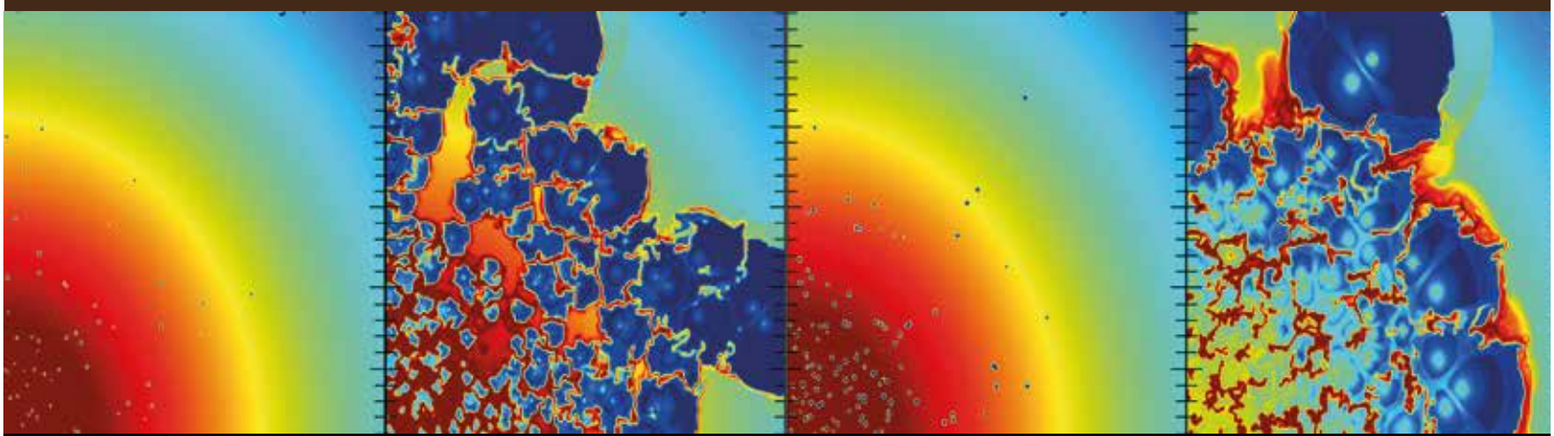
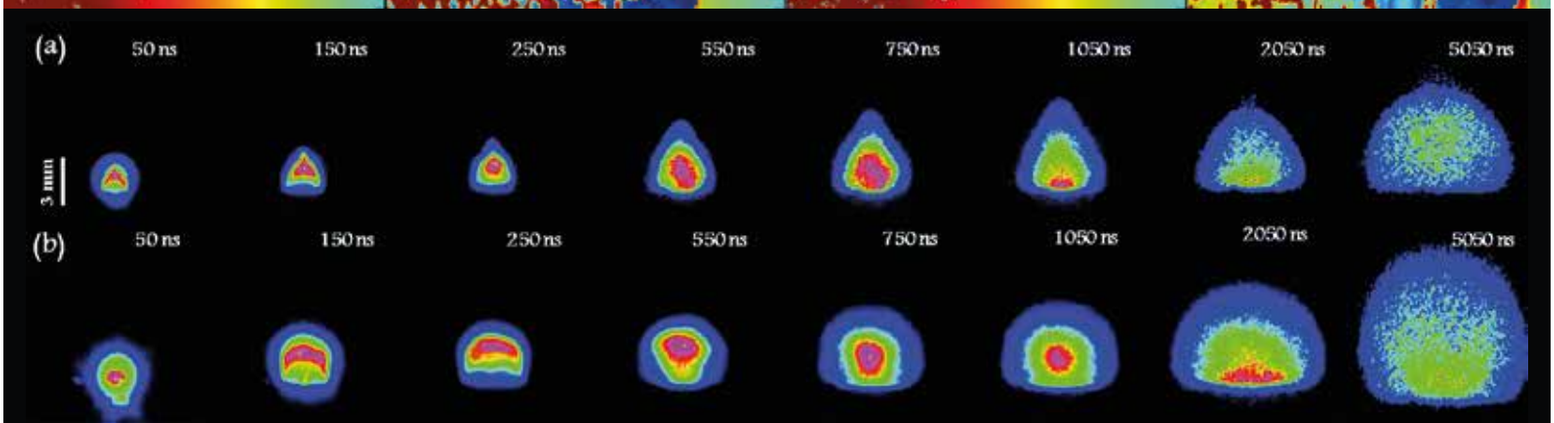
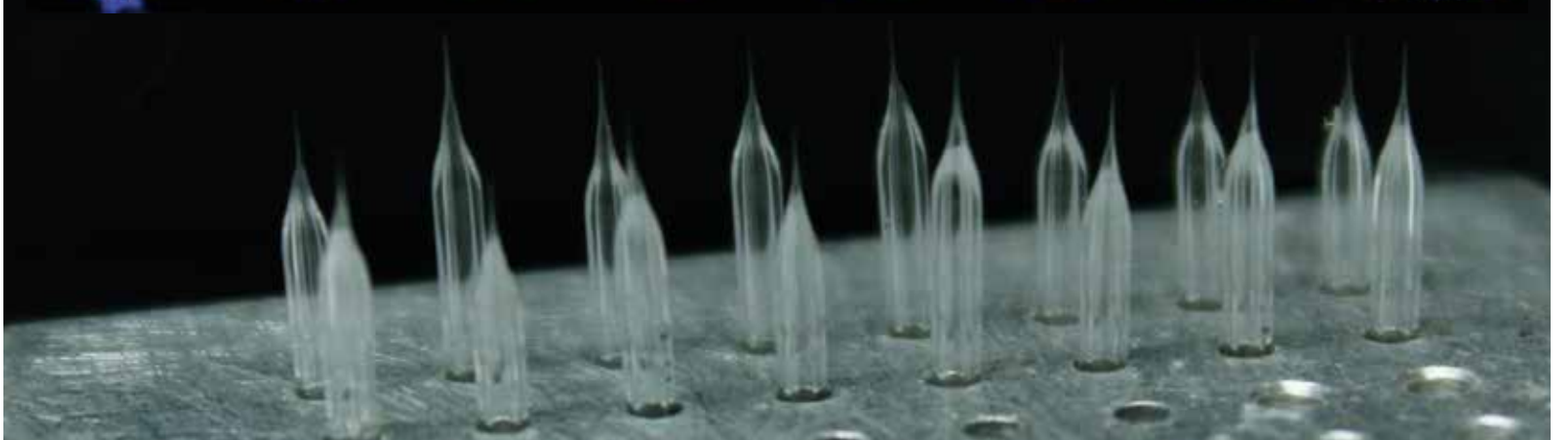
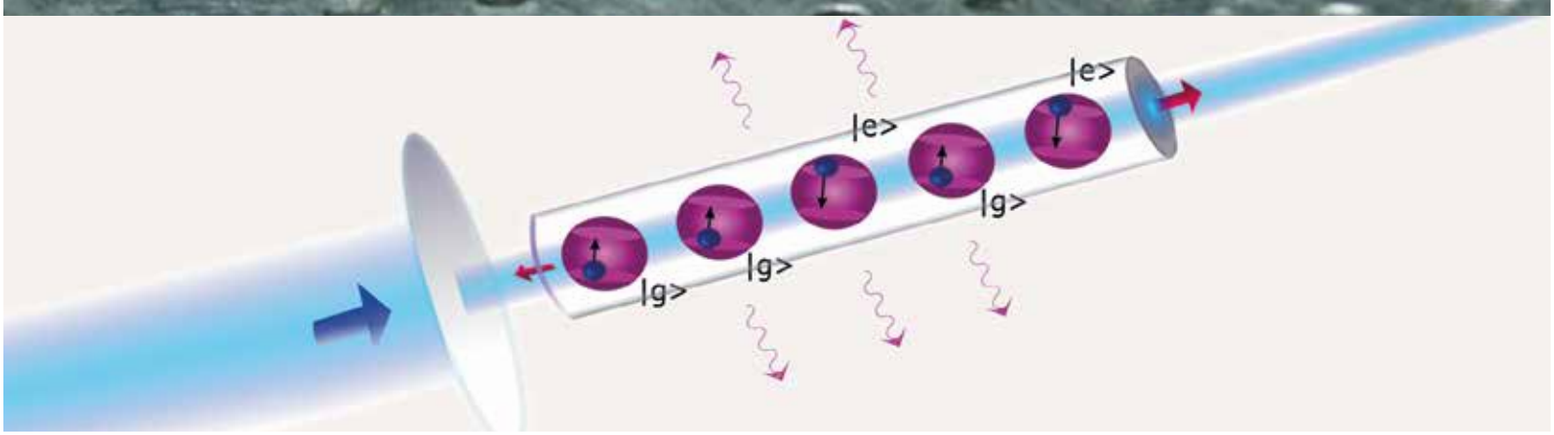
RAMAN RESEARCH INSTITUTE

Annual Report 2017 - 2018









From the Director

The Institute has a mandate to engage in basic science research and we currently have groups working in selected unsolved problems in astronomy and astrophysics, light and matter physics, soft condensed matter and theoretical physics. The fundamental research reporting that forms most part of this annual report is naturally at the boundaries of knowledge and often the investigations are open-ended explorations using physics, mathematics and experimental tools. The quality and elegance of the research simply cannot be quantified in metrics, and can only be measured in the appreciation from erudite peers worldwide who are likewise engaged in parallel pursuits and hence are competent referees and reviewers of the work.

Of course the Institute believes strongly in sharing the joys of research with the younger generation. During the past year we have shared our campus and laboratories with almost 200 post-doctoral fellows, PhD students, research assistants, visiting students, and engage in teaching this next generation advanced learning and experimental methods. And the effort hosting visiting academics, seminars and colloquia on a broad range of basic science, and discussions on noteworthy research---all of which are listed in the sections of this annual report---are activities we must necessarily engage in to keep the campus an institution of scholarship and higher learning, which inspires the younger generation.

The ongoing advanced research enables the Institute to also direct part of its capacity---built up over years---towards key problems that naturally benefit from the specific higher learning and experimental skills on campus. Having signed a MoU with ISRO for development of quantum key distribution via satellites, the Institute has in the year of this report signed another MoU with ISRO for design, development and supply of polarimeter instrument in X-rays (POLIX) for XPoSat Mission, which we expect to be launched in 2019. A third MoU with ISRO was signed for joint development of radiometers and telescopes in the MHz, GHz and THz, aimed at space missions. Additionally, the Institute members have futuristic proposals for joint development of broad-band X-ray polarimeters, a deep space navigation system using X-ray pulsars, and PRATUSH: a lunar orbit mission aimed at detecting Cosmic Dawn when the first stars lit up the universe for the very first time.

Ravi Subrahmanyan
22 Aug 2018

RRI at a Glance

RRI is an icon that symbolizes and represents the heritage of Indian physicist and Nobel Laureate Sir C V Raman, continuing his legacy and style of qualitatively impactful research that earns the nation a respectable place. The Institute preserves the inspirational spirit of this stalwart of our scientific cultural history.

History: Nobel Laureate, Sir C V Raman, founded the Raman Research Institute in 1948 on land that had been gifted to him by the Government of Mysore. After the Professor's demise in 1970, a public charitable trust was created - the Raman Research Institute Trust – and the lands, buildings, deposits, securities, bank deposits, moneys, laboratories, instruments, and all other movable and immovable properties were transferred to the RRI Trust. The function of the RRI Trust was to maintain, conduct and sustain the Raman Research Institute.

In 1972, RRI was restructured to become an aided autonomous research institute and since then has been receiving funds for its research from the Department of Science and Technology of the Government of India. A set of Regulations and Bye-Laws were framed for its administration and management.

Administration: The Governing Council is the executive body of the Institute and conducts the administration and management of the Institute. The Director is the Chief Executive and Academic Officer and is responsible for the administration of the Institute. He exercises general supervision over the programmes and research projects of the Institute. The Administrative Officer is responsible for the general administration of the Institute and represents it in legal and other related proceedings. The Finance Committee helps the Council with financial matters.

Mission: The mandate of the Institute is primarily research in basic sciences that advances the knowledge of mankind by creating new knowledge, secondly communicating this knowledge to the next generation thus empowering them with higher learning and scientific temper, and thirdly maintaining an institution of higher learning where academic culture and scientific temper are promoted. The research conducted at the Institute continually advances knowledge base via an improved understanding of the fundamental laws and behaviour of nature spanning from sub-atomic to cosmological length scales thereby laying the basic foundation for advancement of science and its component benefits to society. More importantly, RRI strives to engender quality research manpower through its vibrant Post-doctoral, Doctoral, Research Assistantship and Visiting Student programmes.

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

Location: RRI is located on a 20-acre site in Bengaluru. The verdant campus with a mix of manicured landscapes and patches of wilderness provides a serene environment away from the hustle and bustle of the developing metropolis beyond its walls, perfectly suited for the creative research and higher learning conducted within.

Research Areas: The research in basic sciences is today in selected areas of Astronomy and Astrophysics, Light and Matter Physics, Soft Condensed Matter Physics, and Theoretical Physics. The research work includes Physics in Biology, Soft Matter Chemistry, Quantum Information, Computing and Communications.

Research Laboratories:

* X-ray Astronomy Laboratory
* Molecular Astronomy Laboratory
* Cosmological Recombination & Re-ionization Laboratory
* Sky Watch Array Network
* Light-Matter Interactions
* Laser Cooling & Quantum Optics
* Ultrafast and Nonlinear Optics
* Quantum Information & Computing
* Quantum Interactions
* Quantum Mixtures Laboratory
* Phase Transitions & Electro-optics
* Rheology and Light Scattering
* Microscopy and Scattering
* Biophysics
* Chemistry
* Electrochemistry and Surface Science
* Liquid Crystal Display
* Microscopy and Dielectric Spectroscopy
* Nanoscale Physics of Soft and Living Matter
* Brain Computer Interface

Research Facilities:

Soft Matter Measurement Laboratories
* Analytical Physical Measurement Lab
* X-ray Diffraction Lab
* SEM Lab
* AFM Lab
* NMR Lab
* Micro-Raman Spectroscopy Lab
* Magnetic Studies Lab
* Photophysical Studies Lab

Mechanical Engineering Services
* Mechanical Workshop
* Sheet metal, paint and carpentry facility

Electronics Engineering Group
Gauribidanur Field Station
Library
Computer Group

Infrastructure:

* Guest House
* Canteen
* Clinic
* Sports facilities
* Crèche

Education: RRI offers the following programmes for advanced learning and knowledge communication in basic sciences, including theoretical and experimental methods and skills.

