Jubb of Imperial College, London, has shown that a causal set proposal for the discrete GH term for spacelike boundaries gives the correct continuum limit.

Another project of note for Surya in this past year has been that of transition probabilities and the Hawking-Hartle Wavefunction in 2D Causal set Quantum Gravity. Lisa Glaser and Surya have adapted the calculation of the expectation values of observables for 2D causal set quantum gravity to fixed initial and final boundaries. This gives an analogue of transition amplitudes for such processes in causal set quantum gravity. In particular this allows a calculation of an expression that can be interpreted in terms of the Hawking Hartle wave function.

Surya along with collaborators Joe Henson (Imperial College), David Rideout (UCSD, San Diego) and Rafael Sorkin (Perimeter Institute) has worked on Markov Chain Monte Carlo simulations for generating Posets upto N=76 elements. In order to set the stage for MCMC simulations for full causal set quantum gravity, it is important to understand how the algorithm fares for the uniform distribution, and to detail the onset of the so-called KR orders which entropically dominate in the large N limit. Using a mixture of link and relational moves, their results provide strong evidence that the KR posets do not dominate the set of n-orders for N less than 76.

In the year gone by Surya has also tackled the question of a Matrix Representation of Causal Set Theory with collaborators Mriganko Roy (PhD student, Raman Research Institute) and Rafael Sorkin (Perimeter Institute). Some of the moves explored in the MCMC simulations discussed above are not useful in getting out of certain bipartite orders, which represent a "glassy phase". In order to expand their algorithm, therefore they have begun MCMC simulations on Directed Acyclic Graphs (DAGs), which are a matrix representation of causal sets. Preliminary work however suggests the appearance of a new glassy phase. Explorations are on to study this new phase.

With Lisa Glaser of Neils Bohr Institute, Copenhagen, Surya has also worked on the Large N Limit of 2D Causal set Quantum Gravity. The results in 2D causal set quantum gravity exhibit a non-extensive behaviour (i.e., dependent on the system size *N*) which makes it difficult to explore the nature of the continuum-crystalline phase transition. It is however possible to rescale the temperature, the action and the non-locality parameter so that the transitions for different *N* collapse onto each other. This suggests that the large *N* limit does indeed exist. This could be useful in finding an RG type flow in these systems, with the hope of providing a non-locality scale in the large *N* limit.

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

During the year gone by he worked towards gauge and diffeomorphism invariance in the Koslowski-Sahlmann representation along with Miguel Campiglia, RRI. This is a major piece of work initiated during the last annual report period.

The discrete spatial geometry underlying Loop Quantum Gravity (LQG) is degenerate almost everywhere. This is at apparent odds with the non-degeneracy of asymptotically flat metrics near spatial infinity. Koslowski generalised the LQG representation so as to describe states labeled by smooth non-degenerate triad fields. Sahlmann further studied his representation with a view to imposing gauge and spatial diffeomorphism invariance through group averaging methods. Motivated by the desire to model asymptotically flat quantum geometry by states with triad labels which are non-degenerate at infinity but not necessarily so in the interior, a generalisation of Sahlmann's considerations to triads of varying degeneracy has been initiated. In doing so, delicate phase contributions to the averaging procedure which are crucial for the correct implementation of the gauge and diffeomorphism constraints, and whose existence can be traced to the background exponential functions recently constructed by Varadarajan have been included. Their treatment emphasizes the role of symmetries of quantum states in the averaging procedure. Semianalyticity, influential in the proofs of the beautiful uniqueness results for LQG, plays a key role in our considerations. As a by product, the group averaging map for standard LQG has been rederived, highlighting the role of state symmetries and explicitly exhibiting the essential uniqueness of its specification.

Varadarajan also studied the quantum configuration space using Koslowski-Sahlmann Representation with Miguel Campiglia. The Koslowski-Sahlmann (KS) representation is a generalization of the representation underlying the discrete spatial geometry of Loop Quantum Gravity (LQG), to accomodate states labelled by smooth spatial geometries. As shown recently, the KS representation supports, in addition to the action of the holonomy and flux operators, the action of operators which are the quantum counterparts of certain connection dependent functions known as "background exponentials". As a part of this study it has been shown that the KS representation displays the following properties which are the exact counterparts of LQG ones:
(i) the abelian_ algebra of SU(2) holonomies and 'U(1)' background exponentials can be completed to a C* algebra
(ii) the space of semianalytic SU(2) connections is topologically dense in the spectrum of this algebra
(iii) there exists a measure on this spectrum for which the KS Hilbert space is realised as the

space of square integrable functions on the spectrum
(iv) the spectrum admits a characterization as a projective limit of finite numbers of copies of SU(2) and U(1)
(v) the algebra underlying the KS representation is constructed from cylindrical functions and their derivations in exactly the same way as the LQG (holonomy-flux) algebra except that the KS cylindrical functions depend on the holonomies and the background exponentials, this extra dependence being responsible for differences between the KS and the LQG algebras. While these results are obtained for compact spaces, they are expected to be of use for the construction of the KS representation in the asymptotically flat case.

The gauge group of gravity in its 4d covariant formulation is that of the Lie group of spacetime diffeomorphisms whereas in its Hamiltonian formulation, the algebra of the generators of gauge transformations is not Lie algebra. This happens because consistent Hamiltonian evolution needs to preserve the spacelike nature of the Cauchy slice whereas the spacetime diffeomorphisms of the 4d formulation are not restricted by this requirement. It is therefore of interest to know what happens to Hamiltonian evolution when it asymptotes to a situation in which the final slice is no longer spacelike. There is a folklore result that it takes infinite time for such a situation to develop. Unable to find a reference showing this, Varadarajan and Campiglia proved the result themselves and, in addition have showed that certain proposed generalizations of Hamiltonian evolution for gravity did not share this beautiful property and would reach the spacelike to null crossover in finite time.

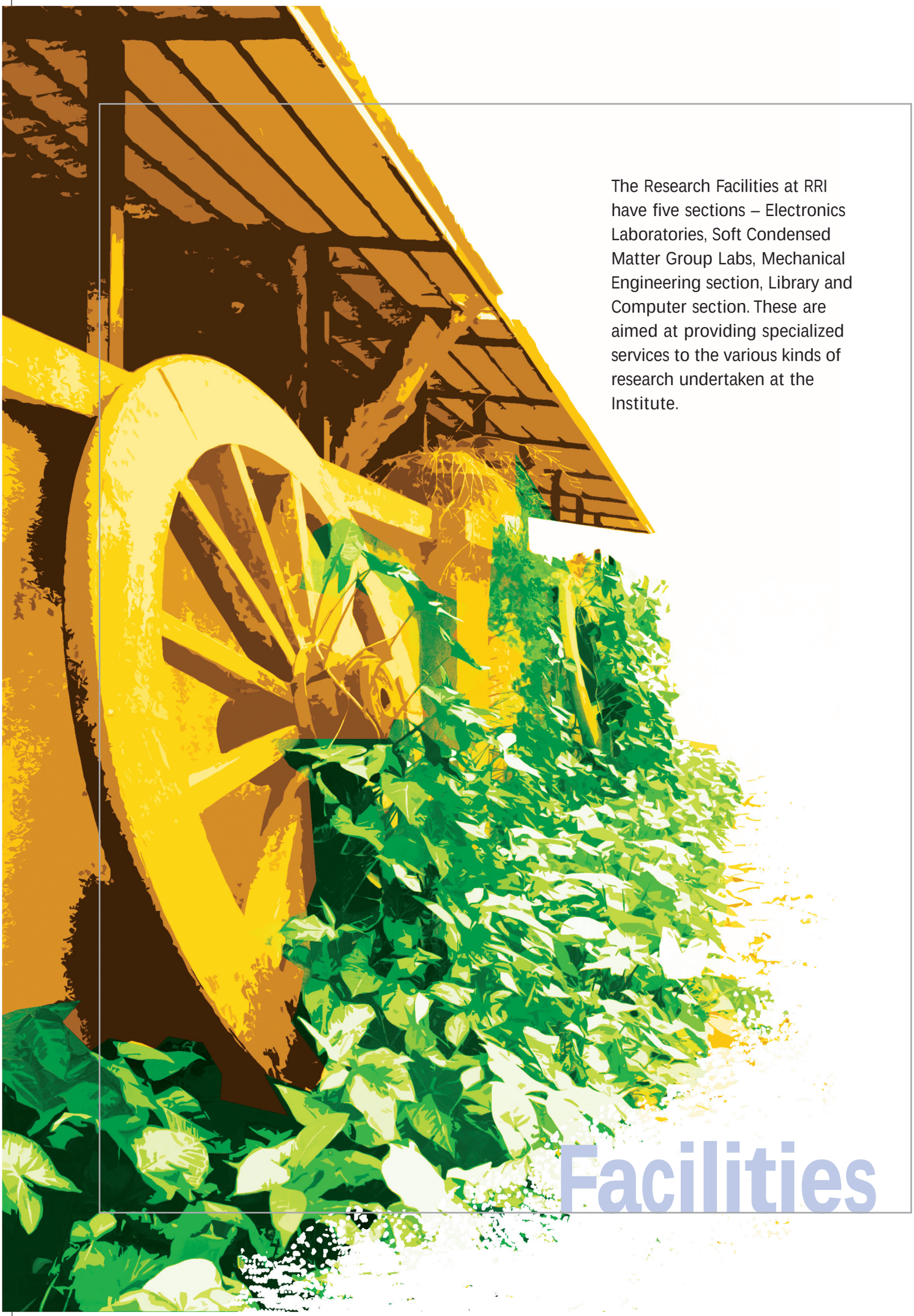
Miguel Campiglia's areas of current professional research interests are in classical and quantum gravity.

During the year gone by he has worked on KS representation of LQG, (Loop Quantum Gravity) with Madhavan Varadarajan (RRI) and (classical) black hole physics in collaboration with Abhay Ashtekar and Samir Shah (Penn State).

Loop quantum gravity (LQG), is an effort at finding a consistent quantum theory for gravity. One of its main successes has been a precise proposal for 'quanta of space', known as 'spin networks'. These quanta of space are excitations around a 'vacuum of geometry' (a state in which geometric objects would have zero areas and volumes). The recovery of classical, macroscopic space from the 'quanta of space' is however quite challenging in this theory.

A way towards incorporating smooth classical geometries within LQG was proposed by Koslowski and Sahlmann (KS) a few years back. Over the past year, in collaboration with Madhavan Varadarajan, Campiglia has been studying this KS representation. They have found, remarkably, that most structures available in LQG admit natural generalizations to the new representation. In particular, they have showed in their first paper, which was published during the period of the last annual report, how diffeomorphism invariance (a key ingredient in Gravity) can be implemented in a similar manner as is done in LQG using KS representation. Further work has been the characterization of the so-called quantum configuration space of this KS representation.

Besides the above, he has completed work in (classical) black hole physics in collaboration with Abhay Ashtekar and Samir Shah.



The Research Facilities at RRI have five sections – Electronics Laboratories, Soft Condensed Matter Group Labs, Mechanical Engineering section, Library and Computer section. These are aimed at providing specialized services to the various kinds of research undertaken at the Institute.

Facilities

Radio Astronomy Lab

RAL or the Radio Astronomy Lab or the Electronics laboratory has skilled electronics engineers, who are capable of conceptualizing, designing, developing and testing complex circuits, customized for special research. One of the major activities of RAL is the design, development and testing of receivers for astronomy. RRI has a long history in the design and development of a variety of analog and digital systems (receivers, spectrometers and correlators) that have improved the capabilities of national and international telescope facilities. The group has designed and built feeds, broadband antennas as well as standard and special purpose front end receiver systems operating at wavelengths from decameter to millimeter. Over the years, the engineers have acquired expertise in the development of FPGA based digital systems.

RAL is equipped with modern measurement and testing instruments for analog and digital electronics. It has fabrication and testing facilities for RF systems, a PCB engraver and modern CAD design packages for the development of FPGA systems. RAL is also fully equipped for the development and testing of X-ray astronomical instrumentation. The infrastructure includes a clean room, X-ray generator, beamline, polariser and monochromator, vacuum systems, mounts and electronics for the evaluation of the performance of X-ray detectors and associated instrumentation.

The major projects that RAL has contributed to in the past year are:

1. Precision spectrometers for Epoch of Reionization & Recombination
2. Brain Computer Interface
3. Bio-Physics
4. LAMP projects
5. Liquid Crystal lab
6. X-ray polarimeter
7. Strategic Engineering Developments
8. STEP-15 metre
9. Development of a wideband digital receiver for radio astronomy

A recently concluded project was the development of digital receivers for the Murchison Widefield Array (MWA). RRI had, a few years ago, entered into the MWA partnership assuming the responsibility for the design and building of the digital receivers for the 2048 dual-polarization wideband 'bow-tie' antennas operating in the frequency range 80–330 MHz, spread over a 3 km area, located in Murchison shire, Australia. RRI had successfully deployed the digital receivers during the period of the last review. The MWA has now been in successful operation in the scientific mode for the past year – a fact that speaks volumes for the quality, reliability and ruggedness of the electronics systems designed, built, optimized and deployed by RRI.

A Full-band Voltage Beam forming mode for the Murchison Widefield Array Digital Receiver is being developed. The digital receiver at the Murchison Wide field Array (MWA) processes signals from eight MWA tiles for a band between 80 and 300 MHz. The digitized outputs

are processed in the digital receiver using a polyphase filter bank to get 1.28 MHz wide sub-bands. During normal operation, 24 such sub-bands (corresponding to a 30.72 MHz band) are selected and sent for processing in an FX correlator. To facilitate sensitive targeted searches and fast transient observations with the MWA, the digital receiver is being enhanced to form a new mode, where a voltage beam is formed across the full 80 to 300 MHz band. The digital receiver's data path and the firmware logic are enhanced to achieve this mode. The enhanced digital receiver can phase the full-band signals from eight tiles to form the voltage beams at each station. This involves phasing of the 8 tiles within each of the stations and the existing data path for 8 tiles within each of the stations. The existing data path for 8 tiles with limited bandwidth is then utilized for data from a single station phased array beam now across most of the ~300 MHz bandwidth. The addition of this beam-former mode to the MWA digital receiver is complete, and the new functionality is being tested in the RRI Electronics Laboratory.

Udaya Shankar N., Anish Roshi D., Avinash A. Deshpande have led the RRI effort, and key RAL participants have been Prabu T., Srivani K.S., Kamini P.A., Madhavi S., Gopala Krishna M.R.

1) APSERa

R. Subrahmanyan, N. Udaya Shankar, S Mayuri, A Raghunathan, R Somashekar, Srivani K.S., Girish B.S. and several Visiting Students and Research Assistants.

The Array of Precision Spectrometers for the Epoch of RecombinAtion- APSERa – is a project to detect recombination lines from the Epoch of Cosmological Recombination. This project shall comprise of an array of 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. As part of APSERa, wide band antennas, front-end receivers and Fast Fourier Transform (FFT) based precision Spectrometer (pSPEC) to sample and process analog signals of bandwidth of about 4 GHz are being developed.

2) Brain Computer Interface

Hema Ramachandran, B. Ramesh with Sujatha S., Ezhilarasi M.S., Somashekar R., Raghavendra Rao K.B., Mohammed Ibrahim, Krishna Prasad, Junaid Ansari and several Visiting Students.

This socially relevant project aims at helping the physically impaired by developing devices that can be operated by brain signals (EEG). The team has developed a generic voice-activated control system that can be used in conjunction with a variety of devices (robotic arm, wheelchair, etc.). The device is now being miniaturised and packaged.

The team has also developed an EEG system that can detect, amplify and digitise EEG signals. Using this, steady-state visually evoked potentials (SSVEP) have been recorded. The ultimate aim is to help a paralysed person activate different devices by utilising SSVEP signals.

Secondly, a voice-activated moving platform (mentioned again during the period of the last report) was brought to its final form, with improvement of the voice-recognition capabilities, optimization of software code, and addition of proximity sensors. This can easily be adapted to a variety of devices like wheelchairs, lifts, and robotic arms.

While wheelchairs have reached a fair level of sophistication, they all lack one aspect – the ability to climb stairs. Ramachandran together with Mohammed Ibrahim (MES) and B. Ramesh have designed and built a prototype that can

climb a flight of steps. This is presently activated by human control using a joystick. Efforts are on to automate it by means of sensors and feedback circuits.

3) Bio-Physics

Pramod Pullarkat with Rishin P.V. and Gopalakrishna M.R. have helped fabricate various key elements for biophysics research at RRI. The particular project involves design and development of a precision X-Y translation stage for use with the microscope in the lab. The unit is designed to facilitate high precision positioning of biological samples in front of the microscope, combined with high levels of repeatability in positioning. Apart from this, the design and development of an Axon puller for experiments on stretching biological Axons is also in progress.

4) LAMP

Sujatha S., B.S. Girish and Somasekhar R., members of RAL, have also worked on various projects of experimental projects of the Light & Matter Physics (LAMP) group. Notable among these is the development of an FPGA based data acquisition system that is used for time-tagged single photon counting. The system provides a time resolution of 5 nanoseconds, and can archive data in real-time. This has been used to measure intensity-intensity correlations of light from a collection of ultra cold atoms.

In addition, RAL members help in designing and building control electronics for frequency stabilized lasers, acousto-optic modulators and magnetic coils used in cold-atom and quantum optics experiments.

5) Liquid Crystals

T. Prabu and Vinutha C. have been involved in the demonstration of Bit Slice Addressing with Texas Instruments DMD Kit.

One of the on-going projects of the Liquid Crystals team at RAL is the demonstration of bit-slice addressing in digital micromirror devices (DMDs). The tiny mechanical mirrors (size of 12 x 12 micrometers) are pixels of a large array (VGA, XVGA etc.) which may be switched at a fast rate to direct light from a source to either ON projection optics or away from it (ON and OFF state of pixels). Project will involve updating the DMD (which is a micro-mechanical device manufactured using semiconductor process) with one bit of the image data at a time and modulating the intensity of the light source simultaneously.

6) X-ray Polarimeter Project

Biswajit Paul with Rishin P.V., Gopala Krishna M.R., Duraichelvan R., Chandreyee Maitra, Rajagopala G., Sandhya P., Mamatha T.S., Ezhilarasi M.S., Nagaraja H.N. and visiting students.

The project involves design and development of an X-ray polarimeter working in the energy band of 5-30 keV based on the principle of Thomson scattering. The instrument is meant to be a payload for a small satellite astronomy mission of ISRO.

The instrument is currently in the Engineering model development phase for most of the sub-systems. On the detector front, mechanical fabrication of the four engineering model units was carried out during the previous years. Two of them have been assembled with wire frames and testing has been completed. The wiring of the third engineering model detector was taken up and completed during this year. The four detectors along with the collimator was assembled together in the Polarimeter configuration and checked for mechanical alignment and compatibility. Apart from this, wiring of a dummy detector wire frame for carrying out vibration tests was also taken up. The plan is to subject this wireframe for qualification level vibration tests and establish reliability. The mechanical design of the jig required for carrying out vibration tests was also taken up.

On the electronics front, lab model version of front-end electronics, processing electronics and the common electronics were developed during the previous years. The main emphasis this year was the conversion of existing Laboratory model electronics to engineering model version. The development of Laboratory model version for the Tele-command and Housekeeping electronics was also initiated during this period.

7) Strategic Developments

Avinash A. Deshpande with Vinutha C., Mamatha T.S., Sandhya P., Raghavendra Rao K.B., Nagaraj H.N., Prabu T., Srivani K.S, Kamini P.A. and Madhavi S.

In the Analog front, a High gain Low Noise Amplifier (LNA) with reasonably high dynamic range for Radio Astronomy observations in strong RFI environment regions is being developed. Another advancement is the design and development of an active circulator for replacement of high rejection band stop filter to avoid the LNA saturation in presence of strong RFI signals. Design and development of a compact Quad Analog Receiver chain is also in progress. Development of firmware for an FPGA based backend to enable on-line spectral and Stokes parameter computation as well as characterizing a 16-bit ADC to assess if the increased dynamic range ensures immunity to RFI are other strategic activities. A miniaturized version of a high-gain analog module consisting of a dual channel heterodyne receiver has been developed and suitable metal housing for this module is being fabricated. A low-cost front-end amplifier module has been developed to provide a flat-gain response over a wide bandwidth with sharp spectral skirts and also allowing rejection of the undesired mid-band region. A Rotman lens for phasing a 1-d array has also been developed for potential applications at low radio frequencies. A prototype in the form of a scaled version at a relatively high frequency is being developed and tested in the Electronics Laboratory of RAL.

8) Fan-beam Telescope

B. Ramesh with Mamatha.T.S, Kasturi.S, Ezhilarasi, K.B.Raghavendra Rao and visiting students.

A Ku-band receiver prototype chain, consisting of LNA, RF and IF GPAs, power dividers, mixers, attenuators, filters, PLL-based local oscillator sources and USB3.0 digitizers is being developed for the Fan Beam Telescope (FBT) by a team, made up of RAL members and VSP students, under the guidance of Ramesh Balasubramanyam. To reduce the overall receiver size, compact and integrated RF components are being developed. The USB digitizer, made of an acquisition board and the handling client software, is envisaged to transfer the sampled IF data straight to the computer hard disk for further processing.

9) Development of a wideband digital receiver for radio astronomy

Girish B.S., Madhavi S., Srivani K.S., Udaya Shankar N, Avinash A. Deshpande and R Subrahmanyan

The development of a generic, high-speed digitizer unit (ViQuad) with the capability to digitize four analog bands, each of ~1GHz bandwidth, was initiated. The aim was to have a common platform that could be used for several applications like broadband spectrometer with a custom-designed channelization algorithm, digital beam forming, pulsar instrumentation and array correlations, with features for data aggregation, packetization and transport through high-speed interfaces. With this in mind, a system was designed and built around two quad analog-to-digital converters (ADCs) and a Virtex-6 Field Programmable Gate Array (FPGA), replete with interfaces to high-speed optical fiber modules, Gigabit Ethernet and a Universal Serial Bus (USB). Two such 18-layer boards were designed, developed, fabricated and assembled in order to evaluate the performance of the ADCs and the Virtex-6 FPGA. As part of the evaluation process, requisite firmware and higher-level routines were developed. The evaluation of the ViQuad has shown that the various stages, namely, individual ADC channels, their respective data paths to the FPGA, and FPGA to PC communication via the Gigabit Ethernet interface are performing to their designed speeds.

As a first application, this high-speed digitized platform, under the name pSPEC (precision SPECtrometer), constitutes the core of the digital receiver system being developed for the Epoch of Recombination Array project. This year has been spent on fine-tuning the firmware and testing the spectrometer for its dynamic range and robustness. Some aspects that were studied in detail are: (1) Necessity to employ an MxN (M pipelined and N parallel FFTs) architecture to implement an 8192-point FFT to channelize a sampled bandwidth of 2 GHz. It may be noted that even though a single 8192-point pipelined FFT engine is available as an IP-core, it is not suitable for our context because an 8192-point FFT engine using Virtex-6 cannot be clocked at more than ~350 MSps. So 1k X 8 complex FFT was decided as optimal for usage, sampling a 2 GHz band with four ADCs each operating at a clock rate of 1 GHz. (2) Matlab simulations to understand the implications of gain, dc & phase offsets in time-interleaved ADCs. They produced an additional component at (sampling frequency/2)- input frequency. 3) The effect of sampling clock jitter on the deviation in the flatness of the sampled pass band was also studied and it was found that a jitter of 200 fs in the sampling clock translates to a bandpass ripple of around 0.001 db. 4) Methodologies to evaluate ERA channelization firmware, at the integrated-level and modular sub-sections of the firmware. Another application that incorporates the Vi-quad board is APODAS v-2, for photon correlation studies.

SCM Group Labs

Chemistry Lab

This lab has state-of-the-art facilities necessary for the synthesis of liquid crystal materials, nanoparticles and other organic and organometallic compounds. Major equipment in the lab includes, microwave synthesizer, rotary evaporators, vacuum pumps, magnetic stirrers with hot plate, etc. Several hundred molecules have been synthesized in the Chemistry Lab.

Analytical Lab

This lab has many modern facilities necessary for the characterization of materials. Major equipment in the lab includes, polarising optical microscopes, differential scanning calorimeter, elemental analyser, thermogravimetric analyser, infrared and UV-visible spectrophotometer, microbalance.

Microscopy and Dielectric Spectroscopy Lab

This lab is equipped with a high performance dielectric measurement system along with multi electrode test interfaces and a high voltage booster for studying broadband dielectric spectroscopy of liquid crystals and polyelectrolytes. Optical polarizing microscopes integrated with a spectrometer and an experimental setup for studying electro-optics, are used in the investigation of phase transitions, defects, switching properties and field induced effects in liquid crystals and liquid crystal-nanoparticle composites. These studies can also be combined with 3-dimensional imaging using a confocal microscope.

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 scattering setup, an acoustic and electro-acoustic spectrometer, a high speed CMOS camera and a rheometer. Rheology, dynamic light scattering, high-speed imaging, ultrasound attenuation and colloid vibration current measurements are some of the measurement techniques used in the lab.

X-Ray Diffraction Lab

The X-ray lab is well equipped for studying the structure of soft matter systems. Facilities available include a powder diffractometer and small-angle scattering instruments. Data can be collected from both oriented and powder samples, over a temperature range from 0 ^{o}C to 250 ^{o}C.

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 motorized microscopes allowing for fluorescence and phase-contrast microscopy measurements, confocal microscope, biosafety

cabinet for growing cells, incubators, centrifuge and a 3D microscope for dissections. Apart from these there are ultra-sensitive force measurement setups like laser based Optical Tweezers and a home-developed optical fiber based force apparatus for studying mechanical properties of neuronal cells.