* PhD Programme
* Postdoctoral Fellowships
* Pancharatnam Fellowships
* Visiting Students Programme
* Research Assistant 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, and extra-mural grants.

Council

Prof AK Sood *Chairman*	Honorary Professor, Department of Physics Indian Institute of Science, Bengaluru 560012
Dr K Kasturirangan	a. Emeritus Professor, National Institute of Advanced Studies, Bengaluru 5600 012 b. Chancellor, Central University of Rajasthan, Dist-Ajmer-305817, Rajasthan
Prof PK Kaw (till 18.6.2017)	Senior Professor & Distinguished Scientist Institute of Plasma Research, Gandhinagar 382 428
Prof. Ashutosh Sharma	Secretary, Department of Science & Technology Ministry of Science & Technology, New Delhi 110 016
Shri J.B.Mohapatra	Joint Secretary & Financial Advisor Ministry of Science & Technology, Government of India, New Delhi 110 016
Prof R. Rajaraman	Emeritus Professor, Theoretical Physics School of Physical Sciences, Jawaharlal Nehru University, New Delhi 110 067
Prof. Vijay Bhatkar	Chairman, ETH Research Lab Bavdhan, Off Mumbai-Bengaluru Bypass, Pune 411 021
Prof Ravi Subrahmanyan	Director, Raman Research Institute (Ex-officio member) Bengaluru 560 080

Finance Committee

Prof AK Sood *Chairman*	Honorary Professor, Department of Physics Indian Institute of Science, Bengaluru 560012
Shri J.B. Mohapatra	Joint Secretary & Financial Advisor Ministry of Science & Technology, Government of India, New Delhi 110 016
Prof. PK Kaw (till 18.6.2017)	Senior Professor & Distinguished Scientist Institute of Plasma Research, Gandhinagar 382 428
Prof Ravi Subrahmanyan	Director, Raman Research Institute (Ex-officio member) Bengaluru 560 080

Academic Committee

Prof. Ravi Subrahmanyan — *Chairman*
Director
Raman Research Institute
Bengaluru 560 080.

Prof. Krishan Kumar
School of Environmental Sciences
Jawaharlal Nehru University
New Delhi 110 067.

Prof. R.P. Singh
School of Life Sciences
Jawaharlal Nehru University
New Delhi 110 067.

Prof. Diptiman Sen
Centre for High Energy Physics
Indian Institute of Science
Bengaluru 560 012.

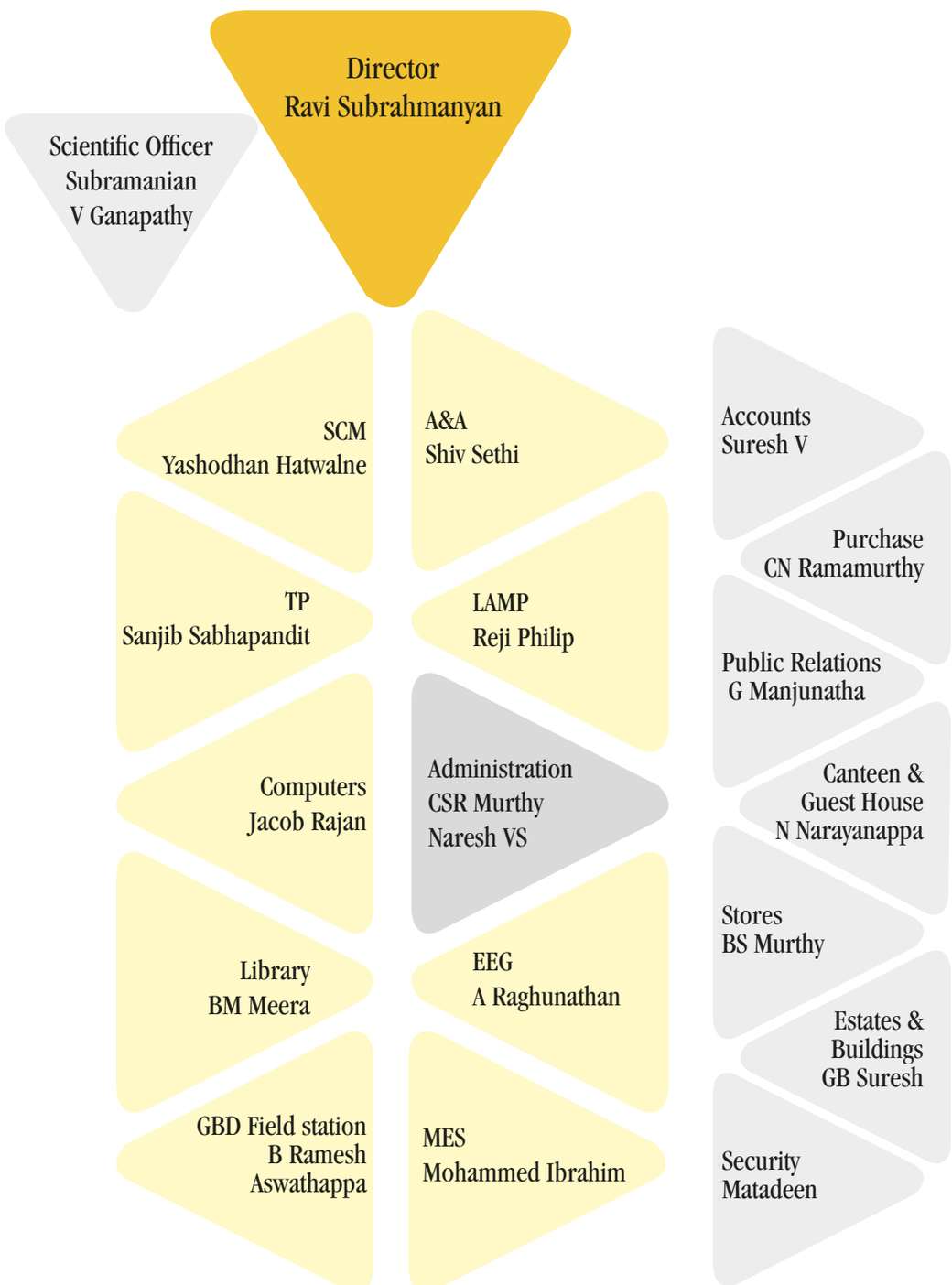
Prof. Vijay Shenoy
Department of Physics
Indian Institute of Science
Bengaluru 560 012.

Prof. V.A. Raghunathan
Soft Condensed Matter Group
Raman Research Institute
Bengaluru 560 080.

Dr. Sanjib Sabhapandit
Theoretical Physics Group
Raman Research Institute
Bengaluru 560 080.

Mr. C.S.R. Murthy — *Secretary*
Administrative Officer
Raman Research Institute
Bengaluru 560 080.

Organization



Committees

RRI Science Forum	Gautam Soni, Andal Narayanan, Nayantara Gupta
Colloquia	Pramod Pullarkat (Chairperson), Joseph Samuel, Sadiq Rangwala, Urbasi Sinha
Hostel Wardens	Shiv Sethi, Arun Roy, B. Ramesh, Urbasi Sinha
Admissions Coordinators	Sanjib Sabhapandit, Pramod Pullarkat
SAAC	V.A. Raghunathan (Chairperson), Sadiq Rangwala, Sumati Surya, Pramod Pullarkat, Shiv Sethi
In-House meeting	PhD students – 3rd year
JAP Representative of RRI	B. Ramesh
Complaints Committee	Srivani (Chairperson), BM Meera, CSR Murthy, Mamatha Bai
Overseas Travel Committee	Biswajit Paul (Chairperson), Reji Philip, Pratibha R
Evaluation Committee	Dwarakanath K.S. (Chairperson), Sumati Surya, Biman Nath, V.A. Raghunathan, Sadiq Rangwala
Coordinator of Visiting Students Programme	CSR Murthy
Library Committee	BM Meera (Chairperson), Yashodhan Hatwalne, Supurna Sinha, Reji Philip, Nayantara Gupta
RRI Official Language Implementation Committee	CSR Murthy (Chairperson), Suresh Varadarajan, Ranjeet Koshta, R Ramesh, CN Ramamurthy, B Srinivasamurthy, BM Meera, G Manjunatha, K. Radhakrishna, V Vidyamani, Harini Kumari, Mamatha Bai, Jacob Rajan, Naresh V.S.

Prelude

The Raman Research Institute (RRI) is an icon that symbolizes and represents the heritage of Indian physicist and Nobel Laureate Sir C V Raman, continuing his legacy and style of qualitatively impactful research. The Institute preserves the inspirational spirit of this stalwart of Indian scientific cultural history.

History:

RRI was founded in 1948 by the Indian physicist and Nobel Laureate, Sir C V Raman, on land that had been gifted to him by the Government of Mysore to continue his studies and basic research after he retired from the Indian Institute of Science. Professor Raman served as its director carrying on his research, which was funded personally by him and with donations from private sources. After the Professor's demise in 1970, a public charitable trust was created - the Raman Research Institute Trust – and the lands, buildings, laboratories, instruments, and all other movable and immovable properties were transferred to the RRI Trust. The function of the RRI Trust was to maintain, conduct and sustain RRI.

Administrative set-up:

The Raman Research Institute is now an autonomous research institute engaged in research in basic sciences. In 1972, RRI was restructured to become an aided autonomous research institute receiving funds from the Department of Science and Technology of the Government of India. A set of Regulations and Bye-Laws were framed for its administration and management. The Governing Council, which is the executive body of the Institute with oversight of the administration and management of the Institute, sets policies towards the mandated goal of conducting research in basic sciences that is qualitatively outstanding, thus giving the country a respected standing amongst the international intelligentsia. Reports of research outcomes and performance are peer reviewed by International experts in the respective fields and the research and assessments are reported at Council Meetings and also made available to the Government of India in the form of Annual Reports. The members of the council include eminent scientific personalities who have worked in National Institutions as well as representatives from the Department of Science & Technology, Government of India.

Objectives of RRI:

The Institute carries out the mandate as defined by the Governing Council and RRI Trust to be basic research with focus in niche fields of:

1. Astronomy & Astrophysics including theoretical astrophysics, observational astronomy, and experimental Radio and X-ray astronomy,
2. Light & Matter Physics including cold atoms, ions, molecules, quantum communications and computing, and intense laser produced plasma,
3. Soft Condensed matter including research in liquid crystals, nano-composites, colloids, chemistry and biological physics, and
4. Theoretical Physics including General Relativity, Foundational quantum mechanics, soft matter physics, and classical and quantum Statistical Mechanics and Gravity.

The goal of the research in basic sciences is to advance the knowledge of mankind by creating new knowledge, communicating this knowledge to the youth thus empowering them with higher learning and scientific temper, maintain an institution of higher learning where academic culture and scientific temper are promoted, thus giving the country a respected standing amongst international peers.

The research conducted at the Institute continually advances knowledge base via an improved understanding of the fundamental laws and behavior of nature spanning from sub-atomic to cosmological length scales thereby laying the basic foundation for advancement of science and its component benefits to the society. More importantly, RRI strives to engender quality research manpower in the above-mentioned areas through its vibrant Post-doctoral, Doctoral, Research Assistantship and Visiting Student programs. The work quality and quantity is evidenced by the documented research reports provided annually to the Department of Science & Technology, Government of India.

The work of the Institute is with three objectives

(i) KNOWLEDGE CREATION, or engagement in the furtherance of the frontiers of the knowledge of humankind. This research activity includes theoretical work exploring foundational mathematics with the aim of arriving at frameworks within which phenomena may be described and hence understood, devising and developing theory of phenomena, and theoretical models for phenomena. Knowledge creation includes observational and experimental activity that tests alternate models and hypotheses, and computational activity that explores consequences of physics theories in complex behaviors. All of these may be individual pursuits, collective efforts of members of the Institute and often in collaboration worldwide with individuals and groups that have complementary expertise, and sometimes as national and international science projects that often bring substantial resources together towards solving key problems that require such collective efforts.

(ii) KNOWLEDGE COMMUNICATION, or engagement in empowering the next generation. The Institute has a PhD program that involves selection of appropriate candidates, guiding them through advanced learning and technical skills in preparation for research in frontier unsolved problems, then proving opportunities for supervised research work leading to a doctorate degree, which is the basic qualification for a research career. The Institute has a 2-tier Post-doctoral program that provides 3-year research experience - both supervised and independent - for outstanding PhDs from both Indian and overseas universities. This provides guided transition from supervised to independent research. The Research Assistantship

program and the Visiting Students program of the Institute invite post-graduate, undergraduate and even motivated high school students to spend weeks, months and up to 2 years participating in the research, experiencing research methods and pathways, so that they may find their passion and be motivated and empowered by the involvement to embark on careers in research in basic science. For more details on the various programs that ensure a steady stream of top quality research manpower for our country the reader may visit the academic programs section of this report.

(iii) PROMOTING ACADEMIC TRADITIONS, by engaging in activities that nurture scholarship, foster academic ambience and activities in the Institute, and facilitate scientific and academic management via participation in institutional, national and international boards that manage scientific planning and projects, thus promoting the cause of science, higher learning and research. The Institute holds specialized seminars in the different disciplines of higher learning that are intended for the specialists, colloquia that provide a wider audience an introduction and review of fields, a regular Science Forum where recent results in emerging areas of research are introduced and discussed in an inclusive manner. For a complete list see Appendices.

Astronomy and Astrophysics

Overview

From the beginning humankind has looked up at the sky with a sense of curiosity. It is no wonder that astronomy is one of the oldest of natural sciences. The field of Astronomy and Astrophysics pertains to a detailed study of the physical, chemical and dynamic properties of celestial objects. The research conducted in the AA group at RRI can be broadly classified into four areas:
(a) *Theoretical Astrophysics* that involves development of analytical models and numerical simulations describing the dynamics, physical properties and underlying physical phenomena in celestial objects like stars, planets, galaxies, interstellar medium etc. Theorists also work on answering fundamental questions on the formation and evolution of the Universe, a branch of astrophysics called cosmology.
(b) *Observational Astronomy* on the other hand uses telescopes built across the globe to study radiation from space across the entire electromagnetic spectrum – low frequency (long wavelength) radio waves to very high frequency (short wavelength and highly energetic) gamma rays. These observations test existing theoretical models and also give rise to new questions that call for answers.
(c) *Experimental Astronomy* involves the *design, construction and operation of telescopes* for very specific purposes to address key unsolved problems, and are strategically located around the world and in space.
(d) *Algorithms & Signal processing* where a variety of methods and modelling are employed to amplify and or isolate the required astronomy signal from other foregrounds, backgrounds and unwanted interference and confusion.

Focus 2017-18

Theoretical Astrophysics and Cosmology

The universe that we inhabit is vast beyond comprehension, complex, constantly expanding and is populated by myriad astronomical entities. The universe is populated by stars, galaxy clusters and active galaxies emitting high energy photons. The space between stars, galaxies and galaxy clusters is permeated by diffuse gas and dust. The Universe is thus a very vibrant place with constant interactions and various dynamic processes that shape their evolution and in turn the evolution of the universe as a whole. By studying these cosmic entities, their interactions and processes Astrophysicists and on a much larger scale, Cosmologists try to understand the evolution of the universe and its workings within the framework of the known laws of physics and chemistry. Analytical modelling and numerical simulations help us to understand the physics of these processes. A brief description of the research focus in Theoretical Astrophysics and Cosmology during 2017-18 follows. For a detailed description of the research mentioned below, the reader is directed to visit ''Knowledge Creation: Astronomy and Astrophysics'' section of this Annual Report.

Astrophysical Fluid Dynamics

Using only elementary mathematical functions, S. Sridhar and Nishant Singh have constructed exact solutions to the Navier-Stokes equation with a background linear shear flow. Stable solutions to these equations might serve as local representations of disturbances in simulations of astrophysical flows. The magnetic fields observed in many astrophysical bodies such as the Sun, stars, galaxies and clusters of galaxies – are thought to be generated by electric currents in the turbulent plasma flows. These magnetic fields can be amplified via the alpha effect when the turbulent plasma flow is helical. S. Sridhar and collaborators Naveen Jingade and Nishant Singh have provided modal solutions and have shown that certain conditions have to be satisfied for exponential growth rate of the large-scale magnetic field undergoing shear flow due to helicity fluctuations with finite correlation time.

Circumgalactic and Intra-cluster Medium

In a first of its kind study, using X-ray luminosity signals and Sunyaev-Zel'dovich (SZ) effect (a distortion in the cosmic microwave background resulting from low energy photons gaining energy when passing through a hot gas) Priyanka Singh, Biman Nath and collaborators have constrained the density and temperature of the hot Circumgalactic Medium and narrowed down the gap of missing galactic baryons. Recently, an absorption feature from the circumgalactic medium corresponding to absorption by Hydrogen, known as the Hα wavelength was reported. Shiv Sethi, Biman Nath and collaborator Yuri Shchekinov have shown that such a signal could not have arisen from the neutral or ionized component of Hydrogen and hence does not correspond to Hα transition but could

have arisen from an unknown dust component or Diffuse Interstellar Band. Asif Iqbal, Biman Nath and collaborators Subhabrata Majumdar and Ruta Kale have studied a sample of galaxy clusters in low frequency radio wavelengths and used X-ray data from Chandra, in order to determine the role of the brightest cluster galaxies (BCGs) in raising the entropy of the intra-cluster medium (ICM) gas. It was found that the correlations match the predictions made in an earlier study on the black hole mass of BCGs and the cluster potential. With Ranita Jana, Biman Nath has calculated the effect of cosmic ray diffusion in the model of reionization of the universe and found that the heating would be rather patchy and difficult to detect.

Galactic Outflows

Using 3D numerical hydrodynamical simulation which simulates star formation sites spread in the disc of a disk galaxy, Aditi Vijayan, Kartick Sarkar, Biman Nath and collaborators Prateek Sharma and Yuri Shchekinov have worked out the mechanisms by which outflowing gas from a star forming disc galaxy emits X-rays. They have demonstrated that most of the X-rays are emitted by gas around bow-shocks that are formed by cold disk gas thrown up by the injection of energy. Following on a previous work on the effect of cosmic rays accelerated in superbubbles triggered by OB associations of stars, Siddhartha Gupta, Biman Nath and collaborators Prateek Sharma and David Eichler have worked out various observational effects of these cosmic rays, in gamma-rays, X-rays and in radio wavelengths. These simulations offer a way to compare observations with theoretical results enabling identification of the site of cosmic ray acceleration.

Cosmology

Probing the Epoch of Reionization (EoR) - a period in the history of the universe that refers to the predominantly neutral gas and dust in the universe becoming ionized by the emergence of luminous sources like stars - is one of the major areas of research in modern cosmology. The most direct way to probe this transition from neutral to ionized is through the detection of redshifted hyperfine 21 cm line of neutral hydrogen (HI). During the past year, Janakee Raste and Shiv Sethi have modelled the early phase of EoR analytically because it could be dominated by thermal inhomogeneities which could result in HI signal being orders of magnitude larger than the later phase. This also enables isolating and studying different inputs from physics to better understand this highly complex process. This phase, modelled using statistical techniques was found to be in agreement with numerical simulations.

High Energy Astrophysics

Eta Carinae is a stellar binary in our Galaxy brightly emitting X-rays and well observed also in gamma ray band by Fermi LAT detector. Nayantara with her collaborator Soebur Razzaque developed a lepto-hadronic modelling for the multi-wavelength photon emission from this binary. They predicted high energy neutrino events could be detected in future from this source by kilometre scale neutrino telescope. This work has been published in Physical Review D.

With Sayan Biswas, she studied the effect of matter density in Milky Way on its effective halo size for cosmic ray propagation. They used the DRAGON code to study cosmic ray propagation in Milky Way, whose observed abundance when compared with theoretical expectations gives strong constraints on the size of the halo. This work has been submitted for publication.

In another work with Raj Prince, Gayathri Raman and other collaborators, Joachim Hahn, Pratik Majumdar, she carried out a detailed data analysis and time dependent modelling of the recent flare from the blazar CTA 102. This flare happened during late 2016 to early 2017. This work is also under review.

Observational Astronomy

It would come as a surprise to many if you tell them that what the human eye sees of the night sky is just a very small portion of what is really coming to us from the heavens above. The reason being that the human eye is sensitive to just one small portion of the much larger panorama called the electromagnetic spectrum, which includes gamma rays, X-rays, ultraviolet, microwave and radio waves. On a fundamental level the above different forms of radiation are all the same, the difference lies in the frequency and wavelengths of the electromagnetic signal. The universe talks to us over the entire electromagnetic spectrum and the innate curiosity of the human mind would want to devise ways to listen.

Radio Astronomy

Using the Giant Meterwave Radio Telescope and the Karl G Jansky Very Large Array telescope, K. S. Dwarakanath, Viral Parekh and collaborators Ruta Kale and Lijo George have discovered twin radio relics (one elongated and the other ring shaped) in the outskirts of the low-mass merging galaxy cluster Abell 168. This is the lowest mass cluster in which relics due to merger shocks have been detected so far. They propose this relic to be an old plasma revived due to adiabatic compression by the outgoing shock which produced the elongated relic. In a previous work, K. S. Dwarakanath, Shiv Sethi and collaborators Apurba Bera, Nissim Kanekar and Benjamin Weiner had stacked HI signal from nearly 850 DEEP2 galaxies to obtain very stringent upper bound on HI emission at $z \approx 1$. Recently, they have extended this work by stacking nearly 7000 DEEP2 galaxies in continuum and the signal was detected at more than 10σ thereby allowing study of star-formation rate in the universe in the redshift range $0.7 < z < 1.3$. Lakshmi Saripalli and collaborators have imaged in radio continuum a large and unique sample of radio galaxies with substantial "off-axis" radio structures. The observations have enabled identification and characterisation of rotationally symmetric radio morphological structures exhibited by the sample sources, which has led to an exploration of historical changes to black hole axis orientations. Correlation analyses of

simultaneous observations of a pulsar by Avinash Deshpande and collaborators S. J. McSweeney, N. D. R. Bhat, and S. E. Tremblay with two radio telescopes has revealed that the individual emission columns above the pulsars rotating carousel of sparks do evolve in frequency in the same way that the global magnetosphere does, hinting at a possible departure from the dipolar field geometry in this pulsar's emission region. Targeted observations to search for pulsars and fast transients by H. A. Ashwathappa, Jigisha Patel, P. K. Manoharan and Avinash Deshpande are continued at 34.5 MHz, using the Gauribidanur Radio Telescope. Following simulation of Lunar Occultation and estimation of dynamic spectral signature, actual lunar occultation observations were carried on a few sources using the Ooty Radio Telescope, and the data are being processed.

X-ray Astronomy

Compact X-ray binaries are composed of a compact object; a neutron star or a black hole and a companion 'normal' star. The intense gravitation field of the neutron star causes matter from the companion star to accrete onto the neutron star, producing X-rays. X-ray astronomy is a powerful tool to study such objects. A plethora of information about system dynamics like orbital period and radius evolution of X-ray binaries, structural evolution of the accretion disk and its time scales, and structures of the stellar wind can be obtained by a careful analysis of the X-ray output from compact X-ray binaries. A brief overview of various aspects of compact X-ray sources investigated by RRI astronomers during 2017-18 is given below.
Recent research by Biswajit Paul and collaborator Aru Beri towards studying the pulse profiles of pulsars in a binary system before, during and after flares have yielded estimates of the timescales required for formation of new accretion streams as well as relaxation to normal state of accretion streams that were modified during flaring. A comparative study of stellar winds between Supergiant Fast X-ray Transients (SFXT) and supergiant high mass X-ray binaries by Biswajit Paul and collaborators Pragati Pradhan and Enrico Bozzo has revealed systematically lower absorption, luminosity and strength of iron emission line in the former, indicating their environment to be significantly different from that of supergiant high mass X-ray binaries. Spectro-timing analysis of the X-ray spectrum from a low mass X-ray binary by Gayathri Raman, Biswajit Paul and collaborator Chandreyee Maitra has revealed, for the first time, structural changes in the accretion disk in timescales of hours as well as the presence of iron absorption lines in the binary system. Analysis of an eclipsing supergiant high mass X-ray binary pulsar by Jincy Devasia and Biswajit Paul has revealed significant absorption of soft X-rays in some segments of the observation which has been attributed to the presence of clumps in the stellar winds of the companion star. A weak correlation observed during simultaneous X-ray and optical observations of EXO 0748-676 by Gayathri Raman and Biswajit Paul was attributed by them to the structural changes in the accretion disc. In a recent review article, Biswajit Paul has discussed some aspects of astrophysical studies that are enabled by neutron stars in X-ray binary systems.

Experimental Astronomy

Apart from carrying out observational astronomy with facilities, RRI astronomers do in fact built specialized telescopes designed to "see" in different frequency bands of radiation with focus on specific unsolved problems. The unrelenting quest for pushing the frontiers of knowledge about the observable universe and the need to see hitherto hidden regions of space has fuelled the need for better, efficient and sensitive telescopes and associated receivers and algorithms. Additionally, new methods and modelling aimed towards extracting the signal of interest from the background is desired. AA research at RRI over the past year has focused on both these aspects and RRI astronomers and engineers have been involved in designing and constructing Radio and X-ray telescopes both nationally and internationally.