Nanoscale Physics of Soft and Living Matter Lab

This lab fabricates nanoscale devices to study role of intermolecular interactions in soft matter as well as in biological systems. We aim to understand their structure-function relationship, at single molecule resolution. Common instrumentation developed in the lab are a state-of-the art nanopore rig to measure translocation of single biomolecules through nanopore devices, gel electrophoresis systems, visualization inverted microscopes and a bio-clean DNA and protein workstation. This lab is fast growing to include two more optical setups; one for low-noise laser optical tweezers coupled to nanopore platform and the other a single molecule resolution TIRF microscopy setup.

Electrochemistry and Surface Science Lab

The lab performs controlled experiments on test surfaces in electrochemical cells using electrochemical instruments such as potentiostats, frequency response analyzer and lock-in amplifier. An electrochemical quartz crystal microbalance is used to measure mass changes on the surface *in situ*. Characterization studies of organic thin films are carried out with a variety of surface probe techniques like scanning tunneling microscopy, atomic force microscopy, scanning electron microscopy etc.,

SEM Lab

The SEM lab is equipped with a field emission scanning electron microscope (FESEM). The FESEM has a scanning transmission electron microscope (STEM) attachment that can be used for imaging nanomaterials as well as an energy dispersive X-ray spectroscope (EDX) to identify elements and the surface composition. The FESEM has a local charge compensation mode to enable imaging of non-conducting surfaces and very low voltage operation mode for organic thin film studies. The microscope has a cryo-microscopy attachment to enable imaging soft materials by freeze-fracture method at liquid nitrogen temperatures. The FESEM is being used extensively for studies of nanomaterials, polymers, liquid crystal nanocomposites and soft matter.

AFM Lab

The AFM lab is equipped with Atomic force microscope with several additional features such as STM, conductive AFM, magnetic force and electric force microscopes with built-in temperature controller and environmental chamber. This microscope is used for the surface studies of organic thin films, liquid crystals, graphene materials, nanocomposites and soft materials both on conducting and non-conducting substrates.

NMR Lab

The NMR lab is equipped with a 500 MHz high resolution (Bruker) Nuclear Magnetic Resonance spectrometer with a built-in temperature controller. This spectrometer is mainly used to identify molecular structures using ^{1}H and ^{13}C NMR chemical shifts. Water molecule association with the nanostructures as a function of temperature is also studied using this spectrometer. 2D NMR and spin-lattice relaxation time experiments can also be carried out.

Micro-Raman Spectroscopy Lab

The micro-Raman Spectroscopy Lab is equipped with a state of the art Triple Raman spectrometer with different laser sources with wavelengths from IR to UV range. The setup is also equipped with a microscope hotstage to study samples at different temperatures from -180°C to 300°C. The micro-Raman mapping of the samples can be carried out using a XYZ nanopositioning stage. Raman Spectroscopy is a sensitive and non-invasive technique to recognize and characterize chemical substances within the samples. Small volume of samples can be analyzed to detect the presence of compounds predominantly by the presence of specific chemical bonds. The Micro-Raman spectrometer is being used for studies of nanomaterials, polymers, liquid crystals, nanocomposites, biomaterials and other soft matters.

Magnetic studies Lab

The Magnetic studies lab is equipped with a 2 Tesla electromagnet with adjustable pole gap and a Faraday balance system with a built-in temperature controller. The Faraday balance is used to study the diamagnetic susceptibility (~10^{-7} cgs) of thermotropic and lyotropic liquid crystals, micellar solutions and liquid crystal nanocomposites as a function of temperature. A home built high-resolution optical birefringence (10^{-7} radians) set up is used in conjunction with the electromagnet to study the magnetic birefringence of soft materials. Magneto electrochemistry measurements are also carried out in this lab.

Photophysical studies Lab

The Photophysical studies lab has two major instruments; solar simulator and photoelectrochemical work station. These instruments are used to study photophysical properties of materials.

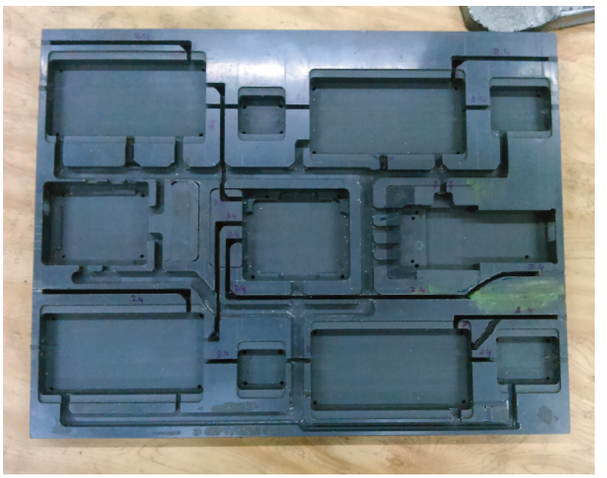
Mechanical Engineering Services

The Mechanical Engineering Services (MES) facilities at RRI consist of a machine shop, and a sheet metal, paint and carpentry shop. Together they cater to the requirements of mechanical design and fabrication of components for the various research groups of the Institute (Radio Astronomy Lab, Light And Matter Physics Group, Soft Condensed Matter Group, X-ray Astronomy Lab, Brain computer interface Lab, Molecular Astronomy Lab, etc.). It has fairly advanced machinery and a team of skilled technicians who undertake the design and fabrication of various sophisticated mechanical components, enclosures, modules and racks.

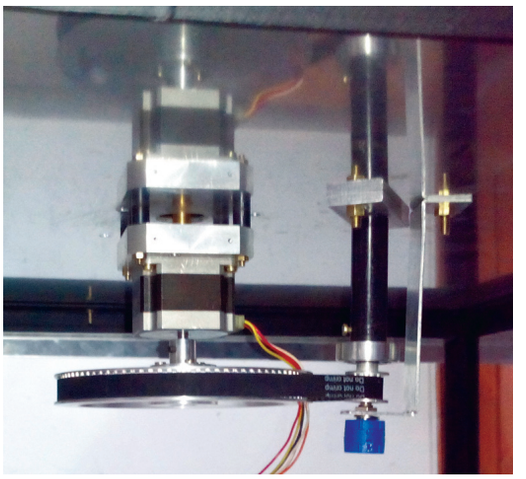
Over the year gone by the major mechanical design and fabrication jobs that have been executed by the MES team for the various research groups of RRI are highlighted below.

Radio Astronomy Lab

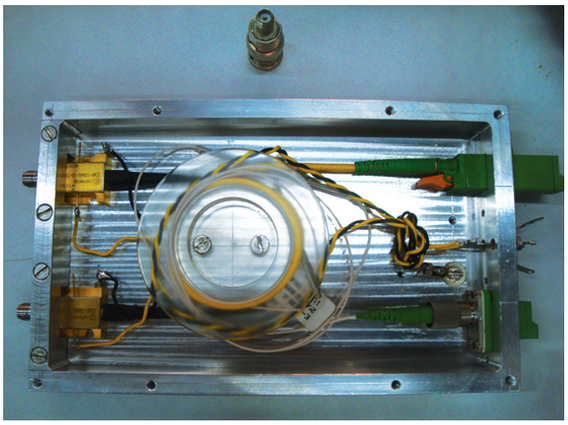
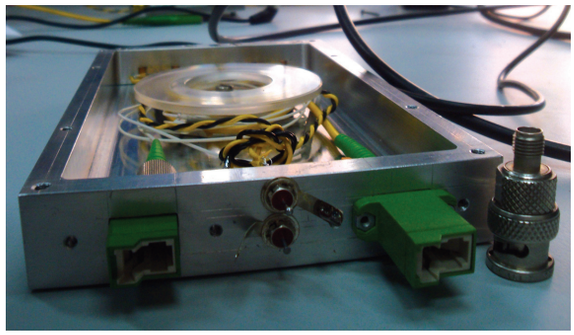
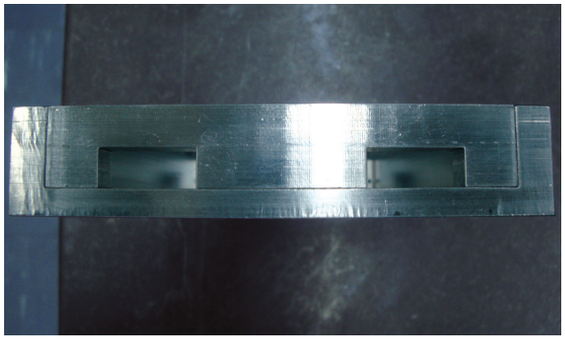
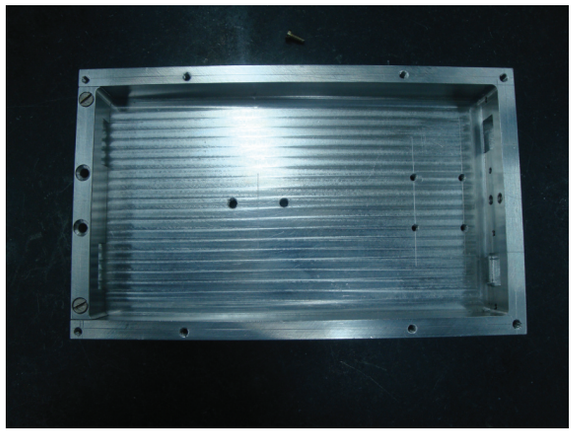
i) Analog chain prototype chassis in PVC for the SD project.
ii) Rotating table assembly with ground plane for the MWA antenna element.
iii) AVAGO fiber optics transmitter and receiver for the ERA project.
iv) 2- 5 GHz monopole antenna.
v) Sheet metal Antenna and ground screen for the ERA and EOR project.
vi) Dual sides filter chassis for the Fan-Beam Telescope project.
vii) Single stage LNA chassis for the ERA project.
viii) Enclosures, modules and rack systems.



PVC analog chain chassis



Rotating table assembly

AVAGO fiber optics chassis

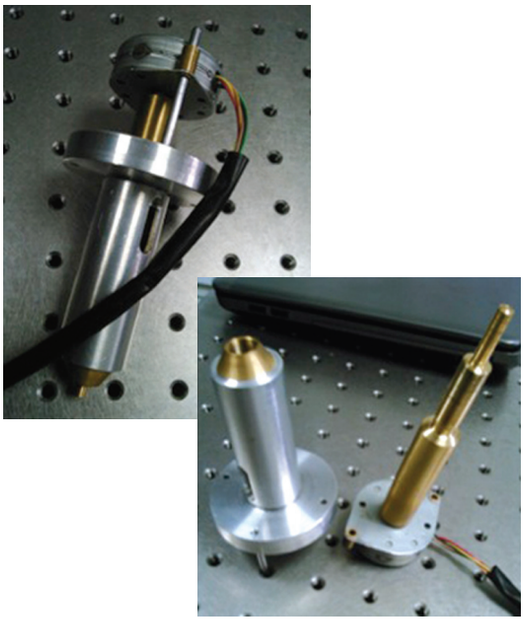
X-Ray Astronomy Lab

For the engineering model of Thomson X-ray polarimeter rectangular detector the following parts were designed and/or fabricated:

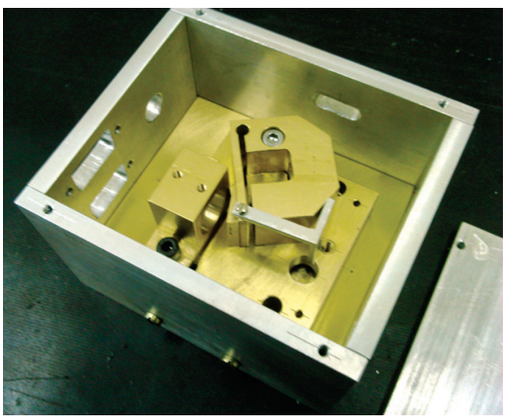
i) An evacuation plate with a slit for shining X-rays which is being used for the purpose of carrying out long term stability tests on the detector and coordinating its CNC fabrication with vendor.
ii) Anode and cathode pins for wire frame of the detector.
iii) The other major work undertaken by the MES for the X-ray astronomy lab is the feasibility and optimization study of a new collimator design. The collimator is designed to have a total length of 200 mm with hexagonal holes forming a honeycomb structure, where each side of the hexagon is 2 mm and the wall thickness between the holes is in the range of 0.2 mm to 0.35 mm. Currently samples are being tried out to optimize the minimum wall thickness achievable without any damage to the hexagonal cells. This is being done in coordination with the vendors for its CNC machining and CNC wire EDM.

LAMP Group Labs

i) Linear actuator as a replicate for the ZST25 actuator by Thorlabs INC for LAMP-QIC lab
ii) External cavity diode laser assembly for LAMP
iii) Mirror mounts, Lens mounts, PMT mount



Linear actuator



External cavity diode laser assembly

Rheology and Light Scattering Lab (SCM group Lab)

i) Rotary stand assembly for the inclined plane to study the clay avalanche model.
ii) Photo gate experimental setup for SCM.

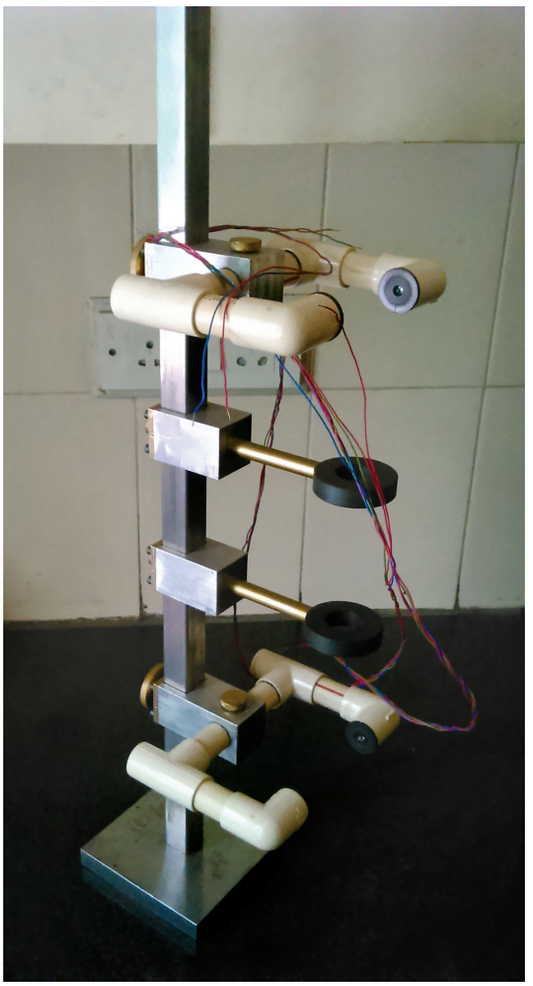


Photo gate experimental setup

Theoretical Physics

i) Polymer stretching experimental setup for the Theoretical physics group.

Polymer stretching experimental setup

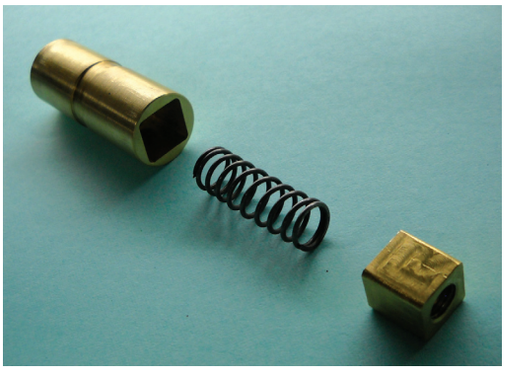
Biophysics Lab

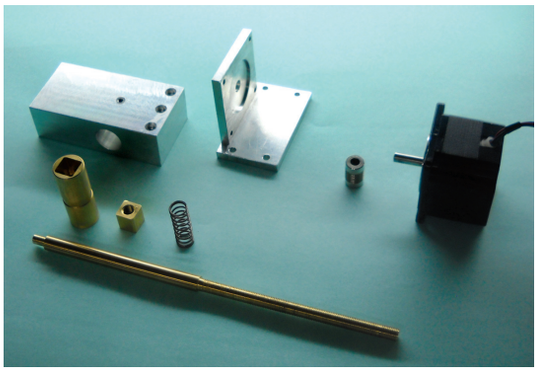
i) The MES designed and fabricated an X-Y stage with high positional accuracy and repeatability with minimal backlash so as to achieve better operational flexibility and performance, and also with a clutch mechanism and limit switches on both axes that can be used for positioning samples in front of a microscope.

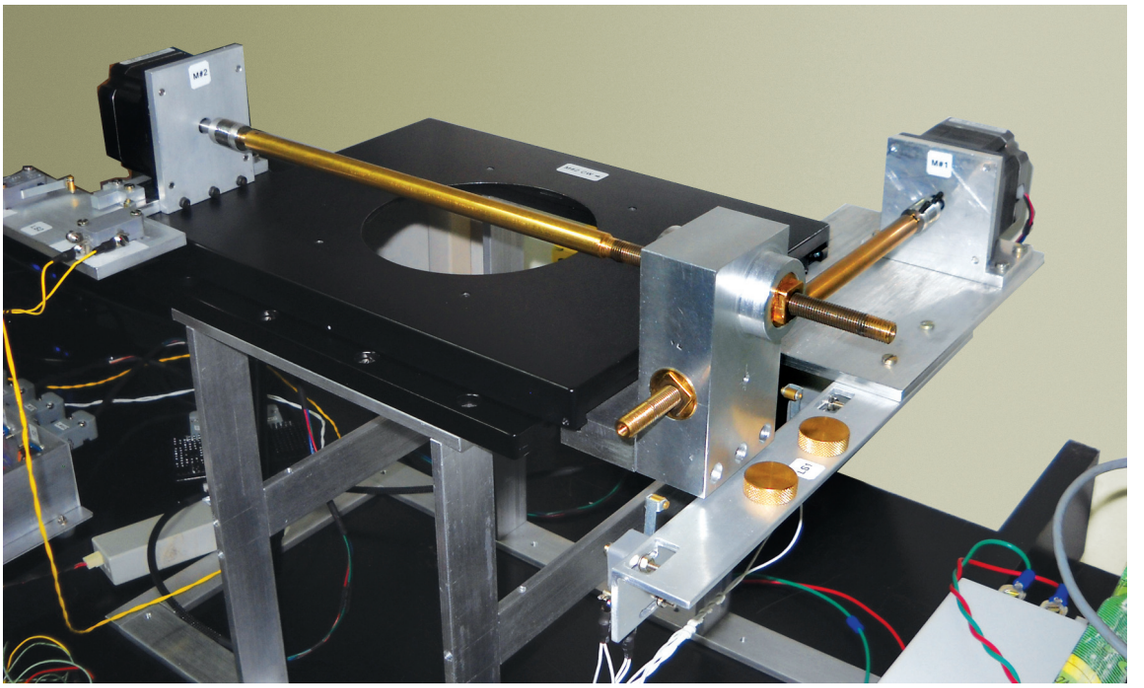
ii) Axon Puller stage with a very slow speed motion stage so as to stretch the biological axons.

iii) Photodiode adaptor for the Inverted Light Microscopes at Bio Physics lab.

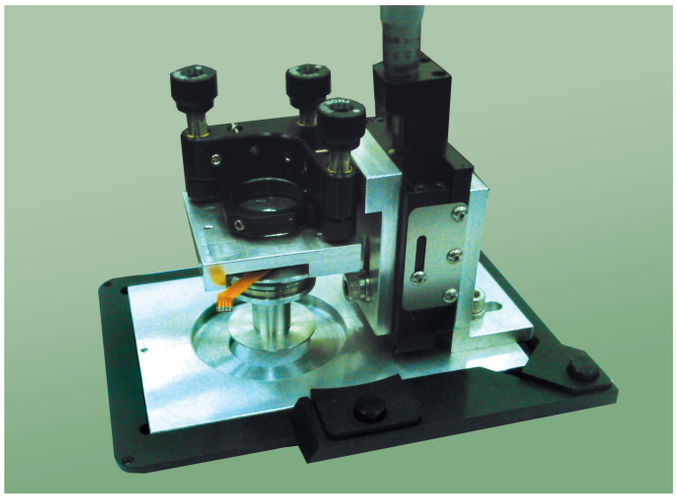
iv) Shear cell assembly.







X–Y Stage setup



Shear cell assembly

Brain computer interface Lab

i) Dry and cup Electrodes (Copper sheet cup electrodes, copper rod electrodes)
ii) Stair climbing wheelchair
iii) Arduino card Chassis

BCI electrodes

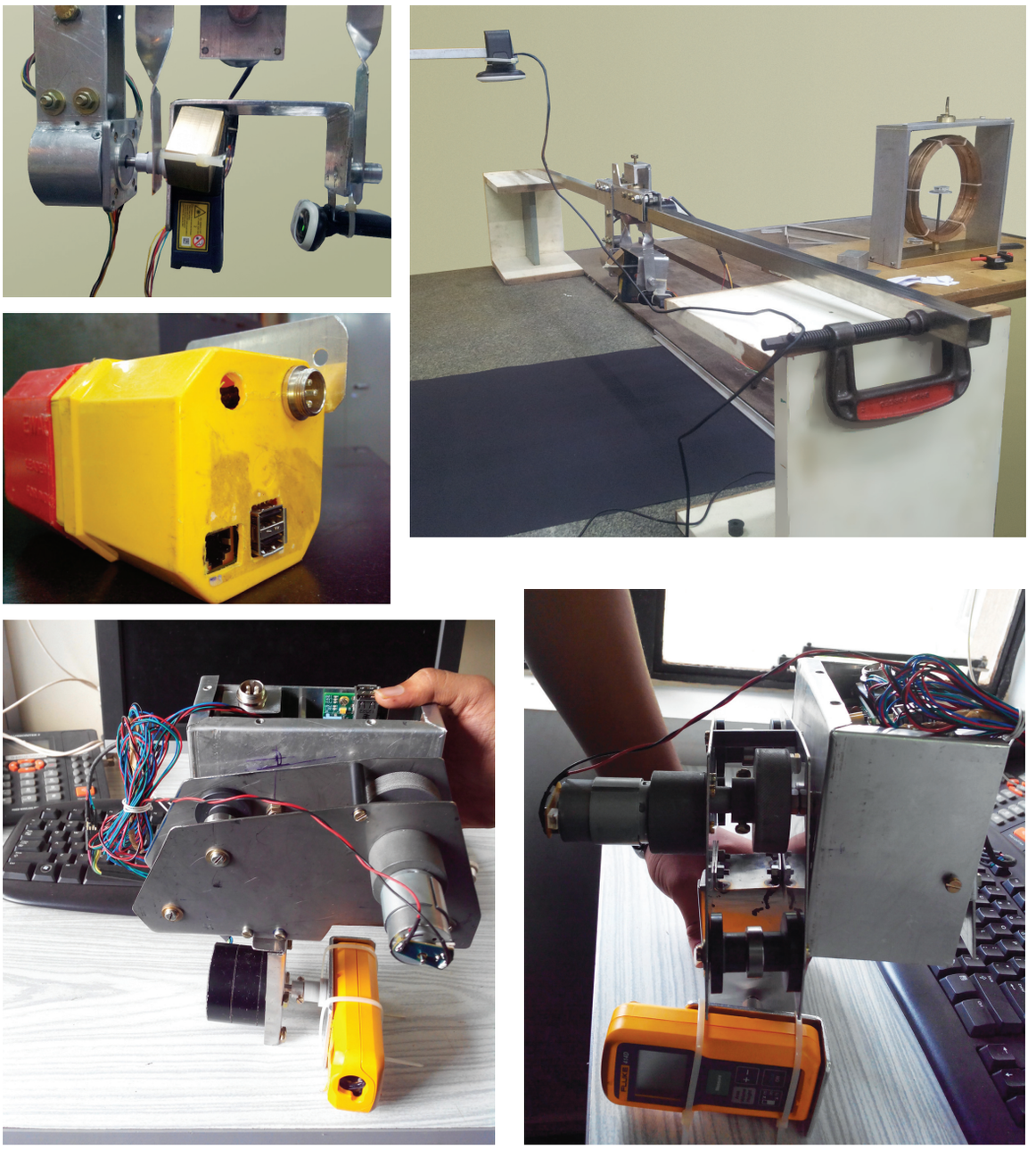
Stair climbing wheelchair

Molecular Astronomy Lab

i) Different versions of 2 axes CMM Laser distance measuring instrument for the surface measurement.

ii) Different versions of mobile robots.

iii) LNA card chassis.



CMM Laser distance measuring instruments

Library

The RRI Library founded by Sir C V Raman started functioning with his personal collection of books and journals. The library has since then grown to become a modern library consisting of both print and electronic information resources. All the functions of the library are completely automated using LIBSYS – Library automation software. The RRI library has been a constant source of both general and specialized information for its users. Currently, the library has a total collection of 68537 books and bound volumes of journals. This collection consists of 27956 books and 40581 Bound Volumes of journals. It also subscribes to 95 journals. Additionally, the library has in its possession 1649 non-book materials that include scientific slides, CD-ROMS, DVD's and audio/video tapes. 31 e-books were also added to the collection.

In the year gone by the library continued its partnership with National Knowledge Resource Consortium. As a result, RRI library users have access to publications of 13 publishers amounting to 3594 journal titles. The library web page has been continuously upgraded to provide single window access to these consortium online resources.

Digital Library Activities

Work on the digitization of archival materials, photographs and audio/video is continuing from the previous year. They are being uploaded on the Institutional Repository, namely the RRI Digital Repository. Current research publications, theses submitted to RRI, photos, audio/video are being added to this repository. The communities on this repository have grown from 17 to 18 and number of uploads from 5594 to 6750 records. 800 photos of Sir C V Raman have been added, thus increasing the total number to 1200.

Springer Protocols Handbooks is a product that collects a diverse range of step-by-step laboratory methods and protocols from across the life and biomedical sciences. The RRI Library subscribed to this product in the past year.

RRI library also supports man power development programs by giving internship training to the students of Bangalore university, Kuvempu university, Shimoga and Shri Jayachamarajendra (Govt) Polytechnic for Women. During the current year, 10 students from Library Science departments were trained.