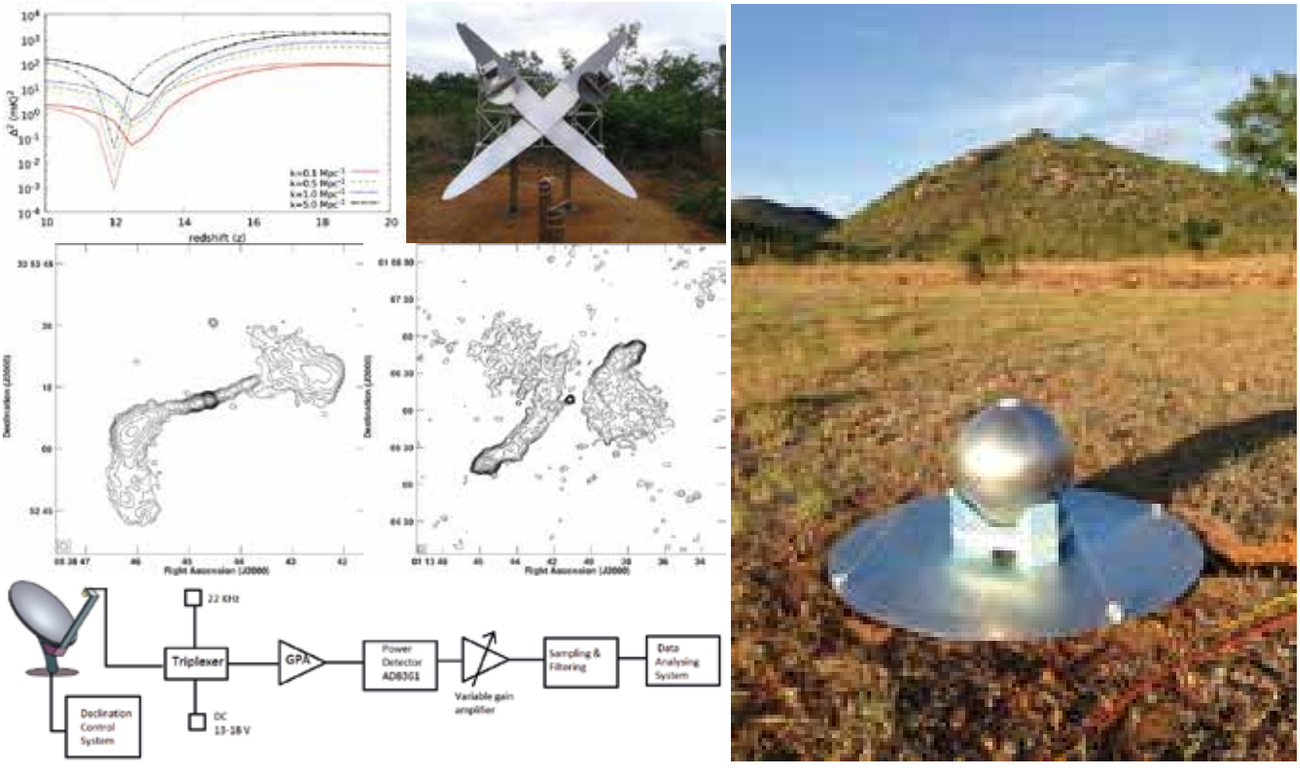
Towards detecting the cosmological epoch of reionization when the first starlight lit up the universe, ended the 'Dark Ages' and ionized the intergalactic gas, RRI joined an international collaboration to build the Murchison Widefield Array radio telescope. Towards the same science goal, a group of RRI astronomers and engineers – Saurabh Singh, Jishnu Nambissan, Mayuri S, Ravi Subrahmanyan, N Udaya Shankar, B S Girish, A Raghunathan, R Somashekar & K S Srivani – built advanced versions of the SARAS radiometer that, for the first time, constrained plausible models for the evolving universe simply based on precision measurements of the spectrum of the cosmic radio background. Efforts by Pavan M. S., Sandeep H., Charles Paul and Ramesh Balasubramanyam are towards building a cm-wave imaging telescope which, by use of a novel optics scheme "efficient linear array imaging", provides good resolution, sensitivity and collection time with 70% less reflector area and easy cum cost effective manufacturing. Another telescope to search for supernova events in our galaxy, based on the One Element Interferometer scheme proposed by Ramesh Balasubramanyam, is being constructed by him and Lekshmi Nair at the RRI field station in Gauribidanur. During the year, the SWAN – Indian Sky Watch Array Network – project continued developments with RRI members Vinutha Chandrashekar, K B Raghavendra Rao, H A Aswathappa, P S Sasikumar, T S Mamatha, H N Nagaraja, Sandhya and Avinash A Deshpande working with numerous students from universities across the country towards exploring the transient sky with specialized receivers and algorithms.

RRI is currently designing and building an Indian X-ray polarimeter (called POLIX), as a payload for a dedicated small satellite mission of ISRO called XPoSat. POLIX is poised to be the first dedicated X-ray polarimeter mission in the world and open a new window in high energy astrophysics by measuring X-ray polarization in about 50 bright X-ray sources, ahead of the NASA and ESA space mission proposals for launching X-ray polarimeters. During the past year Vikram Rana has initiated efforts towards generating a clean room for fabrication of optical components for use in X-ray telescopes.

Algorithms & Signal Processing

Research effort is also focused on developing methods and algorithms that would detect the required signal from background or place useful constraints on the parameter space of theoretical models.

Research in signal processing during the past year has been towards understanding patterns and devising effective methods of their detection. Focusing initially on circular feature detection, Avinash Deshpande and collaborators Pratik Kumar and Joy Mitra have proposed a fast algorithm that overcomes the short-comings of currently available approaches. A new method to detect off-pulse (unpulsed and/or continuous) emission from pulsars, using the intensity modulations associated with interstellar scintillation was proposed by Kumar Ravi and Avinash Deshpande. This method is immune to certain non-idealities in measurement setups and is expected to pave the way for extensive investigations of off-pulse emission from pulsars. Research by Avinash Deshpande and collaborator Akhil Jaini has been towards examining the spatial coverage provided by a novel interferometer system that would enable radio sky imaging at frequencies under 10 MHz. In another study, Avinash Deshpande has proposed a critical test, based on correspondence between spectral manifestation of the dipole anisotropy and monopole spectral slopes for in situ validation of spectral signatures from early epochs, relevant to presently reported and future detections of EoR signal. In an effort to develop novel methods to extract the EoR power spectrum, Akash Patwa, K.S. Dwarakanath and Shiv Sethi in collaboration with the international MWA team have analysed MWA Phase I and Phase II drift scan data and are currently finishing work on determining the one-dimensional power spectrum.



Top left: Analytically modelling the early phase of EoR: Evolution of $\Delta^2 = k^3P(k)/2\pi^2$ $((mK)^2)$ is displayed for a range of scales for spectral index $\alpha = 1.5$, ionization parameter $\varsigma = 10$, and two values of ν_{min}. The thick curves are for $\nu_{min} = 100$ eV and the thin curves are for $\nu_{min} = 1$ keV. Top Right: A photo of the scaled model of Efficient linear imager with dimensions 2.3m x 2.3m at the Gauribidanur field station. Middle: Examples of inversion-symmetric off-axis emission structures in radio galaxies in the study: (Left) off-axis emission originating from outer ends of radio lobes and (right) off-axis emission originating from inner ends of radio lobes. Bottom: Block diagram of the supernova search engine currently being constructed at RRI

The SARAS 2 radiometer built at RRI is shown deployed at the Timbaktu Collective, which is a relatively radio quiet location in Rayalseema district in Andhra Pradesh.

Light and Matter Physics

Overview

Light and matter interaction is at the heart of how scientists learn about the physical properties of objects ranging in size from that of the universe down to atomic scales. At the Raman Research Institute members of the light and matter physics (LAMP) group are engaged in research on fundamental properties of electromagnetic (EM) waves and on the nature of interaction of EM waves with gaseous neutral atoms, ions, ultra-cold and exotic states of matter. The underlying theme of these studies is to unravel fundamental processes which will qualitatively improve our understanding of the studied phenomena and provide new guiding principles. The knowledge thus gained will help in utilization of these principles both at the fundamental and at the applied level.

Focus 2017-18

Ultra-cold Atoms, Ions and Molecules

One major area of research in the LAMP group involves the cooling and trapping of atoms, ions and molecules in order to study interactions at low temperatures. Two years ago, a new experimental facility towards creating a Sodium-Potassium gas mixture at nano-Kelvin temperature was started by Saptarishi Chaudhuri along with Sagar Sutradhar, Sanjukta Roy and Maheswar Swar in the LAMP group. At these very low temperatures the system can be an ideal test bed for investigating quantum nature of interactions between these mixtures. Such a study will throw light on critical physical principles underlying complex condensed matter systems like those that show superconductivity. A major portion of the design and implementation was completed last year and the laboratory is poised to conduct actual measurements and report results in the near future. Cavity based quantum optics is another area of active research in the LAMP group. Strong interactions between neutral atoms and light can be achieved by trapping light in a high-Q cavity. This enables several aspects of strongly coupled light-matter interaction to be studied. Such trapped atom-light studies are conducted both with ultracold atoms at about 100's of microkelvin temperatures and with atoms at room temperature. During the past year, Rahul Sawant and Sadiq Rangwala placed laser cooled atoms within a Fabry Perot cavity and the collective strong coupling between the atoms and the cavity modes resulted in lasing via spontaneous emission into the cavity mode by the driven atoms.

Motivated by recent theoretical analysis of the Quantum diffusion law at low temperatures, Sanjukta Roy along with Hema Ramachandran and Saptarishi Chaudhuri has visualized an experiment to observe diffusion at various temperature regimes; the preliminary experimental results agree with theoretical predictions in the classical regime. Current efforts are towards experimentation in an intermediate regime of temperatures with future goal of exploring quantum degeneracy regime diffusion.

Precision Atom-Light Interaction and Spectroscopy

Precision atom-light interaction and spectroscopy refers to those studies of light matter interaction where resolution in frequency and spatial domains is demonstrated which far exceed those achieved during a single photon scattering process. It also includes studies where a near non-demolition measurement is carried out to obtain information about the system under study.

Magneto optical rotation arising from magnetic spins of thermal atoms which form the noise background of a room temperature atomic system has been carried out by Maheswar Swar, Dhanalakshmi D, Sanjukta Roy, Hema Ramachandran and Saptarishi Chaudhuri. Careful analysis of such studies on noise induced rotation reveal surprising details of the system like the nuclear-g factor and serve as a sensitive probe for fishing out very small amounts of other isotopes present in the atomic ensemble. More importantly they serve as a real time non-destructive measurement of spin populations in various magnetic hyperfine levels.

Using a room temperature thermally broadened atomic ensemble of 550 MHz width and using coherent and phase-sensitive interaction between optical and microwave fields with atoms a very high contrast switch has been demonstrated by Asha Karigowda, Megha Ghosh, Ayyapan Jayaraman, Meena M. S. and Andal Narayanan, along with collaborators Barry Sanders and Fabien Bretenaker. The switch spans over a band-width of 1 MHz. The switching operation enables a high-contrast optical intensity modulation to be effected by a change in phase in the microwave regime. Extension of this study also demonstrates a near noiseless amplification of optical signals using phase-sensitive and preferential accumulation of noise in specific quadratures.

Intense Light Matter Field Interactions

The optical response of a material scales linearly with respect to incident radiation. However, when the intensity of the incoming radiation (in other words the amplitude of the electric field) is sufficiently high the material can respond nonlinearly. The study of interaction of intense light with matter is known as nonlinear optics. Research during the past year has been on studying nanostructured and other materials capable of nonlinearly transmitting light with respect to input intensity. Such materials have a variety of applications including optical limiting and saturable absorption. Optical limiters, for example, are materials that can attenuate intense laser pulses by limiting the output fluence to a safe range so that delicate optical instruments, optical sensors and human eyes can be saved from accidental or hostile exposure. During the past year Ferrite Core-Shell nanoparticles were studied by Sreekanth Perumbilavil, Gaurav Kumar Tiwari and Reji Philip in collaboration with Josep Nogués using ultrashort laser pulses, with the aim of investigating their optical limiting properties. It was found that, in

addition to being robust at high laser intensities they performed on par or better that existing materials making them attractive for ultrafast optical limiting applications. Another work performed by Jijil Nivas, K. K. Anoop and Salvatore Amoruso in collaboration with Reji Philip highlighted the importance of laser pulse wavelength on the formation of various surface features on crystalline Silicon. Plasmas can be generated in the lab by the interaction of intense laser pulses with suitable targets. Such laser-produced plasmas have myriad applications, such as nanoparticle and nanocluster generation, second and high-order harmonic generation, UV and EUV generation, X-ray generation, and attosecond pulse generation. Research over the past year by P. Sankar, Jijil J. J. Nivas, N. Smijesh, G. K. Tiwari and Reji Philip was geared towards understanding the emission dynamics and properties of plasmas generated from Al.

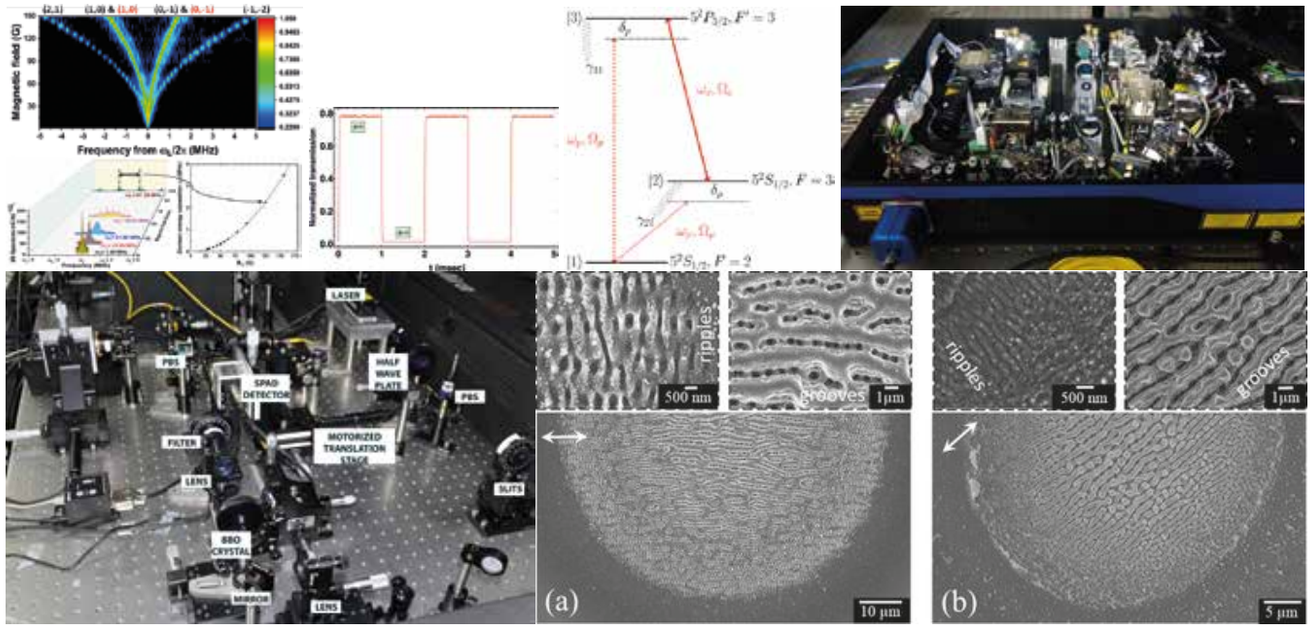
Quantum information, computing and Communication

During the past few years, RRI has accumulated infrastructural capability and intellectual knowhow to conduct cutting edge research in the fields of quantum information, quantum computing and quantum communication using quantum optics based tools. It is worth pointing out Urbasi Sinha and other members of the Quantum Information and Computing (QuIC) lab at the Institute have pioneered the manufacture and applications of single, heralded and entangled photon sources in India which were hitherto unexplored in our country. Any truly quantum application of light requires harnessing it at a single particle (photon) level and this requires dedicated resources and technology to materialize, which has been established at the Institute. During the past year, the QuIC lab members have used the infrastructure developed to further our knowledge base in these research areas.

In the previous annual report, an experimental proposal for manipulation of a phenomenon called Entanglement Sudden Death was published in Journal of Optical Society of America B. During the past year, Ashutosh Singh and Urbasi Sinha in collaboration with A.R.P Rau have made significant headway towards an experimental demonstration of the proposal.

Similarly, in the previous annual report, an appraisal work was reported on the current status of the Quantum Cheshire Cat effect. This work was published this year in Annals of Physics. During the past year, Surya Narayan Sahoo, Sanchari Chakrabarti and Urbasi Sinha in collaboration with Dipankar Home and Alexandre Matzkin have made significant headway towards the first unambiguous Quantum Cheshire Cat experiment using photons.

A broad theme of research at the Institute is in the field of quantum computation, especially harnessing higher dimensional quantum systems. Research over the last few years has been on investigating a system of qutrits formed using the spatial degree of freedom of the single photon. During the past year, an indigenous experimental architecture of generating highly correlated spatial qutrits in a novel quantum setting was established by Debadrita Ghosh and Urbasi Sinha along with collaborators Thomas Jennewein and Piotr Kolenderski. A novel theoretical measure of entanglement which



Clockwise from top left: (1) Observation of the energy splitting due to nuclear magnetic moment and measurement of hyperfine constant using Spin Noise Spectroscopy. (2) Demonstration of a high-contrast, phase-sensitive optical switch in a Delta system. (3) Towards Quantum Entanglement with ultra-cold Rydberg atoms: Photograph of the state-of-the-art TA SHG pro laser system from Toptica Photonics which was installed in the experiment. (4) Surface nanostructuring: SEM (scanning electron microscope) images of a silicon surface after irradiation with 50 laser pulses: (a) fundamental beam at 800 nm with energy 30 micro-Joules; (b) second harmonic beam at 400 nm with energy 5 microJoules. Upper panels report zoomed views of ripples (left) and grooves (right) for each. Arrows indicate the direction of laser polarization. (5) The experimental set up in QuIC lab at RRI which is used to generate spatially correlated bi-partite qutrits.

makes use of the well-known measure of classical correlations, the Pearson correlation coefficient has also been developed by Urbasi Sinha along with collaborators C Jebarathinam and Dipankar Home. Current efforts are towards experimentally testing this measure using the indigenous bi-partite qutrit system in the lab.

Another area of research is towards realization of entanglement scalability via mesoscopic entanglement of large number of ultra-cold Rydberg atoms. During the past year, various components required for the experiment were procured and are being be setup by Sanjukta Roy, Shilpa B. S., Sukanya Mohapatra, Monika and Hema Ramachandran for exploring Quantum Entanglement in 1D and 2D arrays of single atom traps. For a detailed description of the research in the above mentioned topics the reader is directed to the "Knowledge Creation: Light and Matter Physics" section of this Report.

Soft Condensed Matter

Overview

Soft matter, as the name implies, encompasses materials that are easily deformed by thermal fluctuations and external forces. Some common examples of soft matter that we use in our day-to-day life include lotions, creams, milk and paint. The building blocks of these materials are macromolecules with typical size ranging anywhere from few nanometers to few micrometers and are held together by weak inter macromolecular forces and exhibit complex structures and phase behavior. The SCM group at RRI actively studies colloids, complex fluids, liquid crystals, nanocomposites, polyelectrolytes, self-assembled systems, polymers and biological materials. A fundamental understanding of the structure-property correlations, phase behavior of these systems, and response to external stimuli form a major part of the experimental research activities in the SCM group. Theoretical work carried out by the group broadly concerns developing phenomenological theories of elasticity and topological defects in soft matter.

Focus 2017-18

Liquid Crystals

As the name implies, liquid crystal (LC) is a state of matter that has properties intermediate between those of conventional liquids and solid crystals. An LC exhibits many of the physical attributes of a liquid, whereas its molecular units exhibit some form of order. LCs can be divided into thermotropic LCs in which transitions into an LC phase occur with change in temperature, and lyotropic LCs that are formed by dissolving surfactants - amphiphilic materials composed of a polar head group and non-polar chain - in a solvent.

Thermotropic LCs are further subdivided into calamitic LCs made of rod-like molecules and discotics composed of disc-like molecules. More recently a new class of LCs made of bent-core molecules has also been discovered. An attractive feature observed in this type of LC is the interplay between polarity and chirality, which leads to various chiral effects despite the molecules being achiral.

LCs display a variety of phases characterized by the type of molecular ordering, the simplest among them being the nematic phase in which the molecules have no positional order, but they self-align to have long-range orientational order with their long axes roughly parallel, and the smectic A phase in which the molecules are parallel to one another and are arranged in layers with the long axes being perpendicular to the layer plane.

Since their discovery, considerable work has gone into understanding their structure-property relationships, which hold the key for the myriad applications involving LCs. Researchers within the SCM group at RRI have done pioneering work in LCs and that tradition still continues today with research in various aspects of LCs being undertaken. The interesting physical properties resulting from a careful tuning of the molecular shape, concentration, constituents and phase, while expanding the LC knowledge base, serve to open potential avenues for technological applications.

Research focus during 2017-18 was on developing new building blocks like chalcone (H. T. Srinivasa and Sandeep Kumar), anthraquinone (Swamynathan K., Raghunathan V. A. and Sandeep Kumar), a new motif s-heptazine (Irla Siva Kumar and Sandeep Kumar) and thienothiophene for novel LCs with properties tailored for various applications. Wherever possible the synthesis method was chosen such that it is low cost and scalable to ensure commercial viability. For example, Ashwathanarayana Gowda and Sandeep Kumar along with collaborators Manish Pandey, Shuichi Nagamatsu, Wataru Takashima, Shuzi Hayase, and Shyam S. Pandey have synthesized Thienophene based LC's with very high mobility, a highly desirable parameter for planar devices such as organic field effect transistors. Research was also undertaken by Deepshika Malkar and Arun Roy in collaboration with Veena Prasad towards understanding the effects of molecular shape on the phase transition properties and stability of phases as well as the structure-optoelectric properties of smectic nanoclusters in dimeric compounds. Research on LC gels by Neha B. Topnani, Prutha N. and Pratibha R. led to a new type of structured material where self-assembly and pattern formation promotes an interesting grating like motif composed of LC rich and fibre rich regions whose dimensions can be varied depending on the relative concentration of the nematic LC and the gelator. Such a periodically constrained nematic gel can act as a template for positioning nanoparticle arrays in an LC matrix which has the potential to form novel photonic devices. Recent research efforts at RRI have focused on exploring the combined functionalities of LCs and nanoparticles to develop hybrid platforms with unique structure-property relationships suited for applications in optoelectronics, optical and molecular switching, storage and sensing devices. For example, Sandeep Kumar and collaborators Shivani Pandey, Dharmendra Pratap Singh, Kaushlendra Agrahari, Atul Srivastava, Michal Czerwinski and Rajiv

Manohar dispersed CdTe quantum dots in ferroelectric crystals and have shown enhanced memory characteristics with potential in storage applications; while CdSe quantum dots – ferroelectric liquid crystal composite studied by Sandeep Kumar and collaborators D.P. Singh, Yahia Boussoualem, Benoit Duponchel, Sahraouj Abdelak Hadj, Rajiv Manohar and Abdelylah Daoudi displayed pico ampere sensitivity opening up potential applications as sensing devices, in electronic data storage and faster electro-optical devices. During the past year, Manish Kumar, Ashwathanarayana Gowda and Sandeep Kumar have reviewed the synthesis, properties and applications of Discotic LC – graphene composites as well as DLC – nanoparticle composites. C Saichand, A Jaya Kumar, Arun Roy and Yashodhan Hatwalne theoretically studied the energetics of fluid membranes with in plane nematic order. Owing to the ease of synthesizing the studied shapes in the laboratory, efforts are towards substantiating the theoretical results with experiments.

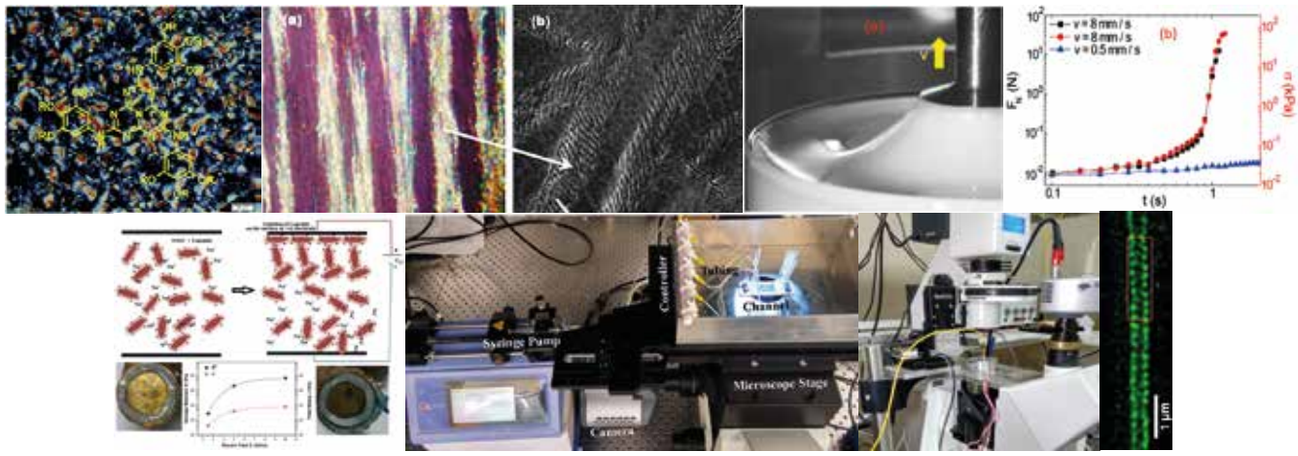
Mechanical Properties of Soft Materials

The transition of a liquid to a glass is a problem that has challenged condensed matter physicists for a long time. One of the objectives of Ranjini Bandyopadhyay's Rheology and Light Scattering laboratory is to use colloidal suspensions as model systems to experimentally unravel the mysteries of the glass transition. The group studies the mechanical properties of dense colloidal suspensions as they approach the jamming transition. These mechanical properties are correlated with structural information, obtained from microscopic or light scattering experiments, to better understand the onset of kinetic arrest (glassiness) in these suspensions. This group is also interested in making new colloidal materials by driving colloidal suspensions out of equilibrium. This is achieved by applying stresses or external fields. These experiments are expected to lead to the development of strong hydrogels with implications in the design of soft machines.

Soft materials show very interesting linear and non-linear mechanical behaviour. Many soft materials also change their mechanical properties depending on external cues in a controlled and reversible manner and can act as adaptable materials. One popular example is a dense suspension of corn starch in water ('oobleck') that can transform from a liquid-like to a solid-like state under sufficiently high applied force and comes back to the liquid-like state once the force is removed. Such adaptations can also be very subtle. For example, biopolymer networks formed by F-actin present inside the cells of our body, can remember the history of applied stress. They can modify their mechanical response depending on the magnitude and direction of previously applied perturbations. One of the research directions of Sayantan Majumdar's lab is to understand and develop design strategies for materials that show force induced adaptations.

Physics of Lipid Membranes and Polyelectrolytes

V A Raghunathan's group is involved in investigations on the structure of soft materials and their phase behaviour, using



Clockwise from top left: Synthesis and chemical structure of trisubstituted heptazine derivatives. • (a) Periodic orientation patterns formed by LC rich and fibre rich domains observed under POM with the N-gel when the N is planar aligned (b) SEM images of N-gel revealing helical morphology of fibrous aggregates • (a) Optical image showing the tensile stress induced transformation of dense corn-starch suspension (volume fraction~0.5) from a fluid-like to a solid-like state under sufficiently high pulling velocity. (b) Force response under different pulling velocities. The formation of the frustum shape [shown in (a)] correlates with huge increase in force / stress on the pulling plate. • A photograph of the setup and a super-resolution image of the periodic spectrin arrangement in an axon taken using a STED microscope in collaboration with IISER-Pune. • Micro fluidic platform to measure force response of a single DNA molecule. •The cartoon shows disk-like Laponite colloids diffusing freely in the aqueous medium in the absence of an electric field and the initiation of a house of cards aggregation mechanism immediately upon the application of a DC field. The application of a DC voltage gives rise to the formation of a jelly like (gel) material on the positive electrode (photo on the bottom right). A gel is not formed when an AC voltage is applied (photo on the bottom left). The plot shows the formation of Laponite gels of progressively higher rigidities with increase in the strength of the DC electric field E.

small-angle and wide-angle x-ray scattering techniques. Systems studied include lipid-sterol membranes, lipid-polyelectrolyte complexes and surfactant solutions. The phase behavior of these systems is also probed using optical and atomic force microscopy. In addition, the mechanical properties of lipid membranes are studied using optical microscopy and micropipette aspiration.

Biophysics

Nanoscale biophysics of biological systems

Gautam Soni's Nano-Biophysics lab's research interests are primarily guided by the role of force in biophysical structure formation and its synergy with functional dynamics. They try to understand mechanisms of force-sensing as well as force-response of cells and molecules. They study this in biological model systems of protein-assembly, DNA-protein complexes as well as whole cell mechano-sensing. They use, as well as develop, novel bio-nano and micro scale tools to decipher biophysical principles governing role of forces in cellular as well as molecular assemblies.