International Conference of Asia-Pacific Digital Library - 2013 was held at Bangalore. RRI Library staff had a major role to play in organizing this conference and RRI was a sponsor of this conference.

Computer Facilities

The computer division team handles the various computing needs of the different research and development groups and the library at the Raman Research Institute.

During the year gone by the campus network upgrade work was started and is in progress. The new network will have 10Gbps fiber interconnect between buildings and 1Gbps Ethernet connection to desktops, campus wide wireless network with support for the latest and faster 802.11n standard. The new network will use IPv6 addressing and will work in dual-stack mode.

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

The computer facilities on campus continued to be upgraded and improved during the last year. Mail server software was upgraded to a more secure and feature rich software. 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, and 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 20 acres replete with trees and shrubs. The hustle and bustle of the busy metropolis outside is left behind as one enters through the gate. The environment inside is as soothing as can be expected from a campus that has integrated so much greenery within its fold together with the various buildings and laboratories. This serene environment creates the perfect surroundings for the creative work and research activities that go on within the campus.

The campus hosts all the office buildings, laboratories, a canteen and the guesthouse. Nevertheless, once inside, one has the overwhelming impression of being surrounded by a natural garden instead of feeling that one is on the campus of a renowned research institute. Sir C.V. Raman had landscaped most of the campus and the RRI Trust is proud to enforce policies that protect this unique, natural environment.

The guesthouse on campus is equipped with all modern facilities to comfortably accommodate distinguished visitors and visiting academics including visiting doctoral students. The canteen on campus provides meals to all guests together with lunch and refreshments to all RRI employees and those who work at the Indian Academy of Sciences. Informal meetings, various gatherings, concerts and dinners are usually organized at the Village – an ethnically designed area near the canteen which provides 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 a part and parcel of campus life and there are two badminton courts available for use by the research faculty, staff and students. Football is also a part of the daily routine for the members of the RRI community. Table tennis and cricket tournaments are regularly organized at RRI and enjoy healthy participation by students, and members of the faculty and staff.

Academic Programmes

PhD Programme

RRI has a comprehensive PhD programme that gives enthusiastic and motivated students the opportunity to join the highly competitive global research community. The PhD programme is an organic process designed to challenge young graduate students to rise to their full creative potential and develop the ability to conduct independent research.

RRI offers an exceedingly high degree of intellectual freedom to students allowing them to pursue their individual interests within the four broad areas of research conducted at the institute. This level of freedom coupled with proper guidance in the form of constant formal and informal interactions with faculty and other students encourages them to not only think for themselves but also critically question others. A regular exchange of ideas and knowledge promotes an open-minded approach towards science and a willingness to learn which is, as acknowledged everywhere, extremely important for success in the academic arena. Apart from the academic members within the Institute itself, graduate students under the PhD programme are also exposed to the larger and more diverse scientific community through attendance of relevant national and international conferences and workshops where they get a perspective on the bigger picture in their field of research.

Students at RRI are registered for their PhD degree with 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 on the PhD programme, admission requirements and procedure can be found on the Institute website.

Currently 74 students are enrolled in the PhD programme and conducting research with research faculty members from the four broad research groups of the Institute. Last year eight PhD degrees were awarded and eight PhD theses were submitted for review.

Postdoctoral Fellowship Programme

RRI offers a postdoctoral fellowship programme that is open for applications throughout the year. This fellowship is initially offered for a period of two years and usually extended to three following review. Postdoctoral fellows are expected to work independently and have complete academic freedom in the sense that they can choose their own research problem and collaborator: it is not mandatory that a post doctoral fellow works under the purview of any of the four broad research groups at RRI or is attached to a specific research faculty at the Institute. Nevertheless, it is desirable that their professional research interests and previous experience in research have a significant overlap with the ongoing and envisaged research plans of the institute. Also participation of the fellows in the academic activities of the Institute and student supervision as co-guides is encouraged even though there are no teaching responsibilities.

Candidates who have at least one year of experience as a postdoctoral researcher and have a proven track record of being able to conduct original and independent research can apply for a limited number of Pancharatnam Fellowships offered at RRI. Here too, applications are accepted throughout the year and the processing takes about 4 to 6 months. The fellowship is for 3 years. Further details about the Postdoctoral and Pancharatnam Fellowships can be found on the website (*www.rri.res.in*).

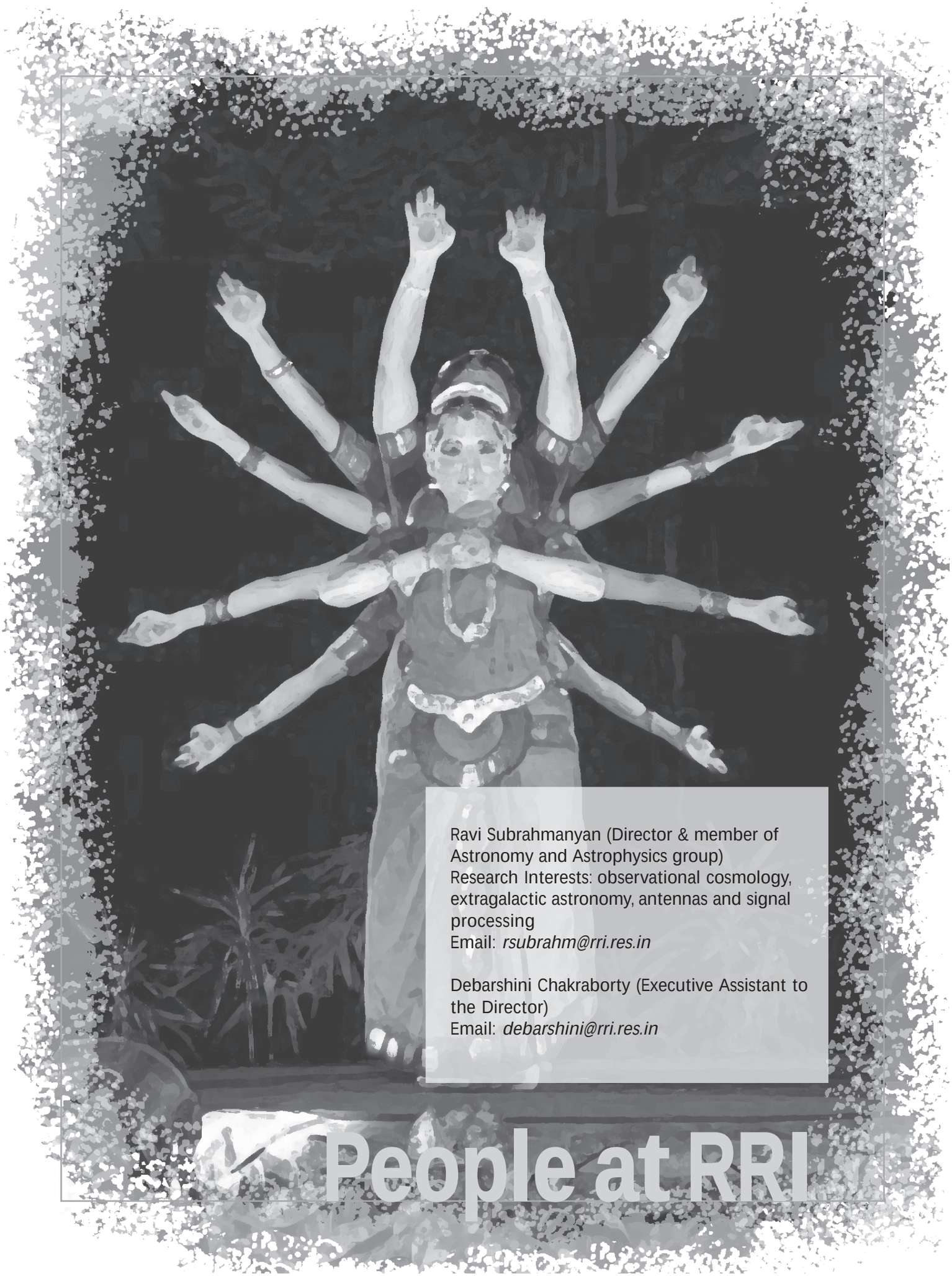
Currently, there are eight Post-Doctoral and Pancharatnam Fellows at RRI.

Visiting Student Programme (VSP)

The Visiting Student Programme at Raman Research Institute is aimed at offering research experience to highly motivated students presently pursuing their undergraduate or master's degree. The Visiting Students Programme runs throughout 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' research work and their interaction with the staff and the existing PhD students of the Institute provide them with a flavour of the various research pursuits at RRI as well as first-hand experience in research. This very often forms the basis of the first exposure these students have to the field of fundamental research.

Total number of visiting students at a time is limited by available projects / mentors and relevant resources. During the year 2013-2014, a total of 176 students from different parts of the country participated in the programme, with their duration of stay ranging anywhere between 6 weeks to 6 months (extendable up to one year). A full list of the visiting students at RRI in the year 2013-2014 is given in Appendix VI.



Ravi Subrahmanyan (Director & member of Astronomy and Astrophysics group)
Research Interests: observational cosmology, extragalactic astronomy, antennas and signal processing
Email: *rsubrahm@rri.res.in*

Debarshini Chakraborty (Executive Assistant to the Director)
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People at RRI

Academic Staff

Astronomy and Astrophysics

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Publications of the Light and Matter Physics group can be found in *Physical Review, Applied Physics, Journal of Optical Society of America, Applied Optics, Applied Physics Letters, Journal of Applied Physics, Nanotechnology, Nano Letters, Nanoscale, Optics Letters, European Physical Journal, Chemistry of Materials, Bulletin of Indian Laser Association, Superconductor Science and Technology, Chemical Physics Letters*, etc.

Theoretical physicists at RRI use journals like *Physical Review, Review of Modern Physics, Proceedings of the National Academy of Sciences, Journal of Physics: Condensed Matter, Classical and Quantum Gravity, Europhysics Letters, Journal of Statistical Mechanics* and others as a medium to share their knowledge with the national and international scientific community.

122 papers with RRI members as authors and/or co-authors were published during 2013–2014. There were 19 publications in conference proceedings and 33 publications (26 in journals and 7 in conference proceedings) are in press.

Members of the Institute also regularly publish books and/or articles for popular science magazines to reach out to a wider audience beyond that of specialized technical and scientific journals. RRI members published 3 book reviews or book chapters in the past year and 2 popular science articles. 3 book chapters are still in press.

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

Conferences

Institute members frequently visit various other institutions both abroad and at home to attend conferences and workshops. These events play an important role in providing an opportunity to exchange ideas with the scientific community at large and thus set the stage for future collaborations with researchers from other institutions, both within India and abroad. Last year, faculty and students of the Institute attended numerous conferences in India, USA, Europe, Australia, Japan, China, South America and Canada.

In addition, research faculty members, engineers and other members of the Institute gave lectures and invited talks at a variety of workshops, international conferences, multinational project meetings and training programmes. As a part of the outreach activities of RRI, members also visited colleges around the country and organized special workshops on different research topics, delivering lectures, talks and presentations.

A full list of conferences attended by the Institute members is available in Appendix II.

Other Activities

Seminars and colloquia

Seminars are regularly organized at the Institute to keep all members abreast of the latest, cutting-edge research being done on specific research topics. They are delivered by visiting faculty and researchers from other institutions and are intended to generate discussions on topics that are of particular interest to RRI members and also initiate collaborative projects between RRI and the visitor's institution.

The Thursday colloquium is a novel event held at the Institute to promote further interaction not only between the various research groups within RRI but also between RRI and the invited speaker and his or her affiliated institution. However, unlike the seminars, the topics covered at the colloquia do not strictly adhere to current research being pursued at RRI. The colloquium aims to cover new science topics and bring an interdisciplinary flavor to the event by introducing themes from various other disciplines to the members of the RRI community.

During the last year, RRI invited speakers from all over the globe to deliver the Thursday colloquia. The topics covered a lot of diverse themes including 'Properties of graphene and its chemical derivatives', 'Thermodynamic properties of cold atoms: classical and quantum aspects', 'Supernovae', 'The global geometry of polarized light – A tale of two spheres', 'Reinventing India by integrating science, technology and innovation: Opportunities and challenges', 'Multi-scale simulation of liquid crystals: A bottoms-up approach', 'Enhanced collective force generation by bio-filaments undergoing chemical switching' and many more.

A complete list of speakers, their lecture topics and dates of visit to RRI is given in Appendix III.

Visiting scholars

The Institute recognizes that it is imperative to stay nationally and internationally open and foster an environment that allows for greater exchange of ideas and more collaboration. With an aim to further augment the interaction between the members of the Institute and scholars belonging to other institutions, RRI actively encourages visits from a large number of scientists, researchers and engineers. These scholars visit the institute and contribute new ideas and skills while also benefiting 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 fruitful collaborations and conceptualization of new, interesting projects for the Institute.

Last year there were altogether 102 scholars who visited RRI from both Indian and international institutions. RRI is happy to have so many friends and thanks all of them for contributing to the wonderful diversity and dynamism of the research atmosphere at the institute.

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

PhD awarded

Nandan Satapathy: Investigations towards Quantum Walk in Optical and Cold Atomic Systems

Venkataraman P.R.: 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

Kshitij Thorat: The cosmic population of extended radio sources: a radio-optical study (JAP student)

Yogesh Maan: Tomographic studies of pulsar radio emission cones and searches for radio counterparts of gamma-ray pulsars (JAP student)

PhD submitted

Wasim Raja: Faraday slicing polarized radio sources

Deepak Pandey: Manipulation of Coherent Light and Coherent Light Manipulation of Atoms

Seunghyun Lee: The study of Trapped Ion Collisions with Cold Atoms and Cold Molecules

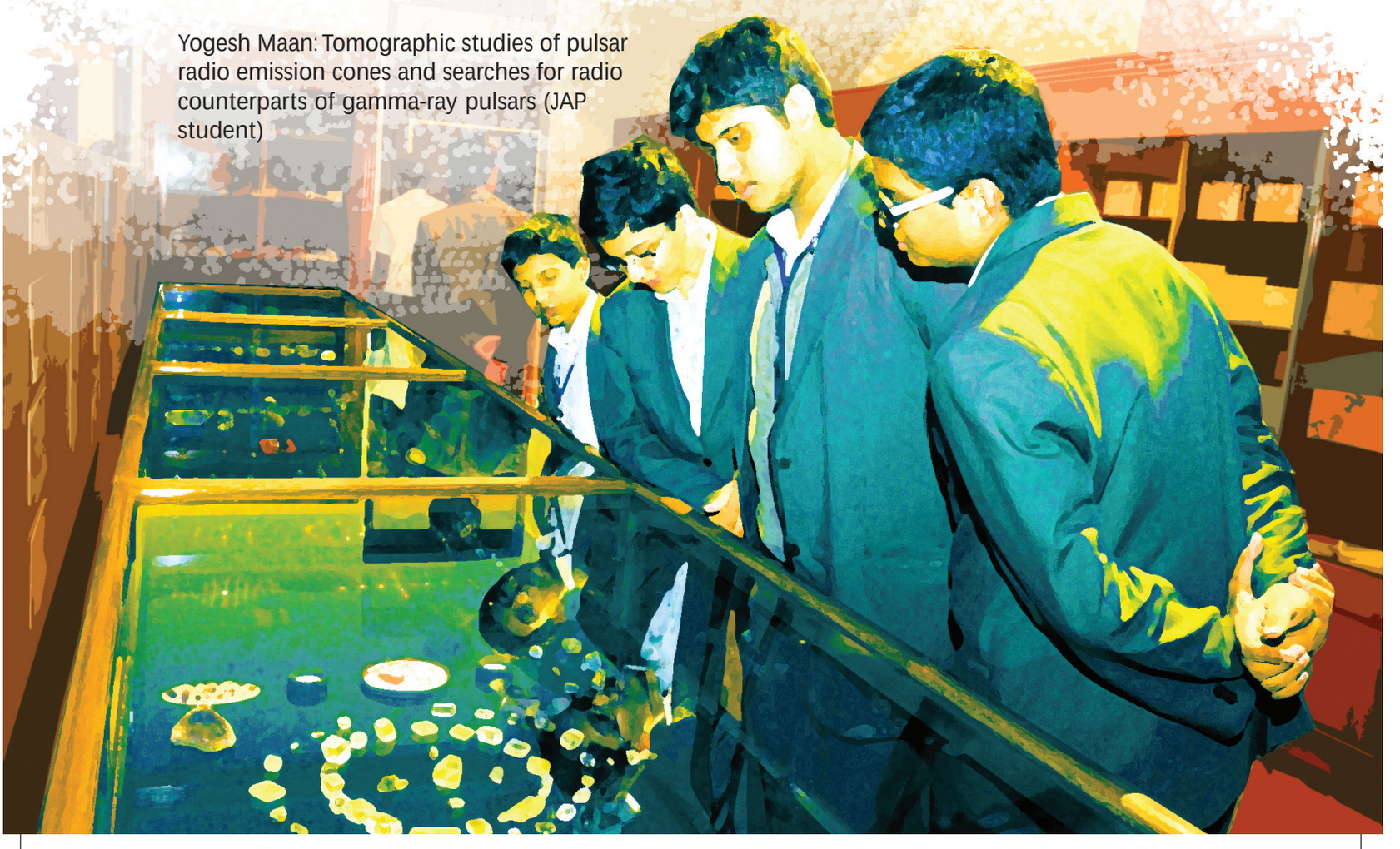
Pragya Srivastava: Active Mechanics of Cortical Actin: Geometry and Shape Deformation

Kanhaiya Lal Pandey: Primordial Magnetic Fields and Early Structure Formation in the Universe

Mahavir Sharma: A Study of Galactic Outflows

Anirban Polley: Molecular Organisation of Active Rafts and Phase Segregation

Chandreyee Maitra: High magnetic field neutron stars: cyclotron lines and polarization (JAP student)



General

The following grants were received from the Department of Science and Technology during the year 2013-2014:

	(Amount in lakhs)
PLAN (Recurring & Non Recurring)	Rs.3215.00
NON-PLAN (Recurring)	Rs.84.75
TOTAL	**Rs.3299.75**

Journal Club

Owing to the very large number of papers that are published annually, these days it is nearly impossible for a scientist to stay abreast of the research going on outside his or her areas of specialization. To partially remedy this situation, the Journal Club was conceptualized and first came into being in 1981 at RRI. As a part of the Journal Club meeting, papers with exciting new results that are often considered landmarks in that particular field are presented to a wider and more general audience. The speakers, both students and faculty, present their selected papers. Based on the presentation, informal discussions, questions and demonstrations are strongly encouraged which lead to a better understanding of the underlying concepts of the work presented. This in turn leads to new ideas and new research problems for the members of the RRI scientific community to work on.

The last Journal Club meeting of the year is traditionally reserved to review the year's Nobel Prize Award in Physics. Some of the papers reviewed during the year 2013-2014 are 'Room temperature solid-state masers', 'D-wave in quantum processing', 'Digital cameras with designs inspired by Arthropod eyes', 'Predictability and suppression of Extreme Events in a Chaotic system' and 'From few to many: Observing the formation of a Fermi sea one atom at a time'.

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

Hindi Cell

Immense efforts have been taken up during the last year at the Institute in pursuance of the targets set by the Official Language Policy of the Government of India. Concerned staff members were instructed to strictly adhere to the Official Language policies. The official-language training programme was re-oriented more towards enhancing the working skills in the usage of Hindi of all the Institute employees. The Institute is taking extra care to fulfill all the targets including identifying and filling up the post of Hindi Translator and Assistant.

Reservations

The Institute follows the same reservation policy as other Government of India scientific departments like the Department of Space and Department of Atomic Energy.

Others

During the period between 2013-2014, the RRI community has organized several special conferences, meetings and workshops described in detail in the next section titled 'Events organized during 2013-2014'. Other annual events and activities at RRI include In-house meetings, formal faculty farewell dinners, college visits and inviting college students to the campus. Formal and informal dinners and high teas, sports tournaments, concerts, and a variety of cultural programmes, both with invited performers and RRI members themselves, are regular features at the RRI campus.

Public outreach

The Professor Harry Messel International Science School (ISS) has been conducted by the Science Foundation for Physics, University of Sydney, Australia, (*http://www.physics.usyd.edu.au/foundation/Outreach/ISS/intro.htm*), since 1962. It brings together about 140 students from around the world for two weeks of advanced study on topics of modern science. This program is conducted once every two years. Students from several countries participate in this program held every alternate year. This is the fourth time that Indian high school students participated in the ISS. The ISS offers scholarships for all the selected students and also supports the coordinators. Five scholarships are for students from India. The Raman Research Institute has been coordinating the student selection within India since 2007. RRI has an intensive selection process to choose the five students for ISS, which includes an interview. The theme of the ISS for 2013 was **Nanoscience**: **Small Wonders, Big Future**.

For the year 2013 applications from Kishore Vaigyanik Protsahan Yojana (KVPY) scholarship holders (science stream) were assessed (applications were accompanied by a CV, letters of reference from the school principal and science teacher, a personal statement) and 15 students were shortlisted for interviews. The five selected students spent 2 weeks at the science school where they listened to lectures on Nanoscience and technology by top international and Australian Nanoscience experts along with leaders from the breadth of science, besides interacting with the scientists and participating in challenging science-related hands-on projects.

This apart, during the period 2013-2014, Dr. Lakshmi Saripalli of RRI organized a talk by Nobel Laureate Prof. Brian Schmidt at the Valley School in August 2013, gave a talk on 'C.V. Raman and his effect' to junior school students at Valley School in February 2014 and co-organized a visit to the institute by junior school students of the Valley School in March 2014, where the students listened to and participated in talks centered around experimental demonstrations of physical principles conducted by Prof. Joseph Samuel and Dr. Supurna Sinha. Dr. Saripalli has also written an article on the 'Sphere of Science' by invitation as the lead article in the Science section for the sixth volume of the book, 'Times Higher Education' published in January 2014 by the Times of India.

Dr. Sumati Surya gave an invited talk on 'The role of Gender in Negotiating an Academic Path' at the Conference on Women in Higher Education Research held between 20–21st June, 2013 in NIAS, Bangalore.

Besides this, many other faculty members at RRI like Prof. Biman Nath, Dr. Supurna Sinha and Prof. Joseph Samuel and others regularly publish popular science articles in journals like *Resonance* and *Current Science* meant for a more general audience. During the year gone by Prof. Biman Nath published a book review for 'Beyond the stars' by P. Saraceno in 104, 9, *Current Science*, 10 May 2013. Dr. Supurna Sinha also published a book review for 'Henri Poincare: A scientific biography' by Jeremy Gray in 105 (06) *Current Science*, 25 September 2013. Prof. Joseph Samuel contributed an article on 'The Geometric Phase' in the proceedings of the one day conference in celebration of Prof. N. Mukunda held at IMSc, Chennai and another titled 'Fermi Transport' in *Resonance*, January 2014, page 62. Dr. Reji Philip has authored a popular science article titled 'An all-carbon solid state optical diode' published in *Photonics News*, Feb 2014 (a publication from CUSAT, Cochin). Prof. Madan Rao has co-authored a chapter named '(Re)Modeling the Golgi' along with Pierre Sens in the book *Methods for analysis of Golgi complex function*.

Events Organised

1. Celebrating RRI participation in the MWA project

The Murchison Widefield Array (MWA) is a radio telescope in the Australian outback of Murchison district, 200 km inland from the Western Australian coast. It was built during the last several years and went into operation in mid 2013. It is the first step towards a better understanding of the birth of the first stars and galaxies almost 13 billion years ago – or the 'Cosmic Dawn' so to speak. Raman Research Institute in partnership with Harvard and MIT in the US as well as a consortium of institutions in Australia and New Zealand, have together achieved this milestone in radio astronomy research.

The digital receivers of the MWA were built by RRI. These receivers take the signals from the 2048 dual-polarization wideband 'bow-tie' shaped antennas and perform complex high-speed signal processing algorithms that process and condition the data prior to its transmission to a central processing unit that computes the imaging information. RRI engineers and scientists worked along with international partners to install and commission the telescope. The Australian Minister for Innovation, Senator Kim Carr launched the MWA operational phase from Melbourne on 9th July 2013. Thereafter the MWA has begun gathering weak radio signals from deep space that will be analyzed by scientists at RRI and in the US and Australia using massively parallel computing systems. The data is expected to provide astronomers an insight into the dramatic evolution experienced by primordial cosmic gas as the first stars and galaxies formed in the early universe. Moreover, the successful completion of the MWA is an important step towards setting up of the international Square Kilometre Array (SKA), a massive global project to build the world's largest radio telescope across Australia and South Africa.

The telescope has seen the light of the day because of several international collaborations involving different funding agencies and research institutes. The Government of India, through The Department of Science and Technology funds the RRI and supports its participation in the MWA Project. In addition, the Australia-India Strategic Research Fund partially supports the collaboration between RRI and Australian teams.

To celebrate the commissioning of the MWA a meeting was held at RRI on 19th August 2013 that included presentations at the Raman Research Institute Auditorium highlighting the engineering achievement by the Radio Astronomy Lab of the Institute and the astrophysical studies that will propel forward the theoretical research based on the observations by the MWA. Australia's High Commissioner to India, Patrick Suckling and Prof. Brian Schmidt AC, 2011 Nobel Prize winner for Physics, attended the meeting.

At this particular meeting, an overview of the MWA project was given to the audience by Professor Udaya Shankar followed by talks by Srivani K.S. and Prabu T. of the Radio Astronomy Lab at RRI who spoke about the MWA receiver design and their installation and commissioning. Professors K.S. Dwarakanath, Shiv Sethi and Avinash Deshpande spoke about the theoretical and observational studies that are the current focus of the scientific research with the MWA; in particular, Galactic and Extragalactic astronomy, dectecting the Epoch of Reionization, and Time Domain Astronomy using the MWA.

The meeting ended with Professor Brian Schmidt delivering the concluding talk at the meeting on the path forward from MWA to the SKA. He said, 'This telescope is an exciting and necessary part of the process of discovery and I see it as a step towards, if not the tool for, an important scientific breakthrough. For the first time we will be able to look at the transformation of the universe from a rather boring environment of hydrogen and helium to the point where stars, galaxies and black holes create the vibrant Universe as we know it.'