Biophysics of Axons

Research in Pramod Pullarkat's lab is towards studying the mechanical responses of axons. Axons are thin tubular extensions produced by neuronal cells in order to conduct electrical signals. In a human body they can be anything from a few tens of microns (in the brain) up to a meter long (in nerves extending into lower limbs) with a diameter of only 1/1000th of a millimetre. They are also highly dynamic structures with an ability to grow, retract and rewire connections. At the same time, they need to have sufficient structural stability as they are subjected to large deformations during limbmovements or as a result of injury. Not surprisingly axons exhibit several remarkable mechanical properties. For example, they show unique viscoelastic responses to buffer fast mechanical stress, they can actively contract using molecular motors in order to minimise the length between connections (for fast signal transmission), and can exhibit tension induced lengthening at long times as during the growth of an organism. Recent experiments conducted in the laboratory using a home-developed, computer controlled force apparatus have shown that they buffer mechanical tension via special "shock-absorber" proteins called spectrins which can unfold and refold in response to mechanical stress giving rise to a strain-softening behaviour. Research in the lab has also shown that abnormal cylindrical to peristaltic shape transformations, often observed as a result of neurodegeneration, can be understood based on a mechanical model invoking plasma membrane tension and elastic responses of the internal polymer skeleton. In general, the laboratory employs biological and genetic tools, novel measurement techniques and theoretical modelling to understand the various axonal responses to mechanical stress or neurodegenerative conditions.

Theoretical Physics (TP)

Overview

Theoretical physics is an endeavor that attempts to make sense of the inner workings of nature, using the language of mathematics. The goal is to model and predict the behavior of all physical systems from the very small (sub-atomic and smaller) to the very large (galaxies and beyond) that constitute this beautiful and complex universe that we live in. The Theoretical Physics group at RRI is actively pursuing research in the following areas: Foundations of quantum mechanics, General Relativity, Quantum gravity and Statistical physics. The TP group has also forged a robust collaboration with experimental groups within RRI. The connection with Light and Matter Physics group is specifically in the areas of foundational questions in quantum mechanics, quantum information and nonlinear quantum optics. The overlap with the Soft condensed matter group is in areas such as biophysics, polymer physics and modeling stochastic search process. Additionally, RRI theorists have fruitful ongoing collaborations in the above research areas with both national and international peers.

Focus 2017-18

Statistical Physics

Statistical physics gives a probabilistic description of systems that evolve in a stochastic manner. Examples of such systems include the motion of colloidal particles in water, motion of bacteria, externally shaken granular particles, as well as gas in equilibrium. For equilibrium systems, there is a well-defined formalism to study the static properties. However, for systems away from equilibrium, there is no standard method. During the past year, Sanjib Sabhapandit and his students at RRI along with collaborators, investigated such nonequilibrium systems using various mathematical methods: (a) Deepak Gupta and Sanjib Sabhapandit have analytically studied the probability density function as well as large deviation function of the stochastic efficiency of an isothermal Brownian work-to-work converter engine, and verified the results using numerical simulations. (b) Sanjib Sabhapandit and collaborators Deepak Bhat, Anupam Kundu and Abhishek Dhar have studied the equilibration of a particle in a potential with a thermal wall and found that the relaxation to the equilibrium state is quite unusual, showing a power-law (sometimes with a logarithmic correction) relaxation in contrast to the usual Debye like exponential relaxation. (c) Sanjib Sabhapandit and collaborators Jishnu Nampoothiri, Kabir Ramola and Bulbul Chakraborty have analyzed the statistics of gaps between successive avalanches in one dimensional random field Ising models in an external field at zero temperature. (d) Sanjib Sabhapandit and collaborators Abhishek Dhar, Anupam Kundu, Satya Majumdar and Gregory Schehr have considered the

one-dimensional coulomb gas (also known as the one-dimensional one-component plasma) in a harmonic potential and analytically found the statistics of the rightmost charge - which turns out to be quite different from the well-known Tracy-Widom distribution. In a related work, they have also computed the index distribution for this system. (e) Sanjib Sabhapandit and collaborators Kanaya Malakar, V Jemseena, Anupam Kundu, K Vijay Kumar, Satya Majumdar, S Redner and Abhishek Dhar have investigated the motion of a run-and-tumble particle in one dimension and found the exact probability distribution of the particle with and without diffusion on the infinite line, as well as in a finite interval. (f) Deepak Gupta and Sanjib Sabhapandit have obtained analytical results for the probability distribution of partial entropy production in a heat transport model as well another coupled nonequilibum system in a confining potential.

Classical and Quantum gravity

Gravity, as we all know is an attractive force between two massive bodies. With Newton's work it became possible to understand gravitational effects with a few simple laws. However, a deeper understanding of gravity only emerged in 1915 with Einstein's theory. The theory of General Relativity explains that the force we perceive as gravity results from the curvature of spacetime (a 4 dimensional entity -3 dimensional space and one dimensional time). An oft-quoted analogy to visualize the curvature of spacetime in the presence of a celestial body is the stretching of a taut rubber sheet around a heavy sphere placed on it. Placing a smaller sphere on this curved region and imparting it with just the right momentum will cause it to revolve around the bigger sphere. The smaller sphere experiences a gravitational pull towards the heavier sphere as a result of the curvature of the rubber sheet. On the other hand, we have the standard model which explains basically everything else in terms of the three forces-electromagnetic (the force that governs the attraction and repulsion of charged particles like electrons), the strong force (the force that keeps the nucleus from falling apart) and the weak force (responsible for radioactive decay). The Standard model and General Relativity are two theories that explain the known world. Unfortunately, owing to their incompatibility, merging the two theories is a very difficult task. In fact, the Holy Grail for many physicists is to merge these two theories into a Theory Of Everything. The incompatibility can be traced to the origin of the fundamental forces. In the standard model systems interact via quantum particles or force carriers and evolve within a background spacetime structure whereas in General Relativity curvature of spacetime is the origin of gravity. The fabric of spacetime acts both as the background structure for gravitational interactions as well as a dynamic phenomenon, giving rise to this interaction.

Loop Quantum Gravity (LQG) overcomes this incompatibility by generalizing standard quantization techniques to a context in which there is no fixed spacetime geometry. The application of LQG techniques to General Relativity seems to hint at a discrete fine structure underlying the continuum classical theory. A network of interconnected loops builds the space that we see around us; the smooth nature of space that we encounter is because we see it from a distance - something akin to matter looking smooth from afar even though it is made of atoms. For example, the area of any spatial region is proportional to the number of threads entering the enclosed surface. LQG attempts to generalize the familiar techniques of quantum mechanics and quantum field theory and apply them to the context of gravitation. This generalization is technically and conceptually very intricate because, unlike the case of quantum field theory where the quantum fields evolve on a fixed spacetime, here it is the very geometry of spacetime that is dynamical. Hence one needs a generalization that does not rely on notions of a background fixed spacetime. While one has a fine understanding of how to describe quantum spatial geometry in LQG (`LQG kinematics'), a key open problem is how to describe quantum spacetime geometry (`LQG dynamics').

During the past year, Madhavan Varadarajan has focused on an extremely non-trivial quantum spacetime system which is obtained as a novel weak coupling limit of Euclidean General Relativity and which exhibits a constraint algebra which is isomorphic to that of Euclidean gravity. Through the introduction of a host of new techniques, he has constructed a quantum representation for this system in which the intricate commutator structure is exactly of the type required.

A radically different, but manifestly covariant approach to quantum gravity is Causal Set Theory (CST). CST is motivated by deep theorems in Lorentzian geometry that demonstrate the primacy of the causal structure of spacetime. The causal structure of any reasonable spacetime forms what is known as a partially ordered set. Rather than quantize the geometry, in CST one quantizes this causal structure. The spacetime continuum is thus replaced by a discrete substructure, which is a locally finite partially ordered set or causal set. A striking phenomenological consequence of the mixture of discreteness and causality is Sorkin's prediction for the cosmological constant several years before it was confirmed by observation.

At the most fundamental level the causal set does not admit a natural split into space and time and hence many tools that are available in the continuum are absent. In particular, recovering induced spatial information is very challenging. Sumati Surya and her collaborators, Astrid Eichhorn and Fleur Versteegen have shown that the spatial distance function on a given Cauchy hyper surface can be recovered entirely from the causal structure and volume of the spacetime and thence also in the causal set.

An important challenge for quantum gravity is whether it can help resolve the UV divergences of quantum field theories (QFTs). Again, standard tools in QFT split spacetime into space and time, but these tools are unavailable in CST. Moreover, QFT on a generic curved spacetime does not possess a preferred vacuum. As was pointed out by Hawking and subsequently, Unruh, the choice of vacuum and thence particles depends on the observer and is not in this sense fundamental. This reinforced the algebraic approaches to quantum field theory in curved spacetime, which are defined without reference

to a vacuum. In the last decade or so, a new prescription has emerged for an observer-independent vacuum, the so-called Sorkin-Johnston or SJ vacuum. This has potentially very interesting phenomenological consequences, especially for the early universe. Unlike the construction of observer dependent vacua, finding the exact SJ vacuum for different spacetimes has proved challenging analytically. In the past year, Sumati Surya and Nomaan X, in collaboration with Yasaman Yazdi, have performed an extensive study of the SJ vacuum in deSitter spacetime. This study involves a combination of numerical and analytic techniques. Simultaneously they have examined the spacetime entanglement entropy for cosmological horizons and found an emergent area law. Abhishek Mathur and Sumati Surya have constructed the SJ vacuum explicitly for the small mass limit in 2d.

Quantum Foundations, Information and Optics

Research at the Institute under the Quantum Theory theme is towards investigating foundational questions including quantum information, quantum interpretation, quantum optics and the geometry behind quantum theory.

Quantum systems can be entangled, that is they show correlations that cannot be classically understood. Entanglement is a resource that one uses in performing quantum information theoretical tasks and it is very important to learn how to detect entanglement. Kumar Shivam, Supurna Sinha and Joseph Samuel have used ideas borrowed from the physics of special relativity to study the entanglement of two qubit quantum systems. Another work undertaken by Joseph Samuel concerns the large distance behaviour of quantum theory and was motivated by the desire to understand the relation between gravitation and quantum mechanics. An analysis of the double slit experiment has shown that gravitational fields can destroy the interference pattern seen in double slit experiment.

Motivated by the different choice of boundary condition that are possible, Supurna Sinha and Joseph Samuel along with collaborators Paolo Facchi, Giancarlo Garnero, Giuseppe Marmo have explored the generation of boundaries, starting from a manifold without boundaries and have investigated various boundary conditions. They considered a free nonrelativistic quantum particle on the circle as an illustrative example. One possible application of this work is in the area of helioseismology.

Another area of research in the TP group has been on studying diffusion in the presence of quantum fluctuations. A dust particle suspended in a fluid will undergo random motion (diffusion) as a result of collisions with a number of atoms or molecules that make up the fluid, whose motion in turn is due to thermal fluctuations. Thermal fluctuations are nothing but the jiggling and wiggling of atoms and molecules, which manifests as temperature of the fluid. Lower the jiggling and wiggling less is the temperature and vice versa. What happens when we lower the temperature of the system and scale down the size of the particle until we reach a regime where thermal fluctuations are negligibly small and the diffusion is driven primarily by zero point fluctuations, purely of quantum origin? During the past year, Urbashi Satpathi and Supurna Sinha have studied the Brownian motion of a charged particle in a magnetic field and they notice a qualitatively interesting transition from a monotonic to an oscillatory behaviour of the mean square displacement growth with time, which can be tested against cold ion experiments.

The optical response of a material scales linearly to the electric field of incident radiation. However, when the intensity of the incoming radiation (in other words the amplitude of the electric field) is sufficiently high, the material could respond nonlinearly. The study of the interaction of intense light with matter is subject of nonlinear optics. Nonlinear quantum optics is a relatively new field to specifically investigate nonlinear light-matter interaction in the quantum regime with few photons. During the past year, Pooja Manasi and Dibyendu Roy have calculated the transmission and reflection of a laser light in the coherent state from different nonlinear optical media and have derived local properties of the atoms driven by the laser field.

Closing remarks

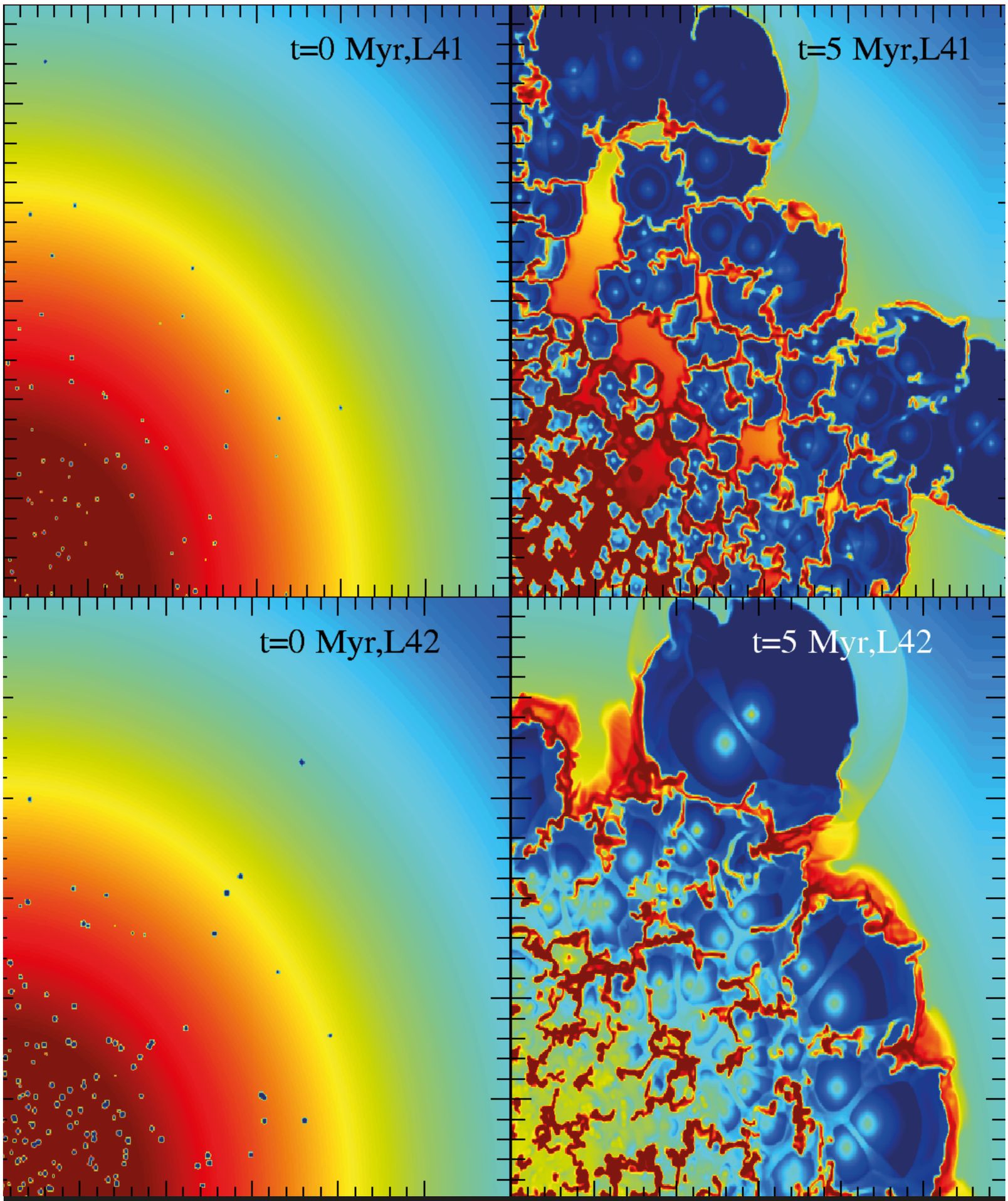
Since the days of our Founder, Sir C V Raman, the Institute has engaged in experimental research of a kind that is becoming uncommon. We selectively target a few unsolved questions in basic science that require purposeful innovation – a building of apparatus in Astronomy, Quantum atom optics and information, Soft matter and Biophysics, which cannot be bought off the shelf and, instead, requires intelligent design, building, calibration, commissioning, and mathematical statistical inference to derive the physics and astrophysics. RRI is distinctive and unique amongst peer research institutions in that several of its research themes have an emphasis on experimental efforts that necessarily require significant in-house technical proficiency and path-breaking advancements in experimental apparatus and methods, which often require years of perseverance and single-minded dedication. This is a continuation of the style of our Founder, Sir C V Raman in a modern context.