During his visit to RRI, Prof. Schmidt also gave a seminar on 'Supernovae' on 19th August 2013, besides giving a lecture under the auspices of Indian Academy of Sciences on 20th August at IISc, and a Public talk on 'Accelerating Universe' on 21st August at Bangalore University.

2. RRI summer school on Signals and Systems in Radio Astronomy – 2013

Several members of the RRI Astrophysics & Astronomy group are actively involved in building astronomy receivers and telescope for specific research goals and have designed, constructed and operated telescopes that have been advantageously located in sites around the world. Of the projects of note are the Gauribidanur Radio Telescope, Mauritius Radio Telescope, Murchison Widefield Array and building of a broadband feed and associated receiver for the Greenbank Radio Telescope. In the near future, RRI is slated to be a part of the worldwide team setting up the Square Kilometre Array (SKA), a massive global project to build the world's largest and most sensitive radio telescope across Australia and South Africa.

The RRI School on Signals and Systems in Radio Astronomy organized by Ravi Subrahmanyan and N. Udaya Shankar was held during July–August 2013. It was intended to give a hands-on experience of experimental radio astronomy to engineering and physics undergraduate and post-graduate students who wish to explore a career in this field in the coming decades. The school was designed to give the students exposure to the systems and science behind exploring cosmic signals at radio wavelengths using state-of-the art antenna arrays.

A group of six young students attended the school. They were given an opportunity to work together to build a Radio Telescope that consisted of a regular antenna array capable of receiving and processing electromagnetic signals from astronomical sources, using both analog and digital signal processing methods. While the fieldwork was conducted at the Gauribidanur observatory, a parallel program introducing the students to aspects of astrophysics and the applications of physics to astrophysical situations was organized at RRI campus. Most members of the Astronomy & Astrophysics group participated in these interactive sessions, tutorials and lectures. Together, the interactive schooling was designed to give the participants a learning of practical radio astronomy and astrophysical contexts in which the observations advance understanding, apart from learning to work together as a team.

As part of the school, the topics covered were

i) Celestial sources of cosmic signals at radio wavelengths
ii) The Astrophysical mechanisms in these Celestial sources
iii) Radio Astronomy, Analog and digital processing of cosmic radiation
iv) Radio Telescopes, Antenna Arrays and Array Signal Processing.

Although the duration of the School was between July-August, 2013, the selected participants were actively encouraged to continue with interactions and participation in research of the Institute through the subsequent academic year.

3. 4th RRI School on Statistical Physics

The RRI Statistical Physics School is an advanced level school first started in 2010 at the Raman Research Institute, Bangalore. The 4th such School was held at RRI between April 01–April 13, 2013.

This pedagogical school is primarily aimed at bridging the gap between Masters level courses and topics in statistical physics at the frontline of current research. It is intended for PhD students, post-doctoral fellows and interested faculty members at the college and university level.

In the 4th edition of the school, there were about 100 selected participants from both within Bangalore and outside. Over duration of 2 weeks, instructors from both within India and abroad offered the following courses to the participants:

1) Theoretical methods in soft matter physics – Ronojoy Adhikari, IMSc, Chennai
2) Models of non-equilibrium physics – Satya N. Majumdar, LPTMS Orsay, France
3) Anomalous Diffusion – Ralf Metzler, University of Potsdam and Tampere, UT
4) Kinetics of Phase Transitions – Sanjay Puri, JNU, Delhi
5) Introduction to soft matter physics – V. A. Raghunathan, RRI, Bangalore
6) Introduction to Biomolecular Networks – Anirvan Sengupta, Rutgers, USA

The courses consisted of 6 lectures a week, each one and a half hours long, apart from a tutorial session at the end of the day dedicated to problem solving. The lectures of the school have been made available online for the benefit of a wider audience. The relevant link is *http://www.rri.res.in/~statphys/2013/materials.html*

4. Wide-spectrum Education: A Focus on Liberal Arts and Sciences in India

A conference on new directions, new curriculum and new institutions aimed at providing a more integrated education in Liberal Arts and Sciences in India at the undergraduate level was held at RRI over 2 days and a morning between January 7–9, 2014. During the conference the relevance and need for Liberal Arts education in India was assessed at length by presidents, founders and vice chancellors of leading liberal arts institutions and foundations in India and abroad. It served as an excellent platform for an exchange of experiences and ideas with the larger goal of learning and motivating action for improving the quality and applicability of education being offered to the youth of India and the world.

Liberal Arts and Science education provides a 'holistic' education that can help train a new generation of graduates to think creatively about complex issues such as the urban-rural divide, the rapidly developing nature of the Indian economy and its social implications, etc. These graduates will approach the world with a more balanced perspective and are expected to help create newer and more fulfilling jobs and programs with greater social responsibility.

The main idea behind Liberal Arts and Science Education is to provide the youth with a chance to explore broadly all areas of knowledge, in an interactive and engaging way. An important point of discussion was the need for an overhaul of the present curriculum so as to bring about greater synergy across various disciplines and respond more effectively to the challenges faced by modern Indian society. In the meeting strategies for implementing online education in

this era of MOOC (Massive open online courses) and its relative merits or demerits as against traditional residential education were also discussed.

The talks were held at the RRI auditorium on the first (January 7) and last day (January 9) of the meeting. The group discussions planned for the second day (January 8) were held at the Indian Institute of Human Settlements City Campus close by. A conference reception and a conference banquet dinner were also hosted by RRI on the evening before the meeting (Jan 6, 2014) and on the first day of the conference at the RRI campus.

Founding Vice Chancellors, Directors, and Presidents of the Ashoka University, Azim Premji Foundation, Indian Institute of Human Settlements, Krishnamurti Foundation, O.P. Jindal Global University, and Shiv Nadar University attended the conference with many of their academic leaders from these new institutions. They were joined by Presidents, Deans and Professors from liberal arts colleges and universities abroad such as Pomona College, Yale-NUS College (Singapore), Duke University, Claremont McKenna College, University of California at Santa Cruz and Carleton College. Professors from Yale University representing all three divisions (Sciences, Social Science and Humanities) led by K. Sivaramakrishnan, Chair, South Asian Studies Council and Director of the Yale India Initiative also attended the meeting.

Plenary talks were given by noted historian, author and thinker Ramachandra Guha and by former Infosys CEO Nandan Nilekani. Ramachandra Guha's plenary talk was titled 'Pluralism and University Education in India and beyond'. He said, '*The Indian Universities are great agents of Nationalism. They are also crucial agents of democracy. What forms of pluralism must an Indian University sustain? Pluralism in the student body; pluralism in the teaching staff; pluralism of discipline; pluralism of approaches within disciplines; and finally, pluralism in funding sources.*'

The conference began with a set of introductory talks outlining the vision of each of the institutions and their rationales behind their chosen curricula. Panels in plenary discussions addressed particular questions relevant to India, such as 'How can higher education create a more just and sustainable India?' or 'What is the role of liberal arts and sciences in training leaders who are responsive to the environmental and societal needs of India?' Panel discussions also discussed the curriculum and the ways in which new institutions and initiatives can provide the best possible undergraduate instruction in science, humanities and social sciences. A final session was held to allow working groups from the various institutions to explore collaborations and partnerships for undergraduate education, curriculum development and research.

As the keynote speaker, Mr. Nandan Nilekani, aptly put it, *'I personally believe that getting our higher education act together is the single biggest catalyst for India to realize its demographic dividend. Conversely, if we don't do it well, I think, as we all know, we will have a demographic disaster or a demographic burden.'*

The meeting was organized by Bryan Penprase (Pomona College, CA), Lakshmi Saripalli (RRI Bangalore), K. Sivaramakrishnan (Yale University, USA), George Joseph (Yale University, USA), Aromar Revi (IIHS, Bangalore, India) and Pramath Sinha (Ashoka University, India)

Further details on the conference can be found in the following webpage – *http://www.astro.pomona.edu/blog/mohra/*

APPENDIX I

Publications

PAPERS IN JOURNALS

1. Light beams with general direction and polarization: Global description and geometric phase
Nityananda R*; Sridhar S
Annals of Physics **341**, 117, 2014

2. The Murchison Widefield Array: solar science with the low frequency SKA Precursor
Tingay, SJ; Oberoi D*; Cairns I*; Deshpande AA; Prabu T; Roshi, Anish D; Udaya Shankar N; Srivani KS; Subrahmanyan, Ravi; + 48 co-authors
Journal of Physics Conference Series **440**, 012033, 2013

3. Conditions for supernovae-driven galactic winds
Nath, Biman B; Shchekinov, Yuri*
Astrophysical Journal Letters **777**, L12, 2013

4. Active Galactic Nucleus Feedback and Entropy Injection in Galaxy Cluster Cores
Chaudhuri A*; Majumdar S*; Nath, Biman B
Astrophysical Journal **776**, 84, 2013

5. Low-frequency radio emission in the massive galaxy cluster MACS J0717.5+3745
Pandey-Pommier M*; Richard J*; Combes F*; Dwarakanath KS; Guiderdoni B*; Ferrari C*; Sirothia S*; Narasimha D*
Astronomy & Astrophysics **557**, A117, 2013

6. Galactic PeV Neutrinos
Gupta, Nayantara
Astroparticle Physics **48**, 75, 2013

7. Possible detection of a cyclotron resonance scattering feature in the X-ray pulsar 4U 1909+07
Jaisawal, Gaurava K*; Nair, Sachindra*; Paul, Biswajit
Astrophysical Journal **779**, 54, 2013

8. Awakening to the Cosmic dawn: Guest Editorial
Subrahmanyan, Ravi
Current Science **105**, 743, 2013

9. SARAS: a precision system for measurement of the cosmic radio background and signatures from the epoch of reionization
Patra, Nipanjana; Subrahmanyan, Ravi; Raghunathan A; Udaya Shankar N
Experimental Astronomy **36**, 319, 2013

10. An octave bandwidth frequency independent dipole antenna
Raghunathan A; Udaya Shankar N; Subrahmanyan, Ravi
IEEE Transactions on Antennas and Propagation **61**, 3411, 2013

11. Unusual displacement of HI due to tidal interaction in Arp 181
Sengupta, Chandreyee*; Dwarakanath KS; Saiki DJ*; Scott TC*
Monthly Notices of the Royal Astronomical Society Letters **431**, L1-L5, 2013

12. Signature of outflows in strong Mg II absorbers in quasar sightlines
Sharma, Mahavir; Nath, Biman B; Chand, Hum*
Monthly Notices of the Royal Astronomical Society **431**, L93-L97, 2013

13. Giant radio galaxies - I. Intergalactic barometers
Malarecki JM*; Staveley-Smith L*; Saripalli, Lakshmi; Subrahmanyan, Ravi; Jones DH*; Dufy AR*; Rioja M*
Monthly Notices of the Royal Astronomical Society **432**, 200, 2013

14. Modelling carbon radio recombination line observations towards the ultracompact H II region W48A
Jeyakumar S; Roshi, Anish D*
Monthly Notices of the Royal Astronomical Society **434**, 2742, 2013

15. Environments of extended radio sources in the Australia telescope low-brightness survey
Thorat K; Saripalli, Lakshmi; Subrahmanyan, Ravi
Monthly Notices of the Royal Astronomical Society **434**, 2877, 2013

16. Superbubbles breakout and galactic winds from disc galaxies
Roy, Arpita; Nath, Biman B; Sharma, Prateek*; Shchekinov, Yuri*
Monthly Notices of the Royal Astronomical Society **434**, 3572, 2013

17. The giant lobes of centaurus A observed at 118 MHz with the Murchison Widefield Array
McKinley B*; Briggs F*; Deshpande AA; Prabu T; Udaya Shankar N; Srivani KS; Subrahmanyan, Ravi; +50 co-authors
Monthly Notices of the Royal Astronomical Society **436**, 1286-1301, 2013

18. Revisiting SW J2000.6+3210: a persistent Be X-ray pulsar?
Pradhan, Pragati*; Maitra, Chandreyee; Paul, Biswajit; Paul BC*
Monthly Notices of the Royal Astronomical Society **436**, 945-952, 2013

19. A survey for transients and variables with the Murchison Widefield Array 32-tile prototype at 154 MHz.
Bell ME*; Murphy T*; Deshpande AA; Prabu T; Roshi A; Udaya Shankar N; Srivani KS; Subrahmanyan, Ravi; +25 co-authors
Monthly Notices of the Royal Astronomical Society **438**, 352, 2014

20. On the detection and tracking of space debris using the Murchison Widefield Array.I. Simulations and test observations demonstrate feasibility
Tingay SJ*; Kaplan DL*; McKinley B*; Deshpande AA; Prabu T; Udaya Shankar N; Srivani KS; Subrahmanyan, Ravi; +52 co-authors
The Astronomical Journal **146**, 103, 2013

21. Torque reversals and pulse profile of the pulsar 4U 1626-67
Beri, Aru*; Jain, Chetana*; Paul, Biswajit; Raichur, Harsha
Monthly Notices of the Royal Astronomical Society ***439****, 1940*, 2014

22. B0707-359: a case study of change in AGN-black hole spin axis
Saripalli, Lakshmi; Malarecki M*; Subrahmanyan, Ravi; Jones DH*; Staveley-Smith L*
Monthly Notices of the Royal Astronomical Society **436**, 690, 2013

23. Overcoming real-world obstacles in 21 cm power spectrum estimation: A method demonstration and results from early Murchison Widefield Array data
Dillon, Joshua S*; Liu, Adrian*; Prabhu T; +16 co-authors
Physical Review D **89**, 023002, 2014

24. A 189 mhz, 2400 square degree polarization survey with the Murchison Widefield Array 32-element prototype
Bernard G*; Greenhill LJ*; Udaya Shankar N; Subrahmanyan, Ravi; Deshpande AA; Prabu T; Roshi, Anish D; Srivani KS; +25 co-authors
The Astrophysical Journal **771**, 105, 2013

25. Pulse-phase-dependent variations of the cyclotron absorption features of the accreting pulsars A0535+26, XTE J1946+274, and 4U 1907+09 with SUZAKU
Maitra, Chandreyee; Paul, Biswajit
The Astrophysical Journal **771**, 96, 2013

26. OH maser sources in w49n: probing magnetic field and differential anisotropic scattering with Zeeman pairs using the very long baseline array
Deshpande AA; Goss WH*; Mendoza-Torres JE*
The Astrophysical Journal **775**, 36, 2013

27. Is there an unaccounted for excess in the extragalactic cosmic radio background?
Subrahmanyan, Ravi; Cowsik, Ramanath*
The Astrophysical Journal **776**, 42, 2013

28. A study of fundamental limitations to statistical detection of redshifted HI from the epoch of reionization
Thyagarajan, Nithyanandan; Udaya Shankar N; Subrahmanyan, Ravi; Srivani KS; Prabu T; +25 co-authors
The Astrophysical Journal **776**, 6, 2013

29. Simultaneous optical and photoacoustic measurement of nonlinear absorption
Chantharasupawong, Panit*; Philip, Reji; Thomas, Jayan*
Applied Physics Letters **102**, 041116, 2013

30. Spectral dispersion of ultrafast optical limiting in Coumarin-120 by white-light continuum Z-scan
Anand, Benoy*; Roy, Nivya*; Sai, Siva Sankara S*; Philip, Reji
Applied Physics Letters **102**, 203302, 2013

31. A thin wire ion trap to study ion–atom collisions built within a Fabry–Perot cavity
Ray, Tridib; Jyothi S; Ram, Bhargava N; Rangwala SA
Applied Physics Letters B **114**, 267-273, 2014

32. Preparation, optical and non-linear optical power limiting properties of Cu, CuNi nanowires
Udayabhaskar R*; Ollakkan, Muhamed Shafi; Karthikeyan B*
Applied Physics Letters **104**, 013107, 2014

33. Structural evaluation and nonlinear optical properties of Ni/NiO, Ni/$NiCo_2O_4$ and Co/Co_3O_4 nanocomposites
Rahulan, K Mani*; Padmanathan N*; Philip, Reji; Balamurugan S*; Kanakam, Charles C*
Applied Surface Science **282**, 656, 2013

34. Corrigendum to "Novel N-substituted-5-phenyl-1H-pyrazole-4-ethyl carboxylates as potential NLO materials" [Arab. J. Chem. (6) (2013) 97-102]
Chandrakanth B*; Isloor, Arum M*; Sridharan, Kishore*; Philip, Reji; Shetty, Prakash*; Padaki, Mahesh*; Fun, Hoong-Kun*
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Pandey D; Satapathy, Nandan; Suryabrahmam B; Ivan, Solomon; Ramachandran, Hema
European Physical Journal – Plus **129**, 115, 2014

17. Long range polarimetric imaging through fog
Fade J*; Panigrahi S*; Carré A*; Frein L*; Hamel C*; Bretenaker F*; Ramachandran, Hema; Alouini M*
Applied Optics **53**, 3854, 2014

18. Chiral symmetry breaking dictated by electric field - driven shape transitions of nucleating conglomerate domains in a bent-core liquid crystal
Deepa GB; Pratibha R
Physical Review E **89**, 062713, 2014

19. Effect of Dispersion of Gold Nanoparticles on the Optical and Electrical Properties of Discotic Liquid Crystal
Supreet; Pratibha R; Kumar, Sandeep; Raina KK*
Liquid Crystals **41**, 933, 2014

20. In situ fabrication of electrochemically grown mesoporous metallic thin films by anodic dissolution in Deep Eutectic Solvents
Renjith, Anu; Roy, Arun; Lakshminarayanan V
Journal of Colloid and Interface Science **426**, 270, 2014

21. Thin Film of Palladium Nanodendrites Supported on Graphite Electrode for Catalyzing the Oxidation of Small Organic Molecules
Pandey RK; Patnaik S; Lakshminarayanan V
Catalysis Letters **144**, 965, 2014

22. Investigation of the dynamical slowing down process in soft glassy colloidal suspensions: comparisons with supercooled liquids
Saha D; Joshi YM*; Bandyopadhyay, Ranjini
Soft Matter **10**, 3292-3300, 2014

23. Graphene-platinum nanocomposite as a sensitive and selective voltammetric sensor for trace level arsenic quantification
Kempegowda R*; Antony D; Malingappa P*
International Journal of Smart and Nano Materials **5:1**, 17-32, 2014

24. Application of a Hough search for continuous gravitational waves on data from the 5th LIGO science run
Aasi J*; Abadie J*; Abbott BP*; Iyer BR; +150 authors (LIGO Scientific Collaboration and Virgo Collaboration)
*Class. Quant. Gra*vity **31**, 085014, 2014

25. The Koslowski–Sahlmann representation: gauge and diffeomorphism invariance
Campiglia M; Varadarajan M
Class. Quant. Gravity **31**, 075002, 2014

26. Constraints on cosmic strings from the LIGO-Virgo gravitational-wave detectors
Aasi J*; Iyer BR, *et. al.* (LIGO Scientific Collaboration and Virgo Collaboration)
Phys. Rev. Lett. **112**, 131101, 2014

In Book Chapters

1. Ionic discotic liquid crystals: recent advances and applications
Pal, Santanu Kumar; Kumar, Sandeep
Nanobiomaterials for Intelligent Medical Devices

2. Liquid Crystalline 1D and 2D Carbon Materials
Hari K Bisoyi*; Kumar, Sandeep; Li, Quan*
Nanoscience with Liquid Crystals: From Self-Organized Nanostructures to Applications; Ed by Li Quan, Springer, Heidelberg 2014; ISBN-978-3-319-04866-6

3. 2.5PN kick from black-hole binaries in circular orbit: Nonspinning case
Mishra CK: Arun KG; Iyer BR
Proceedings of Relativity and Gravitation - 100 Years after Einstein in Prague; Ed. J. Bicak *et. al.* 2014 (In: Springer Proceedings in Physics, Vol. 157) ISBN-978-3-319-06761-2

In Conference Proceedings

1. Average spectral properties of galactic X-ray binaries with 3 years of MAXI data
Islam, Nazma; Mihara T*; Sugizaki, M*; Paul, Biswajit; Nath, Biman B
Astronomical Society of India Conference Series **8**, 109, Edited by Santabrata Das; et al.
Proceedings of Recent trends in the study of compact objects: Theory and Observation Conference held at Guwahati, March 11-13, 2013

2. Hybrid ion, atom and light trap
Jyothi S; Ray T; Ram, Bhargava N; Rangwala SA
International School of Physics "Enrico Fermi" – Varenna, Lake Como, Italy
Course on *"Ion traps for tomorrow's applications"*

3. Cavity optomechanics: quantum mechanics at mesocopic scales
Sainadh, Satya U; Narayanan, Andal
KIRAN (Proceedings of National Laser Symposium 22 held in Manipal University), **24**, 26, 2013

4. Active Cellular Mechanics and Information Processing in the Living Cell
Rao, Madan
Proceedings of the Workshop on Applications of Physics, Mathematics to Consciousness and Cognition at National Institute of Advanced Studies, Bangalore, March 2013

5. Usage Analysis of NKRC Resources: A study at Raman Research Institute
Meera BM
NKRC Nodal Officers Meeting held at Kodaikanal Observatory, IIAP, 5–7 June 2013

6. Unique Author Identifiers: An Introduction
Manjunath, Angadi; Meera BM
Soference 2013, TCS on 19 & 20 October 2013

7. Smart Phones and Library Services: an Evaluative study at Reva Institute of Technology and Management Library and Information Center
Vasantha B; Meera BM
Soference 2013 held at TCS on 19 & 20 October 2013

Erratum to Publications–Appendix I of Annual Report 2012-13 Page No. 128 – sl.no.94

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

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

APPENDIX II

Conferences Attended

Name	Conferences attended/Institutions visited	Title of paper/talk
Abir Sarkar	Astronomical Society of India Meeting 2014 Indian Institute of Science Education and Research, Mohali 20 – 22 March 2014	
Andal Narayanan	Meeting on Quantum Information Processing and Applications 2013 Harish Chandra Research Institute Allahabad 2 – 8 December 2013	A mechanical switch for state transfer in cavity optomechanical systems (*invited*)
	National Laser Symposium Manipal University, Manipal 8 – 11 January 2014	Cavity optomechanical systems: a new paradigm for realizing quantum effects in the macro regime
Anirudh Reddy	International Workshop on Mathematical Structures in Quantum Physics and Applications Indian Institute of Science, Bangalore 3 - 14 February 2014	
Anu Renjith	Novocontrol Dielectric/Impedance Analyser Workshop Raman Research Institute, Bangalore 20 – 21 January 2014	

Name	Conferences attended/Institutions visited	Title of paper/talk
Arpita Roy	Astronomical Society of India Meeting 2014 Indian Institute of Science Education and Research, Mohali 20 – 22 March 2014	In hot bubble: supernova feedback and escape of ionizing radiation
Arun Roy	Conference on Frontiers in Physics 2013 University of Hyderabad, Hyderabad 19 – 21 September 2013	Self organized mesophases of bent-core banana shaped molecules *(invited)*
	Novocontrol Dielectric/Impedance Analyser Workshop Raman Research Institute, Bangalore 20 – 21 January 2014	
	Central Leather Research Institute Chennai 21 – 25 March 2014	
Avinash Deshpande	University of Tasmania, Australia 1 April – 8 June 2013	1. Fascinating life-stories of pulsars *(public lecture)* 2. Pulsars (*lecture*)
	Curtin University, Australia 9 – 12 June 2013	
	National Centre for Radio Astronomy Pune 22 – 27 August 2013	1. Detection, coherence and correlation 2. Sources of errors in radio astronomy 3. Can pulsar rings have multiple sparks *(informal talk)*
	Indian Institute of Technology, Indore 6 – 7 September 2013	
	National Centre for Radio Astronomy Pune 23 – 25 October 2013	
	3rd Pro-Am Meeting in Astronomy Homi Bhabha Centre for Science Education, Mumbai 26 -27 October 2013	An Introduction to opportunities in Radio Astronomy *(invited)*
	Regional Conference on Radio Science 2014 Symbiosis Institute of Technology Pune 2 - 5 January 2014	Searches for transients at low radio frequencies: prospects and challenges *(invited)*

Name	Conferences attended/Institutions visited	Title of paper/talk
	National Centre for Radio Astronomy Pune 24 – 25 January 2014	
	SEDS India National Conference 2014 SASTRA University, Tanjore 1 – 2 March 2014	Fascinating life-stories of pulsars (*invited*)
	Astronomical Society of India Meeting 2014 Indian Institute of Science Education and Research, Mohali 19 – 22 March 2014	1. Transients with SKA (*invited*) 2. Faraday tomography: basis, prospects and challenges *(invited)*
Biman B Nath	St. Joseph's College, Bangalore 23 – 24 October 2013	Galaxy formation and milky way *(2 lectures)*
	National Centre for Radio Astronomy Pune 19 November 2013	Galactic outflows: shocks and surprises with radiation pressure
	RC Gupta Endowment Lecture Inter University Centre for Astronomy & Astrophysics, Pune 20 November 2013	Who first delivered helium in the sun?
	Indian Institute of Astrophysics Bangalore 9 January 2014	Who first delivered helium in the sun? *(public lecture)*
	Astronomical Society of India Meeting 2014 Indian Institute of Science Education and Research, Mohali 20 – 22 March 2014	
Biswajit Paul	Tezpur University, Assam 29 April 2013	X-ray view of the sky: some exciting recent results and future prospects
	Indian Institute of Technology Guwahati 2 May 2013	Investigating neutron stars with X-rays: today and tomorrow
	Gorakhpur University, Uttar Pradesh 5 August 2013	X-rays from neutron stars
	Indian Institute of Science, Bangalore 29 October 2013	X-rays from neutron stars

Name	Conferences attended/Institutions visited	Title of paper/talk
	MIT-IUCAA Workshop on X-ray Studies of Transient Astronomical Sources Inter University Centre for Astronomy and Astrophysics, Pune 13 – 24 January 2014	Accretion torques on neutron stars
	18th National Space Science Symposium Dibrugarh University, Assam 29 January – 1 February 2014	Compact astronomical objects *(plenary)*
	Indian Institute of Technology, Ropar 21 March 2014	X-ray studies of neutron stars
	32nd Meeting of the Astronomical Society of India Indian Institute of Science Education and Research, Mohali 20 – 22 March 2014	X-ray polarimetry *(plenary)*
Buti Suryabrahmam	National Laser Symposium Manipal University, Manipal 8 – 11 January 2014	Photon statistics of fluorescence from magneto optically trapped atoms
Dwarakanath KS	MWA Meeting Raman Research Institute, Bangalore 19 August 2013	Galactic and extra-galactic science with MWA
	National Centre for Radio Astronomy Pune 23 September 2013	Diffuse radio emission in galaxy clusters
	The Metre Wavelength Sky Conference National Centre for Radio Astronomy Pune 9 – 13 December 2013	1. MWA observations of the merging galaxy cluster Abell 3376 2. Low frequency radio emission in galaxy clusters 3. A new low-frequency MWA sky survey 4. Probable detection of HI at z 1.3 using GMRT
	MWA Project Meeting Victoria University of Wellington New Zealand 16 – 17 December 2013	MWA commissioning phase observations of the merging galaxy cluster Abell 3376

Name	Conferences attended/Institutions visited	Title of paper/talk
Gayathri Raman	MIT Workshop on High Energy Timing and Spectral studies of transients Inter University Centre for Astronomy and Astrophysics, Pune 11 – 26 January 2014	
	Astronomical Society of India Meeting 2014Indian Institute of Science Education and Research, Mohali 21 – 24 March 2014	Optical orbital modulation seen in EXO 0748-676 using XMM-NEWTON
	Inter University Centre for Astronomy and Astrophysics, Pune 1 – 15 April 2014	
Geetha S	National Symposium on Library: Transition Management PES Institute of Technology, Bangalore 22 August 2013	
	SoFerence 2013 Conference Tata Consulting Services, Bangalore 19 – 20 October 2013	
	6th KALA National Seminar on Save Libraries and Librarianship City Central Library, Bangalore 16 November 2013	
	15th International Conference on Asia-Pacific Digital Libraries: Social Media and Community Networks 2013 Hotel Le Meridien, Bangalore 9 – 11 December 2013	
Girish BS	The Metrewavelength Sky Conference National Centre for Radio Astronomy Pune 9 – 13 December 2013	A precision spectrometer for measuring cosmological signals
Gopala Krishna MR	18th National Space Science Symposium 2014 Dibrugarh University, Assam 29 January – 1 February 2014	1. Signal processing electronics for a Thomson X-ray polarimeter 2. Thomson X-ray polarimeter – development status

Name	Conferences attended/Institutions visited	Title of paper/talk
Hema Ramachandran	National Laser Symposium Manipal University, Manipal 8 – 11 January 2013	Intensity-intensity correlation of light from an ultracold thermal source
Iyer BR	NR Group MeetingLaser Interferometer Gravitational-wave Observatory, USA 1 – 12 April 2013	LIGO-India status
	APS Physics April Meeting Sheraton Denver Downtown Hotel, Denver 13 – 16 April 2013	IndIGO update on LIGO-India
	LIGO-India Meeting Inter University Centre for Astronomy and Astrophysics, Pune 10 – 14 June 2013	
	Summer School in Numerical Relativity International Centre for Theoretical Sciences, Bangalore 15 – 21 June 2013	
	Workshop on Interface of Numerical relativity with Gravitational-Wave Astronomy, Neutrino Physics and High-Energy Astrophysics International Centre for Theoretical Sciences 24 June – 5 July 2013	1. From IndIGO to LIGO-India *(invited)* 2. PN convergence of spinning binaries *(invited)*
	GWIC Meeting Uniwersytet Warszawski, Poland 7 July 2013	IndiGO, 2012-13 report *(invited)*
	GR20 and Amaldi10 Meeting Uniwersytet Warszawski, Poland 7 – 12 July 2013	
	Conference onField Theoretic Aspects of Gravity 2013 Indian Institute of Technology, Gandhinagar 5 - 8 September 2013	LIGO-India: locating cosmic chirps in the dark universe *(Invited)*

Name	Conferences attended/Institutions visited	Title of paper/talk
	LIGO-Virgo Collaboration Meeting Albert Einstein Institute, Hannover 22 – 27 September 2013 1 October 2013	1. LIGO-India update *(invited)* 2. IndIGO-LSC Senior members presentation
	GEO600 Ruthe/Sarstedt Observatory, Hannover 30 September 2013	
	Gravitational Wave Physics and Astronomy Workshop Inter University Centre for Astronomy and Astrophysics, Pune 17 – 20 December 2013	
	IndIGO-LSC Mid Term Review Meeting (Gravitational Wave Physics & Astronomy Workshop) Inter University Center for Astronomy and Astrophysics, Pune 21 December 2013	
	ICTS Winter School on Experimental Gravitational Wave Physics Raja Ramanna Centre for Advanced Technology, Indore 23 – 28 December 2013	
	Indian Institute of Technology, Kharagpur 20 February 2014	LIGO-India: Locating Einstein's messengers and inaugurating GW astronomy
	Presidency University, Kolkata 20 February 2014	LIGO-India: Locating Einstein's messengers and inaugurating GW astronomy
	Indian Institute of Science Education and Research, Kolkata 22 February 2014	LIGO-India: Locating Einstein's messengers and inaugurating GW astronomy
	Core-Group Meeting of LIGO-India Inter University Centre for Astronomy and Astrophysics, Pune 10 March 2014	

Name	Conferences attended/Institutions visited	Title of paper/talk
	LIGO – Virgo Collaboration Meeting Artemis group (Observatoure de late Cote d'Azur) 17 – 21 March 2014	LIGO-India status update *(Invited)*
Jacob Rajan	Conference on Transform IT with EMC Information Infrastructure Solutions EMC Executive Briefing Center Bangalore 27 August 2013	
	Conference on Accelerate Cloud Journey Hotel The Chancery, Bangalore 10 October 2013	
	Second NKN Annual Workshop Indian Institute of Science, Bangalore 17 – 19 October 2013	
	Conference on Business in Motion Executive Briefing Center, Bangalore 25 October 2013	
	Indo-Taiwan Cloud Computing Workshop The Atria Hotel, Bangalore 7 – 8 November 2013	
Joseph Samuel	Workshop on Quantum Mechanics MLA College, Bangalore 11 - 13 July 2013	Quantum mechanics *(course of lectures)*
	Valley School, Bangalore 15 August 2013	The accelerating universe
	Christ University, Bangalore 28 August 2013	Dark energy at Eureka 2013
	International Workshop on Mathematical Structures in Quantum Physics and Applications Indian Institute of Science, Bangalore 3 – 14 February 2014	Lagrangian embeddings in CPn
	Institute of Mathematical Sciences Chennai 23 – 25 January 2014	The geometric phase

Name	Conferences attended/Institutions visited	Title of paper/talk
	Homi Bhabha Centre for Science Education, Mumbai 4 – 5 March 2014 13 – 15 March 2014	
Jyothi S	Ecole Normale Superieure, Paris 17 – 18 July 2013	Ion-atom hybrid trap within Fabry-Perot cavity
	University of Basel, Switzerland 19 July 2013	Ion-atom hybrid trap within Fabry-Perot cavity
	Enrico-Fermi School on Ion Traps for Tomorrow's Applications International School of Physics Enrico Fermi 22 – 30 July 2013	An ion-atom hybrid trap within a hybrid trap assembly *(invited)*
Kamini PA	Seminar on Sigrity Technologies and Allegro New Release 1.6 Hotel Royal Orchid, Bangalore 5 June 2013	
Karthik HS	13th Asian Quantum Information Science Conference Institute of Mathematical Science Chennai 25 – 30 August 2013	Quantifying non-classical correlations via moment matrix positivity
	Meeting on Quantum Information Processing and Applications 2013 Harish Chandra Research Institute, Allahabad 2 – 8 December 2013	Entropic uncertainty assisted by temporal memory
	International Program on Quantum Information 2014 Institute of Physics, Bhubaneswar 17 – 28 February 2014	Beating entropic uncertainty bound with contextuality
Kartick C Sarkar	Astronomical Society of India Meeting 2014 Indian Institute of Science Education and Research, Mohali 20 – 22 March 2014	Mass and metal outflow from disc galaxies
Krishnamurthy S	Second NKN Annual Workshop Indian Institute of Science, Bangalore 17 – 19 October 2013	

Name	Conferences attended/Institutions visited	Title of paper/talk
Kumar Shivam	International Workshop on Mathematical Structures in Quantum Physics and Applications Indian Institute of Science, Bangalore 3 - 14 February 2014	
Lakshmi Saripalli	Conference on Future of Liberal Arts and Sciences in India Raman Research Institute, Bangalore 7 – 9 January 2014	
	Valley School, Bangalore 26 February 2014	CV Raman: his life, his work
Lakshminarayanan V	International Conference on Emerging trends in Chemical Sciences Vellore Institute of Technology Vellore 5 – 7 December 2013	Surface studies with self-assembled monolayer of organic thiol modified gold *(invited)*
	Chemie Conference 2013 Sathya Sai Institute of Higher Learning, Prasanthi Nilayam 14 – 15 December 2013	Many facets of self-assembled monolayers of organic thiols *(invited)*
Madhavan Varadarajan	20th International Conference on General Relativity and Gravitation and 10th Almadi Conference on Gravitational Waves Uniwersytet Warszawski, Poland 7 – 13 July 2013	Anomaly free constraint algebra for a weak coupling limit of gravity
	LOOPS 13 Perimeter Institute, Canada 22 – 26 July 2013	Towards a consistent quantum dynamics for Euclidean LQG: a weak coupling limit *(invited, plenary)*
	Field Theoretic Aspects of Gravity 13 Indian Institute of Technology Gandhinagar 5 – 8 September 2013	
	St. Stephen's Centre for Theoretical Physics St. Stephens College, Delhi 17 – 28 February 2014	A new identity for the dynamics of gravity *(2 lectures)*
Mahavir Sharma	Scuola Normale Superiore, Italy 20 May – 20 June 2013	

Name	Conferences attended/Institutions visited	Title of paper/talk
	Scuola Internazionale Superiore di Studi Avanzati, Italy 12 June 2013	Supernovae and AGN driven galactic outflows
	Conference on Galaxies and Halos Max Planck Institute for Astronomy Germany 24 – 28 June 2013	Outflows from galaxies and AGN
	Leiden Observatory, Netherlands 1 July 2013	Outflows from galaxies and AGN
	Paris Observatory, France 3 July 2013	Supernovae and AGN driven galactic outflows
	Astronomical Society of India Meeting 2014 Indian Institute of Science Education and Research, Mohali 20 – 22 March 2014	Extraplanar media in galaxies
Manjunath M	Symposium on E-content: Copyright, Licensing, Taxation and Regulatory Norms National Institute of Mental Health and Neuro Sciences, Bangalore 26 July 2013	
	International Conference on Open Access – Scholarly Communication Reincarnated: A Futuristic Approach Bangalore University, Bangalore 19 – 20 August 2013	
	SoFerence 2013 Conference Tata Consulting Services, Bangalore 19 – 20 October 2013	
	6th KALA National Seminar on Save Libraries and Librarianship City Central Library, Bangalore 16 November 2013	
	15th International Conference on Asia-Pacific Digital Libraries: Social Media and Community Networks 2013 Hotel Le Meridien, Bangalore 9 – 11 December 2 013	

Name	Conferences attended/Institutions visited	Title of paper/talk
Mayuri S	The Metrewavelength Sky Conference National Centre for Radio Astronomy Pune 9 – 13 December 2013	
Meena MS	NI Days – Technical Seminar National Institute of Mental Health and Neuro Sciences, Bangalore 4 September 2014	
Meera BM	NKRC Nodal Officers Meeting Indian Institute of Astrophysics Kodaikanal 5 – 7 June 2013	Usage analysis of NKRC resources: a study at Raman Research Institute
	Task Force Meeting of CSIR-wide Access to Online Information Resources CSIR Science Centre, New Delhi 17 June 2013	Usage analysis of NKRC resources: a study at Raman Research Institute *(invited)*
	Symposium on E-content: Copyright, Licensing, Taxation and Regulatory Norms National Institute of Mental Health and Neuro Sciences, Bangalore 26 July 2013	
	National Symposium on Library: Transition Management PES Institute of Technology Bangalore 22 August 2013	Library services at RRI: ranging from conventional to web based *(invited)*
	Royal Society of Chemistry Meeting Novotel Hotel, Hyderabad 30 September 2013	
	SoFerence 2013 Conference Tata Consulting Services, Bangalore 19 – 20 October 2013	1. Unique author identifiers: an introduction 2. Smart phones and library services: an evaluative study at Reva Institute of Technology and Management Library and Information Center
Meera Thomas	Statistical Physical School Raman Research Institute, Bangalore 1 – 13 April 2013	

Name	Conferences attended/Institutions visited	Title of paper/talk
	Novocontrol Dielectric/Impedance Analyser Workshop Raman Research Institute, Bangalore 20 – 21 January 2014	
Miguel Campiglia	LOOPS 13 Perimeter Institute, Canada 22 – 26 July 2013	Condensate representations in LQG
	Conference on Asymptotia Chennai Mathematical Institute Chennai 6 – 8 December 2013	Asympotic quantization *(invited)*
	Universidad de la Republica Uruguay 11 December 2013 – 31 January 2014	
Nagaraj MN	15th International Conference Asia-Pacific Digital Libraries: Social Media Community Networks 2013 Hotel Le Meridien, Bangalore 9 – 11 December 2 013	
	National Conference on Impact of Information Technology on Library Services Suvarna Samskruthi Bhavan Shimoga 27 – 28 December 2013	Electronic resources management at RRI Library
	National Conference – Proceedings of the DEMICT 2014 Mangalore University, Mangalore 24 – 25 January 2014	Open access initiatives in Physics literature: exploratory study
Nazma Islam Syeda	COSPAR Capacity Building Workshop for High Energy Astrophysics Xuyi Observatory Station, China 2 – 13 September 2013	Source detection in M 31 with Chandra and XMM-Newton
	MIT-IUCAA Workshop on X-ray studies of Transient Astronomical Objects Inter University Centre for Astronomy and Astrophysics, Pune 13 – 24 January 2014	

Name	Conferences attended/Institutions visited	Title of paper/talk
	Astronomical Society of India Meeting 2014 Indian Institute of Science Education and Research, Mohali 20 – 22 March 2014	Orbital modulation of the X-ray binary GX 301-2: wind diagnostics
Niranjan Myneni	International Seminar on Current Trends in Quantum Gases, BEC and Solitons Punjab University, Chandigarh 3 – 6 March 2014	
	Indo French Physics Conference Indian Institute of Science, Bangalore 18 – 21 March 2014	
	Bangalore School on Statistical Physics Raman Research Institute, Bangalore 31 March 2014	
Prabu T	The Metrewavelength Sky Conference National Centre for Radio Astronomy Pune 9 – 13 December 2013	A full-band voltage beam forming mode for the Murchison Widefield Array digital receiver
Pramod Pullarkat	Conference on Mechanical Manipulations and Responses at the Scale of Cells and Beyond National Centre for Biological Sciences, Bangalore 19 – 21 April 2013	Passive and active mechanical responses of axons
	Indian Institute of Science Education and Research, Pune 24 – 26 February 2014	Active mechanics and shape instabilities in axons
	Bangalore University, Bangalore 30 – 31 August 2013	Cell mechanics and interactions: the physics biology interface
	MLA College, Bangalore 3 April 2014	Understanding neuronal cell dynamics using ideas from physics
Pramod Tadapatri	Bangalore School on Statistical Physics Raman Research Institute, Bangalore 31 March 2014	

Name	Conferences attended/Institutions visited	Title of paper/talk
Pratibha R	14th International Conference on Ferroelectric Liquid Crystals Otto-von-Guericke-University Magdeburg 1 – 6 September 2013	Electric field induced switchable dark conglomerate phases in a bent-core liquid crystal exhibiting reverse columnar phases
	Inštitut at Jozef Stefan, Jamova cesta - Ljubljana, Slovenija 7 – 21 September 2013	
	12th European Conference on Liquid Crystals University of Patras, Greece 22 – 27 September 2013	Macroscopic chiral symmetry breaking under applied electric fields in a bent-core liquid crystal
Priyanka Singh	Indian Institute of Science Education and Research, Mohali 2 – 17 July 2013	
	Astronomical Society of India Meeting 2014 Indian Institute of Science Education and Research, Mohali 20 – 22 March 2014	Sunaev-Zel'dovich effect from hot gas in galactic halos
Jagdish Chandra Joshi	Workshop on Python Programming in Astronomy Inter University Centre for Astronomy & Astrophysics, Pune 17 – 21 February 2014	
Raghunathan A	The Metre Wavelength Sky Conference National Centre for Radio Astronomy Pune 9 – 13 December 2013	1. Development of a zero-spacing interferometric technique for detecting the EoR signal 2. Design of an integrated front end receiver for array of precision spectrometers for epoch of recombination
	Regional Conference on Radio Science Symbiosis International University Pune 2 – 5 June 2014	Frequency independent antennas for cosmology
	Faculty Development Program on Antenna Technologies BMS College of Engineering, Bangalore 28 January 2014	Design of a frequency independent dipole antenna: a case study *(invited)*

Name	Conferences attended/Institutions visited	Title of paper/talk
Raghunathan VA	Institute of Molecular Biosciences University of Graz, Austria 1 – 8 December 2013	Influence of sterols on the phase behaviour of phospholipids
	Discussion Meeting on Biological Membranes Indian Institute of Science, Bangalore 14 – 15 March 2014	Phase separation in lipid-sterol membranes *(invited)*
Ranjini Bandyopadhyay	Universitat Dusseldorf, Germany 13 May 2013	Scaling laws obtained in the rise of Brazil nuts and in the aging of clay suspensions
	Annual General Meeting of the Global Young Academy German National Academy of Sciences, Germany 15 – 18 May 2013	
	Jawaharlal Nehru Centre for Advanced Scientific Research Bangalore 22 June 2013	The curious case of soft matter
	Bangalore University, Bangalore 26 – 28 September 2013	Soft materials *(lecture series)*
	Soft Matter Young Investigator's Meet Institute of Mathematical Sciences Chennai 5 – 7 January 2014	
	Indian Statistical Physics Community Meeting Indian Institute of Science, Bangalore 1 – 3 February 2014	Ultrasound attenuation spectroscopy study of the size distribution of clay tactoids in aqueous suspension
	International Centre for Theoretical Sciences, Bangalore 7 February 2014	Investigation of the dynamical slowing down of colloidal clay suspensions: comparisons with supercooled liquids
	Asia Meeting of Young Scientists Science Council of Japan, Japan 13 – 14 February 2014	Career tracks, life and lab

Name	Conferences attended/Institutions visited	Title of paper/talk
	Symposium on Soft Condensed Matter Jawaharlal Nehru University, Delhi 10 March 2014	Investigation of the dynamical slowing down of colloidal clay suspensions: comparisons with supercooled liquids *(invited)*
	One-day Lecture Program for Women's Day SRN Adarsh College, Bangalore 11 March 2014	The curious case of soft materials *(invited)*
Ravi Subrahmanyan	2nd Workshop for Pulsar Observatory for Students Radio Astronomy Center, Ooty 9 – 12 July 2013	1. Radio telescopes: from antennas to arrays 2. History of the universe: using radio astronomy
	International Conference on The Radio Universe @ Ger's (wave)-length University of Groningen, The Netherlands 4 – 8 November 2013	The cosmic radio background *(invited)*
	International Conference on "The Metre Wavelength Sky: celebrating 50 years of radio astronomy at TIFR National Centre for Radio Astronomy Pune 9 – 13 December 2013	Cosmology in the cosmic radio background spectrum *(invited)*
	Australia Telescope Compact Array Australia 14 – 18 March 2014	
	Australian National University Australia 18 March – 9 April 2014	Extragalactic background light at long wavelengths: a tracer of cosmic evolution
	Melbourne University, Australia 9 – 12 April 2014	
	University of Western Australia Australia 15 – 18 April 2014	Extragalactic background light at long wavelengths: a tracer of cosmic evolution
Reji Philip	Christ University, Bangalore 19 April 2013	1. Nature of Light 2. Nonlinear Optics

Name	Conferences attended/Institutions visited	Title of paper/talk
	National Conference on Recent Trends in Materials Science and Technology 2013 Indian Institute of Space Science and Technology, Trivandrum 10 - 12 July 2013	Optical nonlinearity in nanostructured materials *(invited)*
	National Workshop on Advanced Materials Research for Device Applications NMAM Institute of Technology Udupi 25 - 26 July 2013	Experimental aspects of materials research in photonics *(invited)*
	International Conference on Perspectives in Vibrational Spectroscopy 2013 Bishop Moore College, Kerala 9 August 2013	Optical nonlinearity in nanomaterials *(invited)*
	Mercy College, Kerala 30 August 2013	Photonic Materials: Techniques and Applications
	Conference on Recent Trends in the Development of Nanomaterials and Nanodevices 2013 SNM College, Malyankara 6 September 2013	Optical nonlinearities in nanomaterials *(invited)*
	IEEE Workshop on Nanotechnology and Sensors Indian Institute of Science, Bangalore 19 September 2013	Nonlinear optical phenomena in nanomaterials *(invited)*
	IUMRS-International Conference on Advanced Materials 2013 Quingdao International Convention Center, China 23 - 27 September 2013	Optical nonlinearity in core-shell type oxide protected nanoparticle systems *(invited)*
	National Seminar on Photonics MES College, Ponnani 9 - 10 October 2013	Intense light-matter interactions *(invited)*
	UGC Academic Staff College Trivandrum 28 October 2013	1. Optical nonlinearity in the nanophase 2. Nanomaterial characterization techniques

Name	Conferences attended/Institutions visited	Title of paper/talk
	Topical Conference of the Indian Society for Atomic and Molecular Physics 2013 on Atomic Processes in Plasmas Institute for Plasma Research 18 - 20 November 2013	Influence of source pulse width on the laser ablation of Zinc in nitrogen ambient (*invited*)
	INSPIRE Internship Camp for Higher Secondary Students Sacred Heart College, Cochin 25 December 2013	History of Light
	Workshop on Nonlinear Optics St. Dominic's College, Kerala 2 - 3 January 2014	1. History of Light 2. Laser pulses 3. NLO of nanomaterials 4. Laser-induced plasmas
	National Laser Symposium Manipal University, Mangalore 8 - 11 January 2014	1. Influence of laser pulse width on the emission dynamics of a laser produced Zn plasma in nitrogen ambient 2. One-pot synthesis of silica capped I-VI metal sulfides and their nonlinear optical properties
	National Conference on Frontiers in Applied Spectroscopy Maharani College, Bangalore 14 February 2014	Nonlinear optical phenomena in nanomaterials *(invited)*
	National Conference on Nanophotonics 2014 Bharathidasan University, Trichy 6 - 7 March 2014	Nonlinear optical phenomena in nanomaterials *(invited)*
Rishin PV	18th National Space Science Symposium 2014 Dibrugarh University, Assam 29 January – 1 February 2014	1. Signal processing electronics for a Thomson X-ray polarimeter 2. Thomson X-ray polarimeter – development status 3. Mechanical design in development of X-ray polarimeters
Ruckmongathan TN	International Display Workshop IDW 2013 Sapporo Convention Center, Japan 4 – 6 December 2013	1. Micro-pulse modulation for grey scales in display devices *(invited)* 2. Micro-pulse width modulation to drive matrix LCDs
Sadiq Rangwala	Tata Institute of Fundamental Research, Mumbai 14 August 2013	Courtship of ions and atoms

Name	Conferences attended/Institutions visited	Title of paper/talk
	COST-IOTA Workshop on Cold Molecular Ions University of Innsbruck, Austria 2 – 5 September 2013	Consequences of interactions in trapped ion-atom systems
	Conference on Resonator QED Max Planck Institute for Quantum Optics, Germany 9 – 13 September 2013	Cavities as detectors for cooled and trapped mixed spices
	IISc. Physics Colloquium Indian Institute of Science, Bangalore 8 November 2013	Dance of ions and atoms
	557.WE-Heraeus-Seminar on Trapped Ions meet Cold Atoms University of Ulm, Germany 27 – 29 March 2014	Cavity enclosed hybrid trap for ions, atoms and molecules
Samim Ali	6th International Conference on Nano Science and Technology 2014 Punjab University, Punjab 3 – 5 March 2014	Using electro-acoustic method for the characterization of aqueous dispersions of nanoclays
	Soft Matter Young Investigators' Meet Institute of Mathematical Sciences Chennai 5 – 7 January 2014	
Sandeep Kumar	Trinity College, Dublin 25 April 2013	Discotic photovoltaics *(invited)*
	4th Meeting of the Monitoring Committee for Development of Polymer Based Sensors Institute of Advanced Study in Science and Technology, Guwahati 2 May 2013	
	INSPIRE Internship Science Camp Raj Kumar Goel Engineering College Pilkhuwa 17 May 2013	Can crystals be liquid? The fascinating world of liquid crystals *(invited)*
	Indian Institute of Science, Bangalore 31 July 2013	