RRI is well aware of its indebtedness to society, the DST and the Government of India for their excellent support. The basic science research conducted at RRI continually advances knowledge base resulting in improved understanding of the fundamental laws and behavior of nature. This is the seed that eventuates into innovations and provides the foundations and solution banks for organizations that directly target societal issues and engage in translational research. Nevertheless, the basic science research at RRI does also result in outcomes that directly impact on the quality of life; examples are the development of a brain computer interface involving a visually activated control system for use in wheel chairs, elevators etc., real time imaging through fog involving a novel low-cost method that uses an algorithm that could be executed using the parellisation capabilities of common desktop computers - this

has now improved with new means of data acquisition wherein the algorithm is implemented optically, resulting in obtaining a fully processed image upon recording a single camera frame with obvious applications in defense, search and rescue and medical imaging to name a few. Other examples include optical limiters for laser safety applications, potential sensing applications via pico molar sensitive nanoparticle based chemical sensors and a nanopore platform for single DNA molecule detection, a milk purity testing device involving an electrochemical impedence measuring device to detect synthetic milk, with potential to save multitudes from adverse health effects that translates into physical well-being of people.

The Institute has a number of schemes that engenders creativity, higher learning and experimental skills in the next generation. In the last year, the scientific staff at RRI have mentored and educated close to 200 students and young researchers, and provided opportunities for development of their potential towards being the scientists of tomorrow, by engaging with them in the Post-doctoral, PhD, Research Assistant, and Visiting Student Programmes.

RRI exercises its social scientific responsibility: by hosting events wherein the society in general and young people in particular are invited to the Institute, and by dissemination of knowledge via active participation in Governmental outreach events, popular lectures, visits and workshops given by RRI staff in various external institutions, schools, colleges and universities. RRI has an ever-increasing digital footprint with regular posts in facebook, twitter and blogs of recent scientific results written in a language that is easily understandable to the general public. It is worth noting that DST has shared many of our posts and tweets through their official social media accounts. The past year saw the launch of the official RRI YouTube channel. The channel has since grown to include videos of lectures, seminars and workshops organized at the Institute



Research: Knowledge Creation

Astronomy and Astrophysics

Astronomy and Astrophysics

Overview

From the beginning humankind has looked up at the sky with a sense of curiosity and wonderment. It is no wonder that astronomy is one of the oldest of natural sciences. The field of Astronomy and Astrophysics pertains to a detailed study of the physical, chemical and dynamic properties of celestial objects and phenomena. The research conducted in the AA group at RRI can be broadly classified into four areas:

(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. Theorists also work on answering fundamental questions on the formation and evolution of the Universe, a branch of astrophysics called cosmology.

(b) *Observational Astronomy* on the other hand uses telescopes built across the globe to study radiation from space across the entire electromagnetic spectrum – low frequency (long wavelength) radio waves to very high frequency (short wavelength and highly energetic) gamma rays. These observations test existing theoretical models and also give rise to new questions that call for answers.

(c) *Experimental Astronomy* involves the *design, construction and operation of telescopes* for very specific purposes to address key unsolved problems, and are strategically located around the world and in space.

(d) *Algorithms & Signal processing* where a variety of methods and modelling are employed to amplify and or isolate the required astronomy signal from other foregrounds, backgrounds and unwanted interference and confusion.

Focus 2017-18

Theoretical Astrophysics and Cosmology

The universe that we inhabit is vast beyond comprehension, complex, constantly expanding and is populated by myriad astronomical entities. The universe is populated by stars, galaxies, galaxy clusters, high energy objects like blazars and more. The space between stars, galaxies, galaxy clusters and the roughly spherical region that extends out from a galaxy is permeated by diffuse gas and dust. These are known as interstellar medium, intergalactic medium, intracluster medium and circumgalactic medium respectively. The Universe is thus a very vibrant place with constant interactions and various dynamic processes that shape their evolution and in turn the evolution of the universe as a whole. By studying these cosmic entities, their interactions and processes Astrophysicists, and on a much larger scale, Cosmologists try to understand the evolution of the universe and its workings within the framework of the known laws of physics and chemistry. Analytical modelling and/or numerical simulations shed light on these processes and add to the knowledge base of our understanding of the Universe. A detailed description of the research focus in Theoretical Astrophysics and Cosmology undertaken at the Institute follows.

Astrophysical Fluid Dynamics

Plane shearing waves of arbitrary form: Exact solutions of the Navier-Stokes equations

S. Sridhar and Nishant K. Singh have constructed exact solutions of the Navier-Stokes equation with a background linear shear flow. Closed form solutions for all three components of the velocity field of the Kelvin modes were derived using only elementary mathematical functions. They have demonstrated that, when Kelvin modes with parallel wave vectors are superposed, they remain exact solutions. They provide, in explicit form, the most general plane transverse shearing waves, with any specified initial orientation, profile and polarization structure, with either unbounded or shear-periodic boundary conditions. Of particular interest is the stability of their solutions; if they are stable then they might serve as local representations of disturbances in simulations of astrophysical flows. [Nishant K. Singh (Max Plank Institute for Solar System Research, Germany) and S. Sridhar]

Generation of large-scale magnetic fields due to helicity fluctuations in shear flows

S. Sridhar along with collaborators Naveen Jingade and Nishant K. Singh have explored the growth of large-scale magnetic fields in a shear flow, due to helicity fluctuations with a finite correlation time, through a study of the Kraichnan-Moffatt model of zero-mean stochastic fluctuations of the 'alpha' parameter of dynamo theory. They have derived a linear integro-differential equation for the evolution of large-scale magnetic field, using the first-order smoothing approximation and the Galilean invariance of the alpha statistics. This enabled construction of a model that is non-perturbative in the shearing rate S and the alpha-correlation time T. After a brief review of the salient features of the exactly solvable white-noise limit, they considered the case of small but non--zero T. When the large-scale magnetic field varies slowly, the evolution is governed by a partial differential equation. They present modal solutions and conditions for the exponential growth rate of the large-scale magnetic field, whose drivers are the Kraichnan diffusivity, Moffatt drift, Shear and a non-zero correlation time. Of particular interest is dynamo action when the alpha-fluctuations are weak; i.e. when the Kraichnan diffusivity is positive. They show that in the absence of Moffatt drift, shear does not give rise to growing solutions. But shear and Moffatt drift acting together can drive large scale dynamo action with growth rate proportional to the shear rate $|S|$.

[Naveen Jingade (Indian Institute of Science), Nishant K. Singh (Max Plank Institute for Solar System Research, Germany) and S. Sridhar]

Circumgalactic and Intra-Cluster Medium

Density profile of circumgalactic medium

With Priyanka Singh, Biman Nath has been trying to constrain the CircumGalactic Medium (CGM) properties from the SZ and X-ray observations. They have shown that the InterGalactic Medium (IGM) may contain a large amount of warm (10^5-10^6 K) gas, and may close the gap of missing galactic baryons.
[Priyanka Singh, Subhabrata Majumdar (Inter-University Center for Astronomy and Astrophysics), Biman Nath and Joseph Silk (Institut d'Astrophysique de Paris, France, John Hopkins University, USA and University of Oxford, UK)]

Absorption line signatures of Circumgalactic medium

Based on their atomic structure, chemical components comprising the gas and dust in a medium absorb specific wavelengths of light passing through them. This unique spectral fingerprint is routinely used in identifying the constituent elements. Recently, an absorption feature from the circumgalactic medium corresponding to absorption by Hydrogen, known as the Hα wavelength was reported. Shiv Sethi, Biman Nath and collaborator Yuri Shchekinov, have shown that such a signal could not have arisen from the neutral or ionized component of Hydrogen and hence does not correspond to Hα transition, but could have arisen from an unknown dust component or Diffuse Interstellar Band.

In a recent paper, a broad Hα absorption in our Galactic halo, with peak optical depth $\tau \cong 0.01$ and equivalent width $W \cong 0.17$ Å corresponding to Hα wavelength was reported. The dependence of the signal on galactic longitude suggested that the signal originated from the local circumgalactic and interstellar medium. Shiv Sethi, Biman Nath and collaborator Yuri Shchekinov have shown that such a signal could not have arisen from the neutral or ionized component of Hydrogen gas and hence does not correspond to Hα transition of hydrogen. As the observed absorption feature is quite broad ($\Delta\lambda = 30$ Å), they also considered CNO lines that lie close to Hα as possible alternatives to explain the feature. However, it was found that such lines could also not account for the observed feature. Alternatively, they suggest that it could arise from diffuse interstellar bands (DIBs) carriers or polyaromatic hydrocarbons (PAHs) absorption and have identified several such lines close to the Hα transition. However, determining the molecule responsible for the observed feature is difficult, partly due to selection effects that prevent identifying DIBs/ PAHs features close to Hα using local observations. To enable one to distinguishing between different possible explanations a deep integration of a few extragalactic sources with high spectral resolution is proposed.
[Shiv Sethi, Yuri Shchekinov (Lebedev Physical Institute, Russia) and Biman Nath]

Role of Brightest cluster galaxy in energy deposition into Intra-Cluster Medium (ICM)

Biman Nath and Asif Iqbal along with collaborators Ruta Kale and Subhabrata Majumdar have studied a sample of clusters in low frequency radio wavelengths and used X-ray data from Chandra, in order to determine the role of the brightest cluster galaxies (BCGs) in raising the entropy of the ICM gas. Incidentally, they found that the correlations match the predictions that Biman Nath had made with a former student back in 2005 (Roychowdhury et al 2005), about the black hole mass of BCGs and the cluster potential.
[Asif Iqbal, Ruta Kale (National Center for Radio Astrophysics), Biman Nath and Subhabrata Majumdar (Inter-University Center for Astronomy and Astrophysics)]

Patchy heating of the intergalactic medium by cosmic rays

Biman Nath had shown in 1993 (Nath & Biermann 1993) that it is difficult to have a model of reionization of the universe by cosmic rays. Recently Sazonov & Sunyaev (2015) pointed out that cosmic rays could heat the IGM gas to a detectable level even if they failed to ionize. With Ranita Jana, Biman Nath has, during the past year, calculated the effect of cosmic ray diffusion in this regard, and found that the heating would be rather patchy, peaking near the star forming halos in such a manner as to make it difficult to detect the heating. This paper has been accepted for publication in MNRAS.
[Ranita Jana and Biman Nath]

Galactic Outflows

Extra-planar X-rays from star forming disc galaxies

Aditi Vijayan has worked out the mechanisms by which outflowing gas from a star forming disc galaxy emits X-rays. Instead of simulating a central star forming region, they have developed a 3D numerical hydrodynamical simulation which simulates star formation sites spread in the disc. She has demonstrated that most of the X-rays are emitted by gas around bow-shocks that are formed by cold disk gas thrown up by the injection of energy.
[Aditi Vijayan, Kartick Sarkar, Biman Nath, Prateek Sharma (Indian Institute of Science) and Yuri Shchekinov (Lebedev Physical Institute, Russia)]

Cosmic rays from Superbubbles/OB associations

Following on previous work on the effect of cosmic rays accelerated in superbubbles triggered by OB associations of stars, Siddhartha Gupta has worked out various observational effects of these cosmic rays, in gamma-rays, X-rays and in radio wavelengths. The simulations offer a way to compare observations with theoretical results, so that one can identify the site of cosmic ray acceleration.
[Siddhartha Gupta, Biman Nath, Prateek Sharma (Indian Institute of Science) and David Eichler (Ben Gurion University, Israel)]

Cosmology

Analytically modelling the early phase of EoR

It is customary to model the epoch of reionization using semi-numerical methods as, given the range of scales needed to model it, it is very difficult to model this phase with numerical simulations. Janakee Raste and Shiv Sethi undertook to model the early phase of EoR analytically because it could be dominated by thermal inhomogeneities, which could result in HI signal being orders of magnitude larger than the later phase. It also allows them to isolate and study different inputs from physics in understanding this highly complex process. They successfully managed to model this phase using statistical techniques and their results agree with numerical simulations (Figure 1). They are currently studying an even earlier phase, which could be marked by inhomogeneities of Lyman-α radiation.