Name	Conferences attended/Institutions visited	Title of paper/talk
	National Conference on Scope of Advanced Materials in Energy & Environment CMR Institute of Technology Bangalore 7 August 2013	Liquid crystalline nanocomposites as advanced materials for energy harvesting *(invited)*
	Department of Electronics and Information Technology, New Delhi 13 September 2013 27 September 2013	
	Central Leather Research Institute Chennai 23 September 2013	Can crystals be liquid? The fascinating world of liquid crystals *(invited)*
	National Conference on Liquid Crystals 2013 Manipal Institute of Technology Manipal 16 – 18 December 2013	Blending of discotic liquid crystals with nanoparticles *(invited)*
	Programme Committee Meeting University of Allahabad 9 December 2013	
	Administrative Staff College of India 30 December 2013 – 10 January 2014	
	INSPIRE Internship Science Camp Raj Kumar Goel Engineering College Pilkhuwa 21 January 2014	Can crystals be liquid? The fascinating world of liquid crystals *(invited)*
	INSPIRE Internship Science Camp Raj Kumar Goel Engineering College Ghaziabad 21 January 2014	Can crystals be liquid? The fascinating world of liquid crystals *(invited)*
	Discussion Meeting on Discotic Solar Cells University of Allahabad, Allahabad 1 February 2014	

Name	Conferences attended/Institutions visited	Title of paper/talk
	International Conference on Nano Science and Technology 2014 Institute of Nano Science and Technology, Mohali 2 – 5 March 2014	Dispersion of Zero-, One- and Two-dimensional Nanoparticles in the Supramolecular Order of Discotic Liquid Crystals *(invited)*
	Indian Institute of Science Education and Research, Mohali 6 March 2014	Nanoparticles in discotic liquid crystals *(invited)*
	National Conference on Emerging Trends in Physical and Chemical Sciences Holkar Science College, Indore 15 – 16 March 2014	Nanoparticles in discotic liquid crystals: a new class of organic semiconductors *(invited)*
	Refresher Course in Chemistry for UG/PG faculty Central College, Bangalore 24 March 2014	An introduction to liquid crystals *(invited)*
Sanjib Sabhapandit	International Centre for Theoretical Sciences, Bangalore 2 July 2013	High energy tail of the velocity distribution of driven inelastic gases
	25th International Conference on Statistical Physics Seoul National University, Korea 22 – 26 July 2013	Fluctuations and large deviations in nonequilibrium systems
	Korea Institute for Advanced Study Korea 27 July - 1 August 2013	Fluctuations and large deviations in nonequilibrium systems
	International Workshop on Small Systems far from Equilibrium: Order, Correlations, and Fluctuations Max Planck Institute for the Physics of Complex Systems, Germany 14 - 18 October 2013	Fluctuations and large deviations in nonequilibrium systems
	8th Conference on Nonlinear Systems and Dynamics Indian Institute of Technology, Indore 11 – 14 December 2013	Extreme value statistics: Near-extreme events and records *(invited)*
	S.N. Bose National Centre for Basic Sciences, Kolkata 17 January 2014	Fluctuations and large deviations in nonequilibrium systems *(Invited)*

Name	Conferences attended/Institutions visited	Title of paper/talk
	Indian Statistical Physics Community Meeting 2014 Indian Institute of Science, Bangalore 1 – 3 February 2014	High energy tail of the velocity distribution of driven inelastic gases
	Pondicherry University, Pondicherry 26 February 2014	Fluctuations and large deviations in nonequilibrium systems *(Invited)*
	3rd International Symposium on Complex Dynamical System and Application 2014 10 – 12 March 2014	Extreme value statistics: Near-extreme events and records *(invited)*
Shabeeb PK	Conference on Role of Acto-Myosin Mechanics at Cell Membrane National Centre for Biological Sciences, Bangalore 19 – 21 April 2013	
Somashekar R	ADS Training Seminar Agilent Technologies, Bangalore 5 – 6 September 2013	
	The Metrewavelength Sky Conference National Centre for Radio Astronomy Pune 9 – 13 December 2013	Design of an integrated front end receiver for Array of Precision Spectrometers for Epoch of Recombination (APSERA)
Sourabh Paul	Murchison Widefield Array Project Meeting Victoria University of Wellington New Zealand 9 – 17 December 2013	EoR Observation with drift scan strategy
	Astronomical Society of India Meeting 2014 Indian Institute of Science Education and Research, Mohali 20 – 22 March 2014	Study of redshifted HI from the epoch of reionization era with drift scan
Sridhar S	Institute for Advanced Study, USA 25 May – 22 June 2013	Dynamo action in shear flows due to alpha fluctuations
	Program on Galactic Dynamics The Institut Henri Poincaré, France 31 October 2013	Towards a theory of resonant relaxation in galactic nuclei *(invited)*

Name	Conferences attended/Institutions visited	Title of paper/talk
	Workshop on Dynamics and Kinetic Theory of self-gravitating systems The Institut Henri Poincaré, France 8 November 2013	Secular modes of Keplerian Stellar Systems *(invited)*
Srivani KS	MWA Meeting Raman Research Institute, Bangalore 19 August 2013	MWA digital receiver system
	The Metrewavelength Sky Conference National Centre for Radio Astronomy Pune 9 – 13 December 2013	
Ezhilarasi MS	ADS Training Seminar Agilent Technologies, Bangalore 5 – 6 September 2013	RF/microwave and systems
Sumati Surya	Conference on Women in Higher Education Research National Institute of Advanced Studies, Bangalore 20 – 21 June 2013	The role of gender in negotiating an academic path *(invited)*
	Conference on General Relativity and Gravitation Uniwersytet Warszawski, Poland 7 – 13 July 2013	Causal set dynamics: results in 2D quantum gravity
	LOOPS 13 Perimeter Institute, Canada 22 – 26 July 2013	Causal set dynamics: results in 2D quantum gravity
	Meeting on Field Theoretic Aspects of Gravity Indian Institute of Technology Gandhinagar 5 – 8 September 2013	Lorentzian geometry from discrete causal structure *(invited)*
	RRI Meeting on the Quantum Measure Raman Research Institute, Bangalore 17 – 18 December 2013	Introduction to Quantum Measure Theory

Name	Conferences attended/Institutions visited	Title of paper/talk
	International Workshop on Mathematical Structures in Quantum Physics and Applications and Anticommutators in Quantum and Statistical Physics Indian Institute of Science, Bangalore 6 February 2014	Hilbert spaces from histories using the quantum measure
Supurna Sinha	Workshop on Quantum Mechanics MLA College, Bangalore 11 - 13 July 2013	1. Waves and particles 2. Probability waves and their description 3. Schrodinger equation and its applications
	Statistical Physics Community Meeting International Centre for Theoretical Sciences, Bangalore 3 February 2014	Statistical mechanics of bent twisted ribbons
	International Workshop on Mathematical Structures in Quantum Physics and Applications Indian Institute of Science, Bangalore 3 - 14 February 2014	Commutators and anticommutators in quantum and statistical physics
Sushil Dubey	Bangalore School on Statistical Physics Raman Research Institute, Bangalore 1- 13 April 2013	
	National Fluorescence Workshop 2013 Indian Institute of Science, Bangalore 24 November 2013	Active and passive responses of axonal cytoskeleton
	Conference on Quantitative System Biology 2013 International Centre for Theoretical Sciences, Bangalore 9 – 20 December 2013	Active and passive responses of axonal cytoskeleton
Tridib Ray	Indo-French Physics Conference Indian Institute of Science, Bangalore 20 March 2014	Hybrid traps for atoms ions and molecules
Urbasi Sinha	Institute for Quantum Science and Technology, Canada 17 July 2013	Quantifying the quantum *(invited)*

Name	Conferences attended/Institutions visited	Title of paper/talk
	Bangalore University, Bangalore 27 September 2013	Quantifying the quantum *(public lecture)*
	Indian Institute of Science, Bangalore 28 November 2013	Quantifying the quantum *(invited)*
	Meeting on Quantum Information Processing and Applications 2013 Harish-Chandra Research Institute, Allahabad 2 – 8 December 2013	Quantifying the quantum *(invited)*
	International Program on Quantum Information 2014 Institute of Physics, Bhubaneswar 17 – 28 February 2014	Whirling waves in interference experiments *(invited)*
	National Science Day BNM Institute of Technology Bangalore 28 February 2014	Quantifying the quantum *(public lecture)*
	American Physical Society March Meeting 2014 American Physical Society, USA 3 – 7 March 2014	Whirling waves in interference experiments
	Womens' Day SRN Adarsh College, Bangalore 11 March 2014	Quantifying the quantum *(public lecture)*
Udaya Shankar N	Student-Scientist Interaction Program Jawaharlal Nehru Planetarium Bangalore 1 June 2013	The universe we live in
	Radio Astronomy Centre, Ooty 9 July 2013	Challenges of observing the invisible sky
	International School for Young Astronomers 2013 National Institute of Aeronautics and Space, Indonesia 5 – 6 September 2013	Radio astronomy past-present-future
	Bharati College, Mandya 26 September 2013	Exploration of the universe

Name	Conferences attended/Institutions visited	Title of paper/talk
	The Metrewavelength Sky Conference National Centre for Radio Astronomy Pune 9 – 13 December 2013	A study of fundamental limitation on the detection of redshifted HI from the EoR
	MWA Science Meeting Victoria University of Wellington New Zealand 16 – 17 December 2013	MWA visibilities to the EoR power spectrum
	Institute for Radio Astronomy and Space Research, New Zealand 19 December 2013	Adventures in low frequency radio astronomy and cosmology
	Faculty Improvement Program BMS College of Engineering Bangalore 28 January 2014	Role of signal processing in phased array antennas
	National Science Day Visveswaraya Industrial and Technological Museum, Bangalore 28 February 2014	The importance of experiments in Physics
Venkata Jagadeesh Rachuri	Novocontrol Dielectric/Impedance Analyser Workshop Raman Research Institute, Bangalore 20 – 21 January 2014	
Vijayaraghavan D	National Conference on Liquid Crystals 2013 Manipal Institute of Technology Manipal 17 December 2013	1H NMR study of an aqueous surfactant solution containing single-walled carbon nanotubes - probing the association of water molecules with the self-assembled structures of carbon nanotubes
Vrinda Benegal	Seminar on OPAC, J-Gate and FedGate-Content Discovery Fortune Park JP Celestial, Bangalore 27 September 2013	
	DST Meeting Raman Research Institute, Bangalore 16 October 2013	

Name	Conferences attended/Institutions visited	Title of paper/talk
	SoFerence 2013 Conference Tata Consulting Services, Bangalore 19 – 20 October 2013	
	International Conference on Digital Libraries 2013 The Energy and Resources Institute New Delhi 27 – 29 November 2013	Digital repository of Raman Research Institute Library
	15th International Conference Asia-Pacific Digital Libraries 2013 Hotel Le Meridien, Bangalore 9 – 11 December 2013	
	Ramakka-Padmakka Endowment Lecture series on Data Analytics for Librarians Tata Consultancy Services, Bangalore 22 March 2014	
Yashodhan Hatwalne	Indian Statistical Physics Meet Indian Institute of Science, Bangalore 1 – 2 February 2014	Morphologies of polymer crystallites

APPENDIX III

Colloquia and Seminars

Name	Title	Date
Surajit Paul Inter University Centre for Astronomy and Astrophysics, Pune	Role of violent explosions in evolution of energy and structures at large scale	2 April 2013
Anil Kumar University of Hyderabad Hyderabad	Buffer gas collisions effect on electromagnetically induced transparency in three level atomic systems	5 April 2013
Vanitha M Bharathidasan University Tiruchirapalli	Internal nonlinear dynamics of continuum and lattice models of DNA	10 April 2013
Amit Das SN Bose National Centre for Basic Sciences, Kolkata	Dimensional crossover in fluids under Nano-meter scale confinement	10 April 2013
Sriramkumar L Indian Institute of Technology Madras, Chennai	The scalar bispectrum during inflation and preheating in single field inflationary models	15 April 2013
Biswaroop Mukherjee Max Planck Institute for Polymer Research Mainz, Germany	Multi-scale simulation of liquid crystals: a bottom-up approach	17 April 2013
Vijay Kumar K Max Planck Institute for Molecular Cell Biology and Genetics Germany	The cell cortex: a thin film of active matter	17 April 2013

Name	Title	Date
Rahul R Nair University of Manchester United Kingdom	Properties of graphene and its chemical derivatives	17 April 2013
Anand Srivastava The University of Chicago Chicago	Membrane-binding proteins in action: examples of membrane-protein association and protein-driven membrane remodelling processes	22 April 2013
Dibyendu Das Indian Institute of Technology Bombay	Enhanced collective force generation by bio-filaments undergoing chemical switching	10 May 2013
Muthukumar M University of Massachusetts, USA	Menagerie of viruses: organizing principles of virus assembly	14 May 2013
Shamik Gupta Universite Paris, France	Statics and dynamics of systems with long-range interactions	15 May 2013
Yogesh M Joshi Indian Institute of Technology Kanpur	Thermally activated asymmetric structural recovery in soft glassy nanoclay suspension	16 May 2013
Vijayaraghavan R Tata Institute of Fundamental Research, Mumbai	High fidelity measurements of superconducting quantum bits	17 May 2013
Gaurav Narain Institute of Mathematical Sciences Chennai	Short distance freedom of quantum gravity	21 May 2013
Sushil Mujumdar Tata Institute of Fundamental Research, Mumbai	Frequency and intensity fluctuations in coherent random lasers	27 May 2013
Manjari Bagchi West Virginia University, USA	Binary radio pulsars: prospects and problems	29 May 2013
Harishankar Ramachandran Indian Institute of Technology Madras, Chennai	Approach to classical behaviour in optical communication links	12 June 2013
Rajaram Nityananda Indian Institute of Science Education and Research, Pune	The global geometry of polarized light – a tale of two spheres	13 June 2013
Rajaram Nityananda Indian Institute of Science Education and Research, Pune	Effect of a strong magnetic field on the equation of state and the Chandrasekhar limit	18 June 2013

Name	Title	Date
Rajaram Nityananda Indian Institute of Science Education and Research, Pune	What we can learn from the strange behavior of water waves	19 June 2013
Shyamal Biswas Indian Institute of Technology Kanpur	Thermodynamic properties of cold atoms: classical and quantum aspects	2 July 2013
Manesh Gopinadhan Yale University, USA	Can we reliably direct self-assembly of soft materials to obtain near-single crystalline materials?	8 July 2013
Vikram Vyas Shiv Nadar University, Uttar Pradesh and Delhi University Delhi	Heavy-quark potential: from a fundamental string to a flux-tube	8 July 2013
Pramod Tadapatri Centre for Soft Matter Research Bangalore	Electric field generated instabilities of thermotropic liquid crystals	9 July 2013
Achamveedu Gopakumar Tata Institute of Fundamental Research, Mumbai	Inspiral templates for spinning compact binaries	18 July 2013
Debjani Bagchi Laboratoire de Physique Statistique, Ecole Normale Superieure, France	Role of fluctuations in molecular motor dynamics and dynamics in ageing systems	18 July 2013
Yuri Shchekinov South Federal University, Russia	Dust outside galaxies	26 July 2013
Gautam V Soni Kavli Institute of Nanoscience The Netherlands	Nanopore biophysics: from gene sequencing to gene silencing	29 July 2013
Girish S Agarwal Oklahoma State University, USA	Photon aided and inhibited tunneling of photons	31 July 2013
Paul Keyes Wayne State University, USA	Generalizing the nematic order parameter	1 August 2013
Paul Keyes Wayne State University, USA	Fluctuation effects near the nematic-isotropic transition	2 August 2013
Venkatesh Gopal Elmhurst College, USA	Sex, files and video (tape) visualizing odor – following behavior in drosophila larvae	5 August 2013

Name	Title	Date
Anupam Kundu Laboratoire de Physique Theorique et Modeles Statistiques, France	Exact distributions of the number of distinct and common sites visited by N independent random walkers	5 August 2013
Bikash Sinha Department of Atomic Energy Saha Institute of Nuclear Physics and Variable Energy Cyclotron Centre	Time, space and the singular universe	7 August 2013
Brian Schmidt Australian National University Australia	Supernovae	19 August 2013
Pinaki Chaudhuri Universitat Dusseldorf, Germany	Numerical studies of shear flow in soft amorphous materials	22 August 2013
Kripa G University of California, USA	A PDE model for spindle self organization	26 August 2013
Aravind Chinchure Reliance Innovation Leadership Centre, Pune	Reinventing India by integrating science, technology and innovation: opportunities and challenges	29 August 2013
Mohanty PS Lund University, Sweden	Escaping the squeeze: soft colloids at high effective volume fractions	2 September 2013
Katherine Blundell Oxford University, Oxford	X-ray and radio studies of giant radio galaxies and quasars	13 September 2013
Sandipan Sengupta Raman Research Institute Bangalore	Topological parameters in gravity	16 September 2013
Jainendra Jain Penn State University, USA and Indian Institute of Science Bangalore	Composite fermions: the magical beauty of emergence	19 September 2013
Michael Kesteven Commonwealth Scientific and Industrial Research Organisation / Australia Telescope National Facility, Australia	Commissioning the ASKAP array	20 September 2013
Alok Kumar Pan Nagoya University, Japan	Aspects of weak measurement : conceptual and metrological implications	23 September 2013

Name	Title	Date
Dipankar Home Bose Institute, Kolkata	Probing non-classicality of the Schrodinger coherent state and quantum classical transition for harmonic oscillator using Leggett-Garg inequality	26 September 2013
Philip J Wyatt Wyatt Technology Corporation USA	Taking coals to Newcastle. Bringing light scattering to the Raman Institute	30 September 2013
Ananthanarayan B Indian Institute of Science Bangalore	The discovery of the Higgs Boson and consequences: On the Nobel prize winning work of Englert and Higgs	22 October 2013
Nissim Kanekar National Centre for Radio Astronomy, Pune	The nature of high-redshift damped Lyman-alpha systems	22 October 2013
Sanjoy K Sarker University of Alabama, USA	Is the pseudogap and superconductivity in cuprates connected with the physics of Mott Insulator?	22 November 2013
Bei-Lok Hu University of Maryland, USA	Gravitational decoherence and alternative quantum theories	26 November 2013
Harilal SS Purdue University, USA	Ultrafast laser ablation and applications	26 November 2013
Sourav Dutta Purdue University, USA	Production and detection of ultracold LiRb molecules	27 November 2013
Bei-Lok Hu University of Maryland, USA	Understanding macroscopic quantum phenomena	28 November 2013
Richard Perley National Radio Astronomy Observatory, USA	The Jansky very large array - a new array for new science	5 December 2013
Buddhapriya Chakrabarti Durham University, UK	Elastodynamics in two contexts, foam micromechanics and ribbon curling	5 December 2013
Namir Kassim Naval Research Laboratory , USA	Update on low frequencies at the VLA, and plans for a commensal system	6 December 2013
Tracy Clarke Naval Research Laboratory, USA	Jovian Decametric studies with the LWA1	6 December 2013
Sanjukta Roy University of Florence, Italy	From few to many body physics: quantum simulations with ultra cold quantum gases	11 December 2013

Name	Title	Date
Saptarishi Chaudhuri University of Florence, Italy	Quantum phase transitions in a system of disordered interacting 1D Bose gas: transport measurements and beyond	12 December 2013
Areejit Samal International Centre for Theoretical Physics, Italy	Phenotypic constraints drive the architecture of biological networks	13 December 2013
Suchand Sandeep CS Delft University of Technology The Netherlands	Photogeneration, carrier multiplication and dynamics of charges in quantum-dot films: Towards third-generation solar cells	16 December 2013
Miller Goss National Radio Astronomy Observatory, USA	JVLA observations of Sagittarius A	17 December 2013
Murukeshan Vadakkematham Nanyang Technological University Singapore	Optical lithography: challenges for meeting the forecasted technological nodes	17 December 2013
Jayashree A Dharmadhikari Manipal University, Manipal	Ultrashort laser filamentation: utility in few cycle pulse generation, material modification and DNA damage	18 December 2013
Aditya K Dharmadhikari Tata Institute of Fundamental Research, Mumbai	Laser assisted, absorber induced rapid dendritic and crystal growth	19 December 2013
Harry van der Laan Leiden University and University of Utrecht, The Netherlands	The development of radio astronomy in the Netherlands and in Europe - past, present and future	19 December 2013
Ron Ekers Commonwealth Scientific and Industrial Research Organisation Australia	Phased array feeds, mosaics and mutual coupling in aperture arrays	26 December 2013
Ron Ekers Commonwealth Scientific and Industrial Research Organisation Australia	Indirect imaging: the history of aperture synthesis in radio astronomy	2 January 2014
Vikram Rentala Michigan State University, USA	WIMPless dark matter	3 January 2014
Bruce Bassett South African Astronomical Observatory, South Africa	A tale of two redshifts – a new cosmological test	7 January 2014

Name	Title	Date
Aswath Babu Indian Institute of Technology Kanpur	Creation and control of nonlinear dynamical phenomena in all optical bistable systems	7 January 2014
Arkaprabha Sarangi University of Basel, Switzerland	Dust and molecules in the ejecta of type II-P supernovae	10 January 2014
Mukunda P Das The Australian National University Australia	Physics of vortex matter of novel superconductors	10 January 2014
Anita Roychowdhury University of Maryland, USA	Design and characterization of a millikelvin dual-tip Josephson scanning tunneling microscope	16 January 2014
Jagdish K Vij University of Dublin, Ireland	Twist bend nematic phase and its fast electroclinic effect	16 January 2014
Rao DVGLN University of Massachusetts Boston	Optical Fourier phase contrast and multimodal microscopy using liquid crystals	21 January 2014
Barry Sanders University of Calgary, Canada	Whither quantum computing?	23 January 2014
Alok C Gupta Aryabhatta Research Institute of Observational Sciences, Nainital	Multi-wavelength studies of blazars	28 January 2014
Chandreyee Sengupta Korea Astronomy and Space Science Institute, Republic of Korea	Sociology of galaxies: some aspects of galaxy evolution in low density environments	6 February 2014
Shri Kulkarni California Institute of Technology USA	The mysterious fast radio bursts	7 February 2014
Benoy Anand Sri Sathya Sai Institute of Higher Learning, Prasanthi Nilayam	Nonlinear optical and ultrafast time resolved studies in nanocarbons and Zno nanostructures	18 February 2014
Sudarshan Khanna Universal Learn Today, Toy Innovation Centre, National Institute of Design, New Delhi	Toying with ideas	20 February 2014

Name	Title	Date
Ronojoy Adhikari The Institute of Mathematical Sciences, Chennai	Hydrodynamics of chemomechanically active microparticles in viscous fluids	28 February 2014
Yasuhiro Sakemi Tohoku University, Japan	Fundamental physics using laser cooled radioactive atoms	4 March 2014
Nirupam Roy Max Planck Institute for Radio Astronomy, Germany	The temperature of the diffuse H1 in the milky way	7 March 2014
Vijay Kumar K Max Planck Institute for Molecular Cell Biology and Genetics and Max Plank Institute for the Physics of Complex Systems, Dresden	Active mechanochemical patterns in morphogenesis	10 March 2014
Vijaykumar Chikkadi University of Amsterdam The Netherlands	A microscopic understanding of the deformation of glasses using colloids	12 March 2014
Ramkarthik Seshadri Indian Institute of Technology Madras	Two studies on quantum entanglement: optimal mixtures and dimerization in the Majumdar Ghosh Model	12 March 2014
Partha Ghose SN Bose National Centre for Basic Sciences, Kolkata	Entanglement in classical optics	17 March 2014
Rajesh R The Institute of Mathematical Sciences, Chennai	Microstructural characteristics of the mammalian cortical bone	19 March 2014
Arijit Kumar De University of California, Berkeley	Probing ultrafast coherent dynamics by incoherent fluorescence detection: Towards a spatiotemporal approach	26 March 2014
Pravabati Chingangbam Indian Institute of Astrophysics Bangalore	BICEP2, PLANCK and inflation – a discussion	27 March 2014
Sreedhar VV Chennai Mathematical Institute Chennai	An exact expression for a flat connection on the complement of a Torus Knot	28 March 2014

APPENDIX IV

Visitors

Name and Institution	Duration of stay
Asif Iqbal Ahangar Kashmir University, Srinagar	15 March – 23 April 2013
Nishant K Singh Inter-University Centre for Astronomy and Astrophysics, Pune	1 – 8 April 2013 18 – 23 May 2013 29 – 30 August 2013
Surajit Paul Inter-University Centre for Astronomy and Astrophysics, Pune	2 – 3 April 2013
Ganesh V Central Electro Chemical Research Institute, Karaikudi	9 – 12 April 2013
Vanitha M Bharathidasan University, Tiruchirappalli	10 - 11 April 2013
Amit Das S.N. Bose National Centre for Basic Sciences, Kolkata	10 - 11 April 2014
Sriram Kumar Indian Institute of Technology, Madras	15 – 16 April 2013
Biswaroop Mukherjee Max Planck Institute for Polymer Research , Germany	16 – 19 April 2013
Harishankar Ramachandran Indian Institute of Technology, Chennai	16 – 19 April 2013 10 – 13 June 2013

Name and Institution	Duration of stay
Anand Srivastava The University of Chicago, Chicago	22 April 2013
Ann Mary Mahatma Gandhi University, Kottayam	22 April – 24 July 2013 1 – 5 October 2013 31 January – 1 February 2014
Mamta Pandey – Pommier Centre de Recherche Astrophysique, de Lyon, France	30 April – 17 May 2013
Muthukumar M University of Massachusetts, USA	8 – 18 May 2013 30 January – 21 February 2014
Dibyendu Das Indian Institute of Technology, Bombay	10 – 21 May 2013
Shamik Gupta Universite Paris, France	13 – 17 May 2013
Yogesh M Joshi Indian Institute of Technology, Kanpur	15 – 18 May 2013
Vijayaraghavan R Tata Institute of Fundamental Research, Mumbai	16 – 18 May 2013
Dibyendu Roy Los Alamos National Laboratory, USA	18 – 24 May 2013
Gaurav Narain Institute of Mathematical Sciences, Chennai	22 – 24 May 2013
Seshadri T R Delhi University, New Delhi	25 May – 10 June 2013 15 – 22 December 2013
Sushil Mujumdar Tata Institute of Fundamental Research, Mumbai	26 – 29 May 2013
Manjari Bagchi West Virginia University, USA	27 – 31 May 2013
Nityananda R Indian Institute of Science Education and Research, Pune	10 – 25 June 2013
Santanu Kumar Pal Indian Institute of Science Education and Research, Mohali	17 – 19 June 2013
Chirag Kalelkar Indian Institute of Technology, Kharagpur	22 June – 7 July 2013

Name and Institution	Duration of stay
Vikram Vyas Shiv Nadar University, Uttar Pradesh and Delhi University, Delhi	1 – 10 July 2013
Manesh Gopinadhan Yale University, USA	8 – 9 July 2013
Robin John Indian Institute of Technology, Madras	8 – 10 July 2013
Shyamal Biswas Indian Institute of Technology, Kanpur	1 – 4 July 2013
Yuri Shchekinov South Federal University, Russia	12 July – 7 August 2013
Rahul Nigam Birla Institute of Technology and Science, Hyderabad	16 – 20 July 2013 17 – 22 December 2013 6 – 9 March 2014
Debjani Bagchi Laboratoire de Physique Statistique Ecole Normale Superiure, France	17 – 20 July 2013
Radhika Vathsan Birla Institute of Technology and Science, Pilani, Goa	17 July - 18 December 2013
Achamveedu Gopakumar Tata Institute of Fundamental Research, Mumbai	18 July 2013
Venkatesh Gopal Elmhurst College, USA	25 July – 14 August 2013
Gautam V Soni Kavli Institute of Nanoscience, The Netherlands	28 – 31 July 2013
Girish S Agarwal Okhalama State University, USA	30 – 31 July 2013
Paul Keyes Wayne State University, USA	31 July – 5 August 2013
Anupam Kundu Laboratoire de Physique Statistique Ecole Normale Superiure, France	4 – 11 August 2013
Honey John Indian Institute of Space Science and Technology, Trivandrum	5 – 7 August 2013

Name and Institution	Duration of stay
Aurnab Ghose Indian Institute of Science Education and Research, Pune	9 – 10 August 2013
Pinaki Chaudhuri Universitat Dusseldorf, Germany	21 – 24 August 2013
Evgenii Vasiliev South Federal University, Russia	27 August – 15 September 2013
Aravind Chinchure Reliance Innovation Leadership Centre, Pune	29 August 2013
Mohanty PS Lund University, Sweden	1 – 4 September 2013
Vanessa Manipal University, Manipal	4 – 18 September 2013
Michael Kesteven CSIRO - Australia Telescope National Facility, Australia	18 – 24 September 2013
Alok Kumar Pan Nagoya University, Japan	22 – 25 September 2013
Dipankar Home Bose Institute, Kolkata	25 – 29 September 2013 4 – 5 October 2013 16 – 22 December 2013
Asha K Mandya	6 – 21 October 2013
Jurek Malarecki International Centre for Radio Astronomy Research, UWA Australia	6 October – 22 November 2013
Esha Kundu Tata Institute of Fundamental Research, Mumbai	17 October – 17 November 2013
Nissim Kanekar National Centre for Radio Astrophysics, Pune	21 – 23 October 2013
Bidisha Bandyopadhyay Delhi University, New Delhi	23 October – 18 December 2013 20 January – 25 February 2014 16 – 31 March 2014
Lutfor Rahman University Malaysia, Pahang	25 October – 2 November 2013

Name and Institution	Duration of stay
Pragati Pradhan St. Joseph's College, Darjeeling	27 October – 10 November 2013 18 December 2013 – 21 February 2014
Aru Beri Indian Institute of Technology, Ropar	3 November 2013 – 30 January 2014
Yogesh Maan Indian Institute of Science, Bangalore	6 – 19 November 2013 20 November – 7 December 2013 15 December 2013 – 15 January 2014
Mukunda P Das The Australian National University, Australia	9 – 12 November 2013
Kavitha MK Indian Institute of Space Science and Technology, Trivandrum	19 – 21 November 2013
Harilal SS Purdue University, USA	25 – 26 November 2013
Bei-Lok Hu University of Maryland, USA	25 – 30 November 2013
Luc Blanchet Institut d' Astrophysique de Paris, France	01 – 13 December 2013
Suchand Sandeep CS Delft University, The Netherlands	1 – 4 December 2013 15 – 17 December 2013
Richard & Peggy Perley National Radio Astronomy Observatory, Socorro	4 – 8 December 2013
Namir Kassim Naval Research Laboratory, USA	4 – 8 December 2013
Tracy Clarke Naval Research Laboratory, USA	4 – 8 December 2013
Rafael Sorkin Perimeter Institute, Canada	6 December 2013 – 14 January 2014
Smijesh N National Institute of Technology, Calicut	10 – 12 December 2013
Ankit Singh Delhi University, New Delhi	11 December 2013 – 3 January 2014
Ashutosh Tripathi Indian Institute of Science Education & Research, Mohali	13 December 2013 – 4 January 2014

Name and Institution	Duration of stay
Murukeshan Vadakke Nanyang Technological University, Singapore	15 – 18 December 2013
Kishore Sridharan Hangyang University, South Korea	15 – 21 December 2013
Harry Van der Laan Leiden University and University Utrecht	15 – 19 December 2013
Miller Goss National Radio Astronomy Observatory, Socorro	16 – 19 December 2013
Ron Ekers CSIRO Astronomy & Space Science, Australia	16 December 2013 – 15 January 2014
Aditya Dharmadhikari Tata Institute of Fundamental Research, Mumbai	17 – 20 December 2013 22 – 23 December 2013
Jayashree Dharmadhikari Tata Institute of Fundamental Research, Mumbai	17 – 20 December 2013 22 – 23 December 2013
David H Roberts Brandeis University, USA	28 December 2013 – 9 January 2014
Katie Weil Brandeis University, USA	28 December 2013 – 9 January 2014
Vandna Gokhroo Okinawa Institute of Science and Technology, Japan	30 December 2013 – 1 January 2014
Aswath Babu Indian Institute of Technology, Kanpur	6 – 7 January 2014
Ish Dhand University of Calgary, Canada	8 January – 15 February 2014
Arkaprabha Sarangi University of Basel, Switzerland	9 – 11 January 2014
Jagdish K Vij University of Dublin, Ireland	14 – 16 January 2014
Anita Roychaudhury University of Maryland, USA	16 January 2014
Barry Sanders University of Calgary, Canada	17 January – 15 February 2014

Name and Institution	Duration of stay
Anne Harvey Green Sydney, Australia	20 – 23 January 2014
Rao DVGLN University of Massachusetts, USA	22 – 24 January 2014
Faye G Institut d' Astrophysique de Paris, Paris	26 January – 8 February 2014
Lisa Glaser University of Copenhagen, Copenhagen	30 January – 28 February 2014
Nampoori VPN Cochin University of Science and Technology, Cochin	1 – 2 February 2014
Manu Kumara Center for Quantum Technologies, Singapore	1 February 2014 – 30 April 2014
Chandreyee Sengupta Korea Astronomy & Space Science Institute, Korea	3 – 7 February 2014
Haripadmam PC Indian Institute of Space Science and Technology, Trivandrum	6 – 8 February 2014
Ravindra Dhar University of Allahabad, Allahabad	11 – 14 February 2014
Sudarshan Khanna Universal Learn Today, New Delhi	20 – 23 February 2014
Yogesh Maan National Centre for Radio Astyrophysics, Pune	6 – 10 March 2014
Nirupam Roy Max Planck Institut Fur Radio Astronomie, Germany	6 – 14 March 2014
Ramkarthik Sheshadri Indian Institute of Technology, Madras	11 – 13 March 2014
Rajesh R Institute of Mathematical Sciences, Chennai	19 March 2014
Arijit Kumar De University of California, Berkeley	26 March 2014

APPENDIX V

Journal Club

Discussed by	Paper discussed	Date
Mayuri S	Selection and Covariance George R Price *Nature* **227**, 520-521 (01 August 1970) doi: 10.1038/227520a0	25 April 2013
Priya Rose	Near infrared spectroscopic analysis of single malt Scotch whisky on an optofluidic chip Praveen C. Ashok, Bavishna B, Praveen and Dholakia K *Optics Express* **19**, 23 (2011)	25 April 2013
Vijayaraghavan D	Molecular manipulator driven by spatial variation of liquid-crystalline order Sadaki Samitsu, Yoichi Takanishi and Jun Yamamoto *Nature Materials* **816**, 9 (2010)	9 May 2013
Suman G Das	Prime Numbers and Brownian Motion Patrick Billingsley *The American Mathematical Monthly*, **80**, 10 (Dec 1973)	9 May 2013
Reji Philip	Interfacing atoms and light: the smaller the stronger Thompson *et. al.*, *Science* **340**, 1202 (2013)	20 June 2013
Prasad V V	How basin stability complements the linear-stability paradigm Peter J Menck, Jobst Heitzig, Norbert Marwan and Jürgen Kurths *Nature Physics* **9**, 89-92(2013)	20 June 2013

Discussed by	Paper discussed	Date
Samim Ali	Collective Motion of Humans in Mosh and Circle Pits at Heavy Metal Concerts Jesse L. Silverberg, Matthew Bierbaum, James P. Sethna, and Itai Cohen *Physical Review* **110**, 228701 (2013)	27 June 2013
Nazma Islam	A rapidly spinning supermassive black hole at the centre of NGC 1365 Risaliti *et. al.* *Nature* **494**, 7438, 449-451 (2013)	27 June 2013
Raghunathan A	Room-Temperature solid-state maser Oxborrow M, Breeze J.D & Alford N.M *Nature* **488**, 353-356 (2012)	25 July 2013
Sadiq A Rangwala	D-wave in quantum processing *Nature Communications* **4:** 1903 doi: 10:1038/ncomms2920 *Nature Communications* **4:** 2067 doi:10:1038/ncomms3067	25 July 2013
Arpita Roy	The Starburst-Driven Molecular Wind in NGC 253 and the Suppression of Star Formation Alberto D and Bolatto, *et. al.* arXiv: **1307.6259**	22 August 2013
Anjan Roy	Brownian Motion of Boomerang Colloidal Particles Q.H. Wei, *et.al.* arXiv: **1308.3656** (19 Aug 2013)	22 August 2013
Jagadeesh R V	Accelerated chemistry in the reaction between the hydroxyl radical and methanol at interstellar temperatures facilitated by tunneling Robin J. Shannon, Mark A. Blitz, Andrew Goddard and Dwayne E. Heard *Nature Chemistry* **5**, 745-749 (2013) doi : 10.1038/nchem.1692	12 September 2013
Madhukar S	Nematic liquid crystal boojums with handles on colloidal handlebodies Qingkun Liu, Bohdan Senyuk, Mykola Tasinkevych, Ivan I. Smalyukha PNAS **110,** 23, 9231-9236, (June 4, 2013)	12 September 2013
Jyothi S	Digital Cameras with designs inspired by the Arthropod Eye *Nature* **497**,95-99 (02 May 2013) doi:10.1038/nature12083	26 September 2013

Discussed by	Paper discussed	Date
Anirudh Reddy S	Momentum Transfer to a Free Floating Double Slit: Realization of a Thought Experiment from the Einstein-Bohr Debates Ph.H. Schmidt, J. Lower, T. Jahnke, S. SchoBler, M.S. Schoffler, A. Menssen, C. Leveque, N. Sisourat, R. Taieb, H. Schmidt-Bocking and R. Dorner. Robin J. Shannon, Mark A. Blitz, Andrew Goddard & Dwayne E. Heard *Phys.Rev.Lett.* **111**.103201(2013)	10 October 2013
Ranjini Bandyopadyay	Granular discharge rate for submerged hoppers Wilson T.J, Pfeifer C.R, Mesyngier N, Durian D.J arXiv:**1307**.**2812** (cond-mat.soft)	10 October 2013
Kumar Shivam	Laser-based acceleration of non-relativistic electrons at a dielectric structure John Breuer, Peter Hommelhoff *Phys.Rev.Lett.* **111**.134803 arXiv:1308.0464 (physics.optics) doi: 10.1103	24 October 2013
Prabu Thiagaraj	Enhanced sensitivity of the LIGO gravitational wave detector by using squeezed states of light The LIGO Scientific Collaboration *Nature Photonics*, **7**, 613-619 (August 2013)	21 November 2013
Arun Roy	Predictability and Suppression of Extreme Events in a Chaotic System Hugo L.D. Cavalcante de S, Marcos Oria, Didier Sornette, Edward Ott, and Daniel J. Gauthier *Phys.Rev.Lett.* **111**,198701 (2013)	21 November 2013
Rahul Sawant	From Few to Many: Observing the formation of a Fermi Sea One Atom at a Time WenzG. Zurn A. N, Murmann S, Brouzos I, Lompe T, Jochim S *Science* 342, 457 (2013)	12 December 2013

APPENDIX VI

Visiting Students' Programme

	Student	Mentor
1	Pavan Iyengar	Srikant R
2	Sharath Puthige	Udaya Shankar N
3	Sahana Prasanna	Ramesh B
4	Mithra K	Vijayaraghavan D
5	Divyashree Ravi	Ramesh B
6	Amith Kumar U R	Ranjini Bandyopadhyay
7	Supreet K Rao	Ramesh B
8	Anup S K	Hema Ramachandran
9	Karthik S Joshi	Urbasi Sinha
10	Tushar Kant Verma	Jacob Rajan
11	Chandan G N	Deshpande A A & Srikant R
12	Guruprasad A R	Prabu T
13	Gaurav Das	Lakshminarayanan V
14	Shashi Kumar R	Ruckmongathan T N
15	Santanu Das	Kumar N
16	Manisha Pranati Caleb	Deshpande A A
17	Deepa B	Ruckmongathan T N
18	Vishwesh R	Pramod Pullarkat
19	Zarin A S	Pratibha R
20	Abhijit Venkatesh	Ramesh B

	Student	Mentor
21	Vineetha N	Andal Narayanan
22	Jijil J J Nivas	Reji Philip
23	Sunny Saurabh	Urbasi Sinha
24	Reena Sayani	Urbasi Sinha
25	Srihari Tagat	Kumar N
26	Priyanka R	Udaya Shankar N
27	Raksha	Udaya Shankar N
28	Sneha J	Udaya Shankar N
29	Palak Tater	Ruckmongathan T N
30	Gayathri Jagamohan	Deshpande A A
31	Shwetha B V	Girish B S
32	Badrinarayan S	Girish B S
33	Aman Bansal	Prabu T
34	Archana M S	Hema Ramachandran
35	Rithika K	Hema Ramachandran
36	Tintu Kuriakose	Reji Philip
37	Madhusudan M R	Arun Roy
38	Shaman N	Udaya Shankar N
39	Niranjan B S	Udaya Shankar N
40	Nikesh Vora	Udaya Shankar N
41	Poonam	Udaya Shankar N
42	Shiva Keerthi P S	Jacob Rajan
43	Abhinand Murthy	Ruckmongathan T N
44	Aarthi Ramesh	Dwarakanath K S
45	Swetavalli Raghavan	Pramod Pullarkat
46	Vivek V K	Ramesh B
47	Parvathi C	Ramesh B
48	Satya Sainadh U	Andal Narayanan
49	Arvind Sai Kumar	Udaya Shankar N
50	Manasa R Prasad	Udaya Shankar N
51	Deepak R	Raghunathan A
52	Pavan Harapanahalli B	Raghunathan A
53	Akhilesh S	Raghunathan A
54	Aquib Jamal	Raghunathan A

	Student	Mentor
55	Debadrita Ghosh	Urbasi Sinha
56	Sapna Ravindran	Ranjini Bandyopadhyay
57	Pooja Nagesh	Hema Ramachandran
58	Arfa Nasir	Hema Ramachandran
59	Pavithra K T	Somashekar R
60	Pranitha Sankar	Reji Philip
61	Jacintha B	Arun Roy
62	Anindya Majumdar	Harshal Bhadkamkar
63	Shasidaran Raj	Ramesh B
64	Nikhil Mukund K	Bala R Iyer
65	Sree Vani J	Dwarakanath K S
66	Swapna T	Pratibha R
67	Mayank Singh	Biman Nath
68	Shrinidhi Kumar Kalwad	Gopalakrishna M R/Rishin P V
69	Aparna D	Gopalakrishna M R/Rishin P V
70	Samanvitha M	Gopalakrishna M R/Rishin P V
71	Krishnapriya S R	Andal Narayanan
72	Ashwin Kalyan V	Udaya Shankar N
73	Paritosh Verma	Bala R Iyer
74	Yugandhar Kamdi	Raghunathan A
75	Pallabi Das	Ranjini Bandyopadhyay
76	Shruti Shahi	Ruckmongathan T N
77	Sreenivasalu Somireddy	Vijayaraghavan D
78	Rudrabhatla Sahithi	Dwarakanath K S
79	Niranjan V K	Ramesh B
80	Himanshu Gupta	Pramod Pullarkat
81	Jayesh A Bafna	Raghunathan V A
82	Hafsa Syed	Ranjini Bandyopadhyay
83	Vinod P	Sandeep Kumar
84	Sukeert	Hema Ramachandran
85	Kulkarni Abhay Prakash	Ramesh B
86	Supravika Hegde M R	Raghunathan A
87	Sreekanth P	Reji Philip
88	Surbhi Khetrapal	Sumati Surya

	Student	Mentor
89	Krishna Prasad S	Hema Ramachandran
90	Rishyashringa J S	Vijayaraghavan D
91	Sai Swaroopa N	Girish B S
92	Vaishnavi Bharadwaj	Girish B S
93	Ashwini Veigas	Deshpande A A
94	Suma N Murthy	Deshpande A A
95	Dharmendra Prasad Shukla	Ranjini Bandyopadhyay
96	Karishma Bansal	Deshpande A A
97	Sayan Patra	Sadiq Rangwala
98	Pridhvi S	Yashodhan Hatwalne
99	Nagendra G M	Andal Narayanan
100	Rashmi M R	Hema Ramachandran
101	Rajsekhar Das	Ranjini Bandyopadhyay
102	Shruthi S	Udaya Shankar N
103	Robert Miller Morton	Ranjini Bandyopadhyay
104	Snehalatha TKAC	Ramesh B
105	Madhu K	Ramesh B
106	Varsha Manikumar	Udaya Shankar N
107	Nidhin P	Srikant R
108	Sumit Haldar	Arun Roy
109	Vagish Das	Lakshmi Saripalli
110	Arpit Dilip Bhugul	Pramod Pullarkat
111	Shreya Ray	Urbasi Sinha
112	Rashi Shroff	Deshpande A A
113	Karthigeyan R	Ramesh B
114	Harshini S	Srivani K S
115	Mintu Francis	Prabu T
116	Anjali P S	Urbasi Sinha
117	Nishtha Agarwal	Sandeep Kumar
118	Sneha R	Prabu T
119	Sarayoo Sasidharan K	Reji Philip
120	Ashvini Purohit	Hema Ramachandran
121	Sriram V	Deshpande AA
122	Praveen Kumar M	Hema Ramachandran

	Student	Mentor
123	Aravind Sarathy	Pramod Pullarkat
124	Pranitha Sankar	Reji Philip
125	Varsha Manikumar	Udaya Shankar N
126	Arun M	Shiv K Sethi
127	Anand Sahay	Lakshmi Saripalli
128	Vinaya Kumara D R	Sandeep Kumar
129	Simin Meshk	Arun Roy
130	Soumya Hegde	Deshpande A A
131	Deepika Udupa	Ruckmongathan T N
132	Rengaraj G	Urbasi Sinha
133	Aditya P M	Ramesh B
134	Kavya H Rao	Reji Philip
135	Krishna Priya S R	Andal Narayanan
136	Vishnu M	Hema Ramachandran
137	Pradeep Kumar N	Urbasi Sinha
138	Animesh Aaryan	Urbasi Sinha
139	Chaitra G V	Srivani K S
140	Bhargavi M	Srivani K S
141	Jake Cohen	Lakshmi Saripalli
142	Divya A P	Hema Ramachandran
143	Aarushi A Karimpanal	Joseph Samuel
144	Pavithra K T	Srivani K S
145	Satish K T	Prabu T
146	Sandeep P	Prabu T
147	Shyam Narayan S	Prabu T
148	Elizabeth Noble	Reji Philip
149	Supriya D M	Pratibha R
150	Guruprasad A R	Prabu T
151	Dinesh Raut	Shiv K Sethi
152	Neha Mahendarkar V	Ruckmongathan T N
153	Anand Sahay	Lakshmi Saripalli
154	Niranjan V K	Ramesh B
155	Aravind H V	Urbasi Sinha
156	Rajaneesh R	V A Raghunathan

	Student	Mentor
157	Ashwini G	Ravi Subrahmanyan
158	Chandan K J	Somashekar R
159	Nikhil B V	Somashekar R
160	Kashyap N	Udaya Shankar N
161	Akshay G H	Udaya Shankar N
162	Sunny Sourabh	Hema Ramachandran
163	Aarushi Karimpanal	Joseph Samuel/Supurna Sinha
164	Kulkarni Abhay Prakash	Ramesh B
165	Kiran Kumar B M	Ramesh B
166	Ashwini R	Prabu T
167	Ashwini S	Prabu T
168	Susav Pradhan	Pramod Pullarkat
169	Sriram Sudarshanam	Hema Ramachandran
170	Manish Kumar	Sandeep Kumar
171	Ishani Salaria	Deshpande A A
172	Pradeep Raja	Vijayaraghavan D
173	Hafsa Syed	Ranjini Bandyopadhyay
174	Anitha Rose Thomas	Reji Philip
175	Jayasheel R	Udaya Shankar N
176	Sachin B S	Udaya Shankar N

RAMAN
RESEARCH
INSTITUTE
BANGALORE

STATEMENT OF ACCOUNTS

2013 – 2014

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", Sir C V Raman Avenue, Sadashivanagar, Bangalore – 560 080, which comprise the Balance Sheet as at 31st March, 2014 and the Statement of Income and Expenditure Account for the year then ended and a summary of significant accounting polices 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
Basavanagudi, Bangalore - 560 004
Phone: 080 - 26566448, 26577448

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

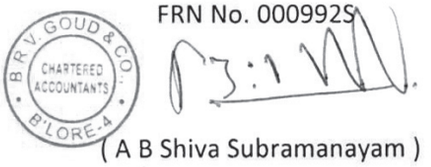
a. in the case of the Balance Sheet, of the state of affairs of the RAMAN RESEARCH INSTITUTE as at 31st March, 2014;

b. 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



(A B Shiva Subramanayam)
Partner
M No. 201108

Place : Bangalore
Date : 27.08.2014

RAMAN RESEARCH INSTITUTE

Bangalore

Balance Sheet as at 31st March 2014

I SOURCES OF FUNDS	SCH.	As at 31.3.2014 Rs.	As at 31.3.2013 Rs.
CAPITAL FUND	1	106,27,08,808	103,69,32,812
GENERAL FUND	2	89,76,976	77,93,670
RETIREMENT FUNDS	3	33,05,55,749	30,60,43,044
UNUTILISED GRANTS	4	95,53,864	5,45,07,195
SUNDRY CREDITORS	5	1,34,33,220	1,90,86,827
PROVIDENT FUND (contra)	6	10,72,09,969	9,94,79,359
PENSION FUND (contra)	7	8,42,43,409	6,83,47,127
TOTAL		161,66,81,995	159,21,90,034

II APPLICATION OF FUNDS			
FIXED ASSETS	8	91,35,58,453	90,30,07,129
INVESTMENTS - RETIRMENT FUND	9	33,05,55,749	30,60,43,044
CURRENT ASSETS, ADVANCES AND DEPOSITS	10	14,34,51,298	12,55,70,648
CASH AND BANK BALANCES	11	3,76,63,117	8,97,42,727
PROVIDENT FUND (contra)	12	10,72,09,969	9,94,79,359
PENSION FUND (contra)	13	8,42,43,409	6,83,47,127
TOTAL		161,66,81,995	159,21,90,034

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

K. KRISHNAMA RAJU
Administrative Officer

RAVI SUBRAHMANYAN
Director

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

Place : Bangalore
Date : August 27, 2014

RAMAN RESEARCH INSTITUTE

Bangalore

Income and Expenditure Account for the year ended 31.03.2014

A INCOME	SCH.	2013-2014 Rs.	2012-2013 Rs.
GRANT-IN-AID:			
Non-Plan-Recurring		84,75,000	1,07,10,000
Plan-Recurring		27,48,84,330	25,43,51,849
Interest & Miscellaneous Income	14	1,32,83,023	1,11,99,110
TOTAL (A)		29,66,42,353	27,62,60,959
B EXPENDITURE			
Salaries & Allowances	15	18,92,31,387	17,44,38,223
Working Expenses	16	10,62,27,660	10,07,34,514
TOTAL(B)		29,54,59,047	27,51,72,737
C SURPLUS/(DEFICIT)FOR THE YEAR (A-B)		11,83,306	10,88,222

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

K. KRISHNAMA RAJU
Administrative Officer

RAVI SUBRAHMANYAN
Director

A. B. SHIVA SUBRAMANYAM
Partner
M No. 201108

Place : Bangalore
Date : August 27, 2014

RAMAN RESEARCH INSTITUTE
Bangalore

Receipts and Payments account for the year ended 31.03.2014

RECEIPTS	SCH.	2013-2014 Rs.	2012-2013 Rs.
Opening Balance	A	11,61,696	1,70,78,789
Grant-in-aid	B	33,44,30,040	35,97,01,815
Miscellaneous Receipts	C	1,41,06,229	1,20,90,853
Deposits and other Items	D	4,16,58,740	3,60,79,409
Short term Bank Deposits & Investments		78,90,32,482	57,06,82,750
TOTAL		118,03,89,187	99,56,33,616

PAYMENTS			
Recurring Expenditure (Plan and Non-Plan)	E	29,74,66,347	27,71,52,277
Plan - Non-Recurring Expenditure	F	7,63,44,329	6,91,68,839
Expenditure out of Grants/ Assistance from Government Agencies	G	94,17,048	54,08,670
Advance to Suppliers	H	1,52,24,672	85,48,116
Deposits and other items	I	4,38,22,223	3,45,30,236
Short term Bank Deposits & Investments		73,40,00,000	59,96,63,782
Closing Balance	J	41,14,568	11,61,696
TOTAL		118,03,89,187	99,56,33,616

Notes on accounts. 17
Schedules A to J & 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 : August 27, 2014

RAMAN RESEARCH INSTITUTE

Bangalore

Schedules forming part of the Audited Statements of Account for the year ended 31st March 2014

PARTICULARS		As on 31.03.2014 Rs.	As on 31.03.2013 Rs.
SCHEDULE - 1			
Capital Fund			
Balance as on 1.4.2013		103,69,32,812	100,60,79,708
Add: Assets acquired/transferred during the year			
1) Plan - Non - Recurring		9,15,69,001	7,77,16,955
2) Scientific Publications acquired during the year		1,05,14,977	1,16,06,350
		113,90,16,790	109,54,03,013
Less: Assets deleted during the year	110,63,206		
Less : Accu.depn.(Vide Sch.8 col. 9)	57,09,027	53,54,179	2,06,408
		113,36,62,611	109,51,96,604
Less: Depreciation		7,09,53,803	5,82,63,793
TOTAL		106,27,08,808	103,69,32,812
SCHEDULE - 2			
General Fund			
Balance as on 1.4.2013		77,93,670	67,05,448
Add/((Less) : Surplus/ (Deficit) for the year		11,83,306	10,88,222
TOTAL		89,76,976	77,93,670

PARTICULARS		As on 31.03.2014 Rs.	As on 31.03.2013 Rs.
SCHEDULE - 3			
Retirement Funds - vested with SBI Life Insurance			
1. Gratuity Fund			
Opening Balance	7,29,83,498		
Add : Interest earned	64,48,000		
Less: Claims paid	34,28,151		
		7,60,03,347	7,05,64,706
2. Leave Salary			
Opening Balance	6,06,11,273		
Add : Interest earned	53,57,898		
Less: Claims paid	27,26,658		
		6,32,42,513	6,06,11,273
3. Commutation of Pension Fund			
Opening Balance	17,55,13,806		
Add : Interest earned	1,57,96,083	19,13,09,889	17,48,67,065
TOTAL		33,05,55,749	30,60,43,044
SCHEDULE - 4			
Unutilized Grants			
Plan Non- Recurring		95,53,864	5,45,07,195
TOTAL		95,53,864	5,45,07,195

PARTICULARS		As on 31.03.2014 Rs.	As on 31.03.2013 Rs.
SCHEDULE - 5			
Sundry Creditors			
a. Un-Utilised Grants - Projects/Meetings etc.,			
1. Enabling New Sciences- MWA		36,269	13,80,000
2. Australia-India Strategic Research Fund			2,38,540
2. DBT - Biomechanics of synaptogensis		7,321	7,321
3. ISRO - for SSO Project			39,96,781
4. INSA Fellowship		33,418	1,40,000
5. CSIR - Jr. Research Fellowship			33,609
6. IFCPAR Research Project		1,37,525	3,72,300
7. Indo-Australian(BMWF) Joint Research		1,55,000	
8. Implementation of India & Russia basic Science		4,73,600	
b. Others			
1. Earnest Money Deposits		6,70,794	10,21,505
2. Contractors' Security Deposits		10,95,967	9,35,850
3. Group Insurance Scheme		1,641	1,091
4. Indian Academy of Sciences (for Land)		1,00,00,000	1,00,00,000
5. Service benefits and other liabilities		6,09,985	6,56,054
6. Duties & Taxes (TDS)			93,112
7. Caution Deposits (Hostel)		1,71,000	1,54,500
8. Profession Tax		40,700	40,950
9. Sundry Creditors			15,214
		1,34,33,220	1,90,86,827
SCHEDULE - 6			
Provident Fund			
FUND BALANCES:			
A. Employees Subscription			
a) Contributory Provident Fund		3,96,78,747	3,72,44,899
b) General Provident Fund		2,20,45,037	1,79,33,696
B. Institute Contribution to Contributory Provident Fund		3,36,94,545	3,12,02,124
C. New Pension Scheme		8,26,817	6,09,591
GENERAL FUND -	98,47,500		
Add: Excess of income over expenditure for 2013-14	11,17,323		
		1,09,64,823	98,47,500
RRI Pension Fund			26,41,549
TOTAL		10,72,09,969	9,94,79,359
SCHEDULE - 7			
Pension Fund			
Capital Fund-Opening Balance	6,83,47,127		6,83,47,127
Add: Institute's Contribution for the year (Corpus Fund)	107,86,030		
Add : G P F Contribution for the year	28,49,143		
		8,19,82,300	
Raman Research Institute - P F Account		22,61,109	
TOTAL		8,42,43,409	6,83,47,127

SCHEDULE - 8
Fixed Assets

Sl.No	DESCRIPTION	GROSS BLOCK					DEPRECIATION BLOCK				NET BLOCK	
		Original Cost as on 01.04.2013	Addition during the year	Deletion during the year	Original cost as on 31.03.2014	Rate	Total up to 01.04.2013	Less Accu.Depn.on Deletion (on col. No.5)	For the year 2013-2014 (on Col.No.6)	Total up to the end of 31.03.2014 (8-9+10)	As on 31.03.2014 (6-11)	As on 1.04.2013
1	2	3	4	5	6	7	8	9	10	11	12	13
		Rs.	Rs.	Rs.	Rs.	%	Rs.	Rs.	Rs.	Rs.	Rs.	Rs.
1	Land											
	(a) R M V II Stage	3,78,735			3,78,735						3,78,735	3,78,735
	(b) Malleswaram	31,19,436			31,19,436						31,19,436	31,19,436
	(c) H M T, Jalahalli	8,00,63,261			8,00,63,261						8,00,63,261	8,00,63,261
2	Building	16,10,15,857	94,60,284	1,71,480	17,03,04,661	1.63	2,15,73,577	30,746	27,75,966	2,43,18,797	14,59,85,864	13,94,42,280
3	Capital Equipment	76,14,74,663	4,17,51,977	1,08,91,726	79,23,34,914	4.75	23,21,87,582	56,78,281	3,76,35,908	26,41,45,209	52,81,89,705	52,92,87,081
4	Canteen Infrastructure	42,76,021			42,76,021	4.75	6,09,333		2,03,111	8,12,444	34,63,577	36,66,688
5	Computers	12,61,86,123	2,19,61,269		14,81,47,392	16.21	12,22,74,597		1,82,83,701	14,05,58,298	75,89,094	39,11,526
6	Furniture & Fixture	1,23,12,060	7,28,996		1,30,41,056	6.33	55,89,499		8,25,499	64,14,998	66,26,058	67,22,561
7	Vehicles	43,09,188	7,00,133		50,09,321	9.50	33,32,542		4,75,885	38,08,427	12,00,894	9,76,646
8	Books and Journals	21,41,37,738	1,22,56,647		22,63,94,385	4.75	7,86,98,823		1,07,53,733	8,94,52,556	13,69,41,829	13,54,38,915
	TOTAL	1,36,72,73,082	8,68,59,306	1,10,63,206	1,44,30,69,182		46,42,65,953	57,09,027	7,09,53,803	52,95,10,729	91,35,58,453	90,30,07,129

PARTICULARS	As on 31.03.2014 Rs.	As on 31.03.2013 Rs.
SCHEDULE - 9		
Investments - Retirement Funds - vested with SBI Life Insurance		
Gratuity Fund	7,60,03,347	7,05,64,706
Leave Salary	6,32,42,513	6,06,11,273
Commutation of Pension Fund	19,13,09,889	17,48,67,065
TOTAL	33,05,55,749	30,60,43,044
SCHEDULE - 10		
Current Assets, Advances and Deposits		
a) Stock on Hand	14,01,170	13,67,825
b) Advances and Deposits:		
1. Advance to Suppliers	3,89,62,445	2,37,37,773
2. Advance for purchase of Land	8,89,61,800	8,89,61,800
3. Advances to Staff	54,81,111	43,97,115
4. Other Advances/Deposits	21,59,548	14,43,084
5. Tax Deducted at Source	17,856	17,344
6. Indian Academy of Sciences	6,271	6,271
7. Ramanujan Fellowship	15,47,951	18,60,071
8. Swarana Jayanthi Fellowship		7,61,984
9. Customs Duty Receivable	27,91,120	27,91,120
10. TIFR	77,810	46,261
11. CSIR - Extra Murual Research project	3,60,000	1,80,000
12. ISRO - for SSO Project	1,09,961	
13. CSIR - Jr. Research Fellowship	2,22,391	
14. Australia-India Strategic Research Fund	4,820	
15. SBI LIFE	11,53,522	
16.DBT - Ramalingaswami Re-entry Fellowship	1,93,522	
TOTAL (a+b)	14,34,51,298	12,55,70,648
SCHEDULE - 11		
Cash and Bank Balances		
Cash at Banks - In Savings Bank Accounts/MODs :		
State Bank of India	32,49,860	37,78,373
State Bank of Mysore	28,57,819	67,16,403
Canara Bank	5,15,923	1,65,348
Union Bank of India	3,10,21,535	7,90,62,031
Central Bank of India	17,695	17,008
Stamps on hand (Franking Machine)	285	3,564
TOTAL	3,76,63,117	8,97,42,727

PARTICULARS	As on 31.03.2014 Rs.	As on 31.03.2013 Rs.
SCHEDULE - 12		
Provident Fund		
Investments (At Cost)	9,11,13,889	8,95,13,889
Refundable Advances	5,01,800	18,06,365
Interest earned on Investments	16,94,495	12,92,782
Income-tax Deducted at Source Receivable	4,67,349	3,72,108
Raman Research Institute Pension Fund A/c	22,61,109	
Cash at Banks:		
State Bank of India	50,92,697	58,67,361
HDFC Bank	60,78,630	6,26,854
TOTAL	*10,72,09,969*	9,94,79,359
SCHEDULE - 13		
Pension Fund		
Investments (At Cost)	5,68,06,484	4,88,41,107
Interest earned on investments	12,90,178	12,73,905
Income-tax deducted at source	3,92,654	3,40,334
Raman Research Institute	1,78,51,270	1,50,25,628
Raman Research Institute (PF A/c)		20,35,236
Cash at Banks:		
Central Bank of India	3,29,238	1,54,109
State Bank of India (S B A/c)	12,95,899	3,49,661
State Bank of India (MOD A/c)	20,98,187	
HDFC Bank	41,79,499	3,27,147
TOTAL	8,42,43,409	6,83,47,127
SCHEDULE - 14		
Interest & Miscellaneous Income		
Interest on :		
Letters of Credit Margins	5,07,188	2,08,827
Short Term Deposits & Savings Bank A/cs	80,72,461	87,14,862
Miscellaneous Income		
Grant-in-aid from -		
Raman Research Institute Trust	1,00,000	1,00,000
License fee from quarters	4,26,356	3,69,177
Other Receipts	10,03,667	12,25,994
Sale of unserviceable items	31,73,351	5,80,250
TOTAL	1,32,83,023	1,11,99,110
SCHEDULE - 15		
Salaries & Allowances		
Pay	6,34,62,422	6,10,74,701
Allowances	8,55,30,407	7,49,71,595
Medical Reimbursement	62,79,867	52,51,662
Leave/Home Travel Concession	14,84,929	6,60,432
Leave Salary Encashment - LTC	6,58,304	2,28,363
Leave Salary on Retirement/Resignation		1,52,640
Contributions towards :		
Retirement Funds	86,97,080	77,81,886
Provident Fund	19,87,540	19,53,743
Pension Fund	46,91,409	54,25,430
N P S Contribution	14,13,801	11,80,279
SBI Life Insurance - Annual premia		33,11,800
Shortfall in Pension	1,50,25,628	1,24,45,692
TOTAL	18,92,31,387	17,44,38,223

PARTICULARS	As on 31.03.2014 Rs.	As on 31.03.2013 Rs.
SCHEDULE - 16		
Working Expenses		
Travelling Expenses	39,27,968	20,78,179
Wages	3,38,500	4,30,625
Honoraria and Professional Fees	16,07,635	16,54,664
Printing, Stationery (Schedule - 16 A)	13,48,235	12,96,178
Telephone and Communication Charges	30,84,252	21,69,008
Electricity Charges (including maintenance of generators)	1,01,69,414	93,20,927
Water Charges	4,56,324	6,06,016
Advertisement	69,813	13,809
Vehicle Maintenance/Transport	19,77,469	18,96,239
Liveries and Uniforms	2,34,883	2,32,418
Postage and Courier Services	1,86,908	2,81,105
Seminars/Conferences/Colloquia, Summer School Programme etc.,	29,62,723	21,94,494
Bank Charges	6,840	8,739
Amenities	12,23,620	11,20,605
Crèche	2,40,000	2,40,000
Entertainment and Hospitality	2,85,178	1,86,380
Audit fee	47,191	47,191
Repairs and Maintenance	85,89,790	65,00,036
Campus Maintenance	74,17,815	68,96,652
Payroll processing charges	3,67,639	3,56,234
Safety Audit Expenses		92,898
Security	69,79,615	68,64,915
Stores and Consumables (Schedule - 16 A)	2,06,09,986	2,45,35,752
Project Working Expenses	41,53,035	40,99,037
Subscriptions to Journals & Publications	1,09,70,469	1,22,97,586
Ph.D. Programme	42,83,058	23,81,901
Pancharatnam Fellowship	96,592	6,45,782
Lease Rent of Land	2,71,092	2,39,932
Corporation Taxes	3,04,018	3,03,779
Freight, etc.	2,36,596	2,39,704
Conveyance	3,96,698	3,78,457
Visiting Students Programme	82,31,549	64,92,675
Inter Institutional Collaboration & Visiting Scientists' expenses	26,23,157	11,40,171
Outreach	6,49,356	7,99,894
Patent Fees	9,65,459	19,14,607
Miscellaneous Expenses	6,14,783	5,77,925
Affiliation Fee for Universities	3,00,000	2,00,000
TOTAL	10,62,27,660	10,07,34,514

SCHEDULE - 16 - A

Stores / Consumables & Stationery items

SL. NO.	DESCRIPTION	OPENING STOCK AS ON 1.4.2013	PURCHASE DURING THE YEAR	LESS:CLOSING STOCK AS ON 31.3.2014	CONSUMPTION DURING THE YEAR
		Rs.	Rs.	Rs.	Rs.
1	Stores and Consumables	10,98,443	2,05,58,890	10,47,347	2,06,09,986
2	Printing & Stationery	2,69,382	14,32,676	3,53,823	13,48,235
	TOTAL	13,67,825	2,19,91,566	14,01,170	2,19,58,221

PARTICULARS	2013-2014 Rs.	2012-2013 Rs.
SCHEDULE - A		
Opening Balance		
Cash at Banks -		
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
SCHEDULE - B		
Grants-in-aid		
a) Ministry of Science & Technology (Department of Science & Technology)		
1. Non-Plan Recurring	84,75,000	1,07,10,000
2. Plan Recurring	27,48,84,330	25,43,51,849
3. Plan Non-Recurring	4,66,15,670	9,36,48,151
4. Swarna Jayanthi Fellowship	15,00,000	
5. Implementation of India & Russia Basic Science	4,73,600	
6. Indo-Australian(BMWF) Joint Research	1,55,000	
7. Ramanujam Fellowship	3,12,120	
b) INSA - Fellowship	2,30,000	3,34,586
c) CSIR - Extra Murual Research project	3,60,000	
d) CSIR - Jr. Research Fellowship		2,84,929
e) IFCPAR Research Project	14,24,320	3,72,300
TOTAL	33,44,30,040	35,97,01,815

PARTICULARS	2013-2014 Rs.	2012-2013 Rs.
SCHEDULE - C		
Miscellaneous Receipts		
Grant-in-aid from Raman Research Institute Trust	1,00,000	1,00,000
License fee from staff quarters	4,26,356	3,69,177
Interest on Letters of Credit Margins	5,07,188	2,08,827
Interest on Short term Deposits & SB Accounts	80,72,461	87,14,862
Other Receipts	10,03,267	12,25,994
Sale of unserviceable items	31,73,751	5,80,250
Recoveries/Adjustments of Advance		
Conveyance Advance	1,94,150	1,90,010
House Building Advance	3,09,418	4,53,958
Festival Advance	1,92,450	1,81,425
Computer Advance	1,27,188	66,350
TOTAL	1,41,06,229	1,20,90,853
SCHEDULE - D		
Deposits and other items		
Recoveries from Staff towards:		
Provident Fund-Subscriptions & loan repayments	1,73,49,856	1,42,64,596
N P S Subscription	14,13,801	15,09,454
Profession Tax	4,87,900	4,97,600
LIC - Salary Savings Scheme	24,17,906	22,96,646
Group Insurance Scheme (LIC)	13,02,908	14,29,889
Income Tax deducted at Source	1,28,00,467	1,01,48,806
Housing and other loans	6,20,544	7,63,434
Caution Deposits for Hostel	28,500	30,500
Staff/Miscellaneous Advances & Deposits (Net)		18,92,607
Indian Academy of Sciences		13,300
Sundry Creditors		16,127
Recoveries from Contractors towards:		
Income Tax Deducted at Source	8,87,586	8,48,512
Earnest Money Deposits	20,56,998	18,83,000
Security deposits	4,92,274	4,84,938
Others (amounts received for meetings etc.,)		
TIFR - Bombay for conducting US India	18,00,000	
Advanced studies		
TOTAL	4,16,58,740	3,60,79,409

PARTICULARS	2013-2014 Non-Plan Rs.	Plan Rs.	Total Rs.	2012-2013 Rs.
SCHEDULE - E				
Recurring Expenditure (Non-Plan and Plan)				
Pay	65,17,727	5,69,44,695	6,34,62,422	6,10,74,701
Allowances	1,29,38,138	7,25,92,269	8,55,30,407	7,49,71,595
Medical Reimbursement	11,72,313	48,30,563	60,02,876	57,79,366
Leave/Home Travel Concession	1,90,690	18,93,719	20,84,409	7,11,422
Leave Salary Encashment - LTC tour	1,58,796	4,99,508	6,58,304	2,28,363
Leave Salary on Retirement/Resignation				1,52,640
Contribution towards:				
Provident Fund		19,87,540	19,87,540	19,53,743
Pension Fund	7,66,286	39,25,123	46,91,409	54,25,430
N P S Contribution	86,428	13,27,373	14,13,801	11,80,279
Retirement Fund		86,97,080	86,97,080	77,81,886
SBI Life Insurance - Annual premia				33,11,800
Shortfall in Pension		1,50,25,628	1,50,25,628	1,24,45,692
	2,18,30,378	16,77,23,498	18,95,53,876	17,50,16,917
Travelling Expenses		48,90,184	48,90,184	29,98,751
Wages		3,38,500	3,38,500	4,30,625
Honoraria & Profession fees		16,07,635	16,07,635	16,54,664
Printing Stationery & binding of Scientific journals	8,358	14,24,318	14,32,676	12,19,288
Telephone and Communication charges		30,84,252	30,84,252	21,69,008
Electricity Charges *(incl.Rs.4,80,972/- being outlay on maintenance of generators)*		1,01,69,414	1,01,69,414	93,20,927
Water Charges		4,56,324	4,56,324	6,06,016
Advertisement		69,813	69,813	13,809
Vehicle Maintenance/Transport		19,77,469	19,77,469	18,96,239
Liveries & Uniforms		2,34,883	2,34,883	2,32,418
Postage & Courier Services		1,86,908	1,86,908	2,81,105
Seminars, Conferences, Colloquia, etc.,		29,62,723	29,62,723	21,94,494
Bank Charges	6,840		6,840	8,739
Amenities		12,23,620	12,23,620	11,20,605
Crèches expenses		2,40,000	2,40,000	2,40,000
Entertainment and Hospitality		2,85,178	2,85,178	1,86,380
Audit Fee	47,191		47,191	47,191
Repairs & Maintenance (incl. Maintenance of Computers)		85,89,790	85,89,790	65,00,036
Campus Maintenance		74,17,815	74,17,815	68,96,652
Payroll processing charges		3,67,639	3,67,639	3,56,234
Safety Audit Expenses				92,898
Carried forward	2,18,92,767	21,32,49,963	23,51,42,730	21,34,82,996

PARTICULARS	2013-2014			2012-2013
	Non-Plan Rs.	Plan Rs.	Total Rs.	Rs.
Brought forward	2,18,92,767	21,32,49,963	23,51,42,730	21,34,82,996
Security		69,79,615	69,79,615	68,64,915
Stores & Consumables		2,05,58,890	2,05,58,890	2,48,34,166
Project Working Expenses		41,53,035	41,53,035	40,99,037
Subscription to Scientific Journals & other Publications		1,09,70,469	1,09,70,469	1,22,97,586
Ph.D. Programme		42,83,058	42,83,058	23,81,901
Pancharatnam Fellowship		96,592	96,592	6,45,782
Lease Rent of Land		2,71,092	2,71,092	2,39,932
Corporation Taxes		3,04,018	3,04,018	3,03,779
Freight, etc.,		2,36,596	2,36,596	2,39,704
Conveyance		3,96,698	3,96,698	3,78,457
Inter Institutional Collaboration & Visiting Scientists' expenses and Visiting Students programme		1,08,54,706	1,08,54,706	76,32,846
Outreach		6,49,356	6,49,356	7,99,894
Patent Fees		9,65,459	9,65,459	19,14,607
Miscellaneous Expenses		6,14,783	6,14,783	5,77,925
Affiliation Fee for Universities		3,00,000	3,00,000	2,00,000
Advances to Staff (HBA, Vehicle, Festival & Computer advances)	6,89,250		6,89,250	2,58,750
TOTAL	2,25,82,017	27,48,84,330	29,74,66,347	27,71,52,277

PARTICULARS	2013-2014 Rs.	2012-2013 Rs.
SCHEDULE - F		
Plan Non-Recurring Expenditure		
Capital Equipment	6,37,13,246	5,93,57,651
Buildings, Works and Services	94,60,284	75,14,699
Books	17,41,670	17,40,536
Furniture & Fixture	7,28,996	5,55,953
Vehicle	7,00,133	
TOTAL	7,63,44,329	6,91,68,839
SCHEDULE - G		
Expenditure out of Grants/Assistance from other Government Agencies		
a) Ministry of Science & Technology -		
1) Ramanujam Fellowship		13,88,985
2) DBT - Biomechanics of synaptogensis		3,648
3) Swarna Jayanthi Fellowship	7,38,016	3,50,980
4) Enabling New Sciences- MWA	15,87,091	1,61,460
5) DBT - Ramalingaswami Re-entry Fellowship	1,93,522	
b) ISRO - SSO Project	41,06,742	27,94,226
c) IFCPAR Research Project	16,59,095	
d) INSA - Fellowship	3,36,582	2,78,051
e) CSIR - Extra Murual Research project	5,40,000	1,80,000
f) CSIR - Jr. Research Fellowship	2,56,000	2,51,320
TOTAL	94,17,048	54,08,670
SCHEDULE - H		
Advance to Suppliers (Net)		
Plan -Non-Recurring	1,52,24,672	85,48,116
TOTAL	1,52,24,672	85,48,116

PARTICULARS	2013-2014 Rs.	2012-2013 Rs.
SCHEDULE - I		
Deposits & Other Remittances		
Remittances of recoveries from staff:		
Provident Fund Subscriptions and Loans	1,73,49,856	1,42,64,596
N P S Subscription	14,13,801	15,09,454
Professional Tax	4,88,150	4,56,650
LIC - Salary Savings Scheme	24,17,906	22,96,646
Group Insurance Scheme	13,02,358	14,31,389
Income Tax Deducted at Source	1,28,00,467	1,01,48,806
Housing and other loans	6,20,544	7,63,434
Caution Deposits for Hostel	12,000	20,000
Sundry Creditors	61,283	8.00.996
Staff/Miscellaneous Advances & Deposits (Net)	18,03,233	
TDS Receivable	512	
Remittances/Refunds of recoveries from Contractors:		
Income Tax deducted at Source	9,80,698	8,30,016
Earnest Money Deposits	24,07,709	13,63,000
Security Deposits	3,32,157	94,515
Others (amounts received for meetings etc.,)		
TIFR - Bombay	31,549	5,50,734
TIFR - Bombay for conducting US India Advanced Studies	18,00,000	
TOTAL	4,38,22,223	3,45,30,236
SCHEDULE - J		
Closing Balance		
Cash at Bank:		
State Bank of India	3,08,397	71,886
State Bank of Mysore	28,57,819	3,51,859
Canara Bank	5,15,923	1,65,348
Union Bank of India	4,14,449	5,52,031
Central Bank of India	17,695	17,008
Stamps on hand	285	3,564
TOTAL	41,14,568	11,61,696

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

K. KRISHNAMA RAJU
Administrative Officer

RAVI SUBRAHMANYAN
Director

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

Place : Bangalore
Date : August 27, 2014

RAMAN RESEARCH INSTITUTE
BANGALORE

SCHEDULE: - 17

SIGNIFICANT ACCOUNTING POLICIES AND NOTES ON ACCOUNTS FOR THE YEAR ENDED 31.03.2014

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 is 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 is 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 is directly credited to the Capital Fund A/c, the balance of Plan grants is reckoned as Income and shown in Income & Expenditure Account.

6. FOREIGN CURRENCY TRANSACTIONS:

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

7. RETIREMENT BENEFITS:

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

B.NOTES ON ACCOUNTS

a). CURRENT ASSETS, ADVANCES AND DEPOSITS:

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

b) EMPLOYEES RETIREMENT BENEFITS:

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

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

II. The Institute also has taken a Fund/Policy 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. Getting no objection certificate from Government of India, through HMT Limited is under process.

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

K. KRISHNAMA RAJU
Administrative Officer

RAVI SUBRAHMANYAN
Director

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

Place : Bangalore
Date : 27th August 2014