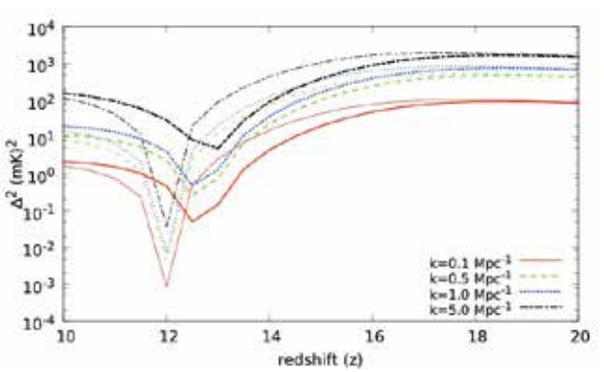


Figure. 1. Evolution of $\Delta^2 = k^3P(k)/2\pi^2$ ((mK)^2) is displayed for a range of scales for spectral index $\alpha = 1.5$, ionization parameter $\varsigma = 10$, and two values of ν_{min}. The thick curves are for $\nu_{min} = 100$ eV and the thin curves are for $\nu_{min} = 1$ keV.

[Janakee Raste and Shiv Sethi]

High Energy Astrophysics

This group is involved in modelling of propagation of Galactic and extragalactic cosmic rays with Monte Carlo simulations. They do multi-wavelength modelling of Galactic and extragalactic gamma ray sources to reveal the underlying physics of high energy particle production within cosmic accelerators.

Fermi LAT Observation of the Brightest Flare from CTA 102

Raj Prince, Gayathri Raman, Nayantara Gupta along with collaborator Pratik Majumdar undertook a multi-wavelength study of the FSRQ CTA 102 using Fermi-LAT and simultaneous Swift-XRT/UVOT observations. The Fermi-LAT telescope detected one of the brightest flares from this object during the observations conducted during September 2016 to March 2017. In the 190 days of observation period the source underwent four major flares. A detailed analysis of the temporal and spectral properties of these flares indicated that flare-3 (at MJD 57751.594) has a γ-ray flux of $(30.12 \pm 4.48) \times 10^{-6}$ ph cm^{-2} s^{-1} (from 90 minutes binning) in the energy range of 0.1– 300 GeV. This has been found to be the highest flux ever detected from CTA 102. Time dependent leptonic modelling of the flares showed that the luminosity in injected electrons increases nearly by a factor of 7 during the flares when compared to the pre-flare state.
[Raj Prince, Gayatri Raman, Nayantara Gupta, Pratik Majumdar (Saha Institute)]

Constraining the halo size from possible density profiles of hydrogen gas of Milky Way Galaxy

Secondary cosmic rays (CRs) (e.g. boron, antiproton) play an important role to understand the propagation of CRs in the Milky Way Galaxy. Such secondary CRs are produced due to interaction of primary CRs with the gaseous components of interstellar medium (ISM).

Recent observations and hydrodynamical simulations provide new forms of density profiles of hydrogen gas in Milky Way Galaxy. Sayan Biswas and Nayantara Gupta consider mainly molecular, atomic, and ionized components of hydrogen gas for the study. In the DRAGON code, they implemented the chosen density profiles, based on realistic observations in radio, X-ray and γ-ray wavebands, and hydrodynamical simulations of interstellar hydrogen gas to study the variation in the height of the halo required to fit the observed CR spectra, keeping all other parameters unchanged. Their results showed the half-height of halo (L) varies in the range of 1 to 4 kpc for the density profiles considered in the work.
[Sayan Biswas and Nayantara Gupta]

A lepto-hadronic model of gamma rays from Eta Carinae and prospects for neutrino telescopes

During the past year, the stellar binary η Carinae was observed during its full orbital period in gamma rays by Nayantara Gupta and collaborator Soebur Razzaque using the Fermi-Large Area Telescope (LAT). The shock-accelerated electrons in the colliding winds of the two stars radiate synchrotron photons in the magnetic field of the shocked region and inverse Compton photons, where the target photons are from the thermal emissions by the more massive and luminous of the two stars. The inverse Compton emission dominated the gamma-ray flux data from the η Carinae, however the spectral energy distribution showed signature of a hadronic component in the ~10-300 GeV range during the periastron passage. Current and future air Cherenkov telescopes will be able to constrain this component at TeV energies. Acceleration of cosmic-ray protons to » 1 TeV energies in the colliding winds, required to explain the hadronic emission component through photopion interactions, can lead to detectable signal of $\gtrsim$10 TeV neutrino events in large kilometer scale neutrino telescopes.
[Nayantara Gupta and Soebur Razzaque (University of Johannesburg, South Africa)]

Observational Astronomy

It would come as a surprise to many if you tell them that what the human eye sees of the night sky is just a very small portion of what is really coming to us from the heavens above. The reason being that the human eye is sensitive to just one small portion of the much larger panorama called the electromagnetic spectrum, which includes gamma rays, x-rays, ultraviolet, microwave and radio waves. On a fundamental level the above different forms of radiation are all the same, the difference lies in the frequency and wavelengths of the electromagnetic signal. The universe talks to us over the entire electromagnetic spectrum and the innate curiosity of the human mind would want to devise ways to listen. Astronomers have in fact built specialized telescopes designed to "see" in different frequency bands of radiation. RRI has been involved in designing and constructing Radio and X-ray telescope facilities both nationally and internationally - for example the Murchison Widefield Array (MWA), a precursor to the SKA telescope, which is a megaproject of the nation, and ASTROSAT, a multi institutional collaborative satellite mission launched by ISRO - which they routinely use to study cosmic objects of interest. Research effort is also focused on developing methods and algorithms that would detect the required signal from background or place useful constraints on the parameter space of theoretical models.

Radio Astronomy

Twin radio relics in the nearby low-mass galaxy cluster Abell 168

K. S. Dwarakanath and Viral Parekh along with collaborators Ruta Kale and Lijo George have reported the discovery of twin radio relics in the outskirts of the low-mass merging galaxy cluster Abell 168 (redshift=0.045). One of the relics is elongated with a linear extent ~ 800 kpc, a projected width of ~ 80 kpc and is located ~ 900 kpc toward the north of the cluster center, oriented roughly perpendicular to the major axis of the X-ray emission. The second relic is ring-shaped with a size ~ 220 kpc and is located near the inner edge of the elongated relic at a distance of ~ 600 kpc from the cluster center. They imaged these radio sources at 323 and 608 MHz with the Giant Meterwave Radio Telescope and at 1520 MHz with the Karl G Jansky Very Large Array (VLA). The elongated relic was detected at all the frequencies with a radio power at 1.4 GHz of $1.38\pm0.14 \times 10^{23}$ W Hz^{-1} having a power law in the frequency range 70 - 1500 MHz ($S \propto \nu\alpha, \alpha = -1.1\pm0.04$). This radio power is in good agreement with that expected from the known empirical relation between the radio powers of relics and the host cluster masses. This is the lowest mass ($M_{500} = 1.24\times10^{14}$ $M_\odot$) cluster in which relics due to merger shocks are detected. The ring-shaped relic has a steeper spectral index (α) of -1.74±0.29 in the frequency range 100 - 600 MHz. They propose this relic to be old plasma revived due to adiabatic compression by the outgoing shock, which produced the elongated relic.
[K. S. Dwarakanath, Viral Parekh, Ruta Kale (National Center for Radio Astrophysics) and Lijo George]

Probing star formation in galaxies at $z \approx 1$ via a Giant Metrewave Radio Telescope stacking

K. S. Dwarakanath and Shiv Sethi along with collaborators Apurba Bera, Nissim Kanekar and Benjamin Weiner have used the Giant Metrewave Radio Telescope (GMRT) to carry out deep 610 MHz continuum imaging of four sub-fields of the DEEP2 Galaxy Redshift Survey. They stacked the radio emission in the GMRT images from a near-complete (absolute blue magnitude MB −20) sample of 4002 blue star-forming galaxies with spectroscopic redshifts $0.7 < z < 1.45$ to obtain a statistical detection (at 14σ significance) of the median rest-frame 1.4 GHz radio continuum of the sample. The stacked emission is unresolved, with a rest- frame 1.4 GHz luminosity of $L_{1.4} = (3.54 \pm 0.27)\times10^{22}$ W Hz^{-1}. They used the local relation between total star formation rate (SFR) and 1.4 GHz flux density to infer a median total SFR of 20.9±1.6 $M_\odot$ yr^{-1} for blue star-forming galaxies with MB 20 at $0.7 < z < 1.45$. This is ≈ 2.4 times larger than the median SFR inferred from the OII3727 line; the ratio of total SFR to obscured SFR increases with both color and stellar mass. The median SFR and the median specific SFR (sSFR) both increase with increasing redshift, with SFR $\propto (1 + z)^{2.16\pm0.29}$ and sSFR $\propto (1 + z)^{3.67\pm0.37}$. They detect the main sequence relation between SFR and M_* , obtaining SFR $= (11.9\pm1.0)\times M_*^{0.79\pm0.05}$, and find that the normalization of the relation increases with increasing redshift, while the power-law index shows no change over z≈0.7-1.45.
[Apurba Bera (National Center for Radio Astrophysics), Nissim Kanekar (National Center for Radio Astrophysics), Benjamin Weiner (University of Arizona, USA), Shiv Sethi and K. S. Dwarakanath]

Probing black hole-axis orientation history in radio galaxies

The size and location of accretion disk-black hole systems at centres of galaxies preclude access to most telescopes across the electromagnetic spectrum and it is in this regard that extended morphologies of radio galaxies provide a unique handle to probe them. Radio galaxies are manifestations of central-engine activity where twin jets of synchrotron plasma advance through the ambient medium. As they advance depositing the plasma in the ambient medium, the deposited plasma starts expanding to form 'lobes'. With the jets created along the supermassive black hole spin axis, the radio galaxy lobes (now formed over few to several hundred kiloparsec scales) and the axis along which they form, serve as proxy for black hole spin axes. The lobes also retain features in them over long timescales, thanks to the large radiative lifetimes of relativistic electrons in synchrotron plasmas. Both these aspects of radio galaxies make them valuable probes of the central engines residing at the centres of their host galaxies. This reasoning was used by Lakshmi Saripalli and her collaborators in probing the past history of black hole axes in radio galaxy hosts.

Identifying and characterizing changes to the central black hole axis have so far only been via individual case studies, which do not allow for the full range of axis perturbations to be probed in a systematic

way. Full range of axis perturbations and their characteristics form useful ingredients in evolution studies of supermassive black hole spins, also leading to studies of black hole mass growth-rate through cosmic times.

The research involved imaging of a unique radio galaxy sample of 100 sources at high enough resolution and sensitivity to reveal morphological details in their radio structures. This enabled identification and characterization of the variety seen in radio morphological signatures exhibited by the sample sources, leading to a systematic exploration of historical changes to black hole axis orientations (Saripalli and Roberts, 2018).

Radio galaxies specifically selected to have low axial ratios were chosen for the study. The purpose was to reveal lobe radio emission located well off the radio axis to be able to identify and characterize changes to the black hole axis over time.

The sample of low axial-ratio radio galaxies was imaged using the Karl G. Jansky Very Large Array in a multi-band (1.4 GHz, 3GHz), multi-array campaign. The imaging revealed structures in sufficient detail (Roberts, Saripalli, Wang et al, 2018), enabling sample refinement by discarding radio galaxies that were superposition of unrelated sources or obviously shaped by large-scale motions – whether of the host galaxy itself through the galaxy cluster or due to likely effects of buoyancy. Examination of the remaining images revealed large samples of radio galaxies with distinct rotationally symmetric lobe morphologies of S and Z-type as well as X-shaped radio galaxies (XRGs) and ones with central inner-S "spine" features.

The study has further revealed that rotationally symmetric offset radio emission is bimodal and that it originates from one of two strategic locations: outer ends of radio lobes or from inner ends of the lobes (closer to the central host galaxy; see figure 2.). Those with off-axis emission originating from the inner or central regions abound in the sample by a factor of about 2 to 1. They are also predominantly of a type that create powerful backflows within lobes.

How these radio galaxies attain their inner-deviant lobe structures with their impressive central off-axis 'wings' is not understood although several models have been suggested in the literature. The unique data obtained by Saripalli and collaborators has allowed for a new model to be proposed towards the formation of these radio galaxies. Taking into account the various structural details revealed by the new data, Saripalli and Roberts proposed a rapid spin-axis change of the central black hole hosting an extended radio galaxy, followed by an activity epoch in a new axis direction, of a type that generates powerful backflows that flow into the now 'relic' channels of the past activity. They also suggested that age-related evolution in morphology of the radio features relates the various structures observed in this class of radio galaxies and further, that the enigmatic XRGs form a subset of this class.

The study also points to the possibility of black hole axis precession, drifts, or flips in a significant fraction of radio galaxies that have prominent off-axis emission. Using the detection rates for the various types of axis rotations revealed by the study, it was estimated that at least 4% of the general population of radio galaxies undergo black hole axis rotation. With binary supermassive black holes being important contenders for causing axis precession, such a study, with its rich haul of rotationally symmetric S-shaped radio galaxies, has shown the usefulness of low axial-ratio radio galaxy samples in the search for binary supermassive black holes.

In the past year this study also resulted in a scientific proposal to the Long Baseline Observatory (USA) by the RRI group and collaborators to search for twin radio cores, which are strong signs of binary supermassive black holes. The proposal, led by Lakshmi Saripalli, has since been successful having been awarded all the time requested. The observations are expected to be carried out in the latter half of 2018.

[Lakshmi Saripalli, Ravi Subrahmanyan, Mayuri Sathyanarayana Rao, David H Roberts (Brandeis University, Boston, USA)]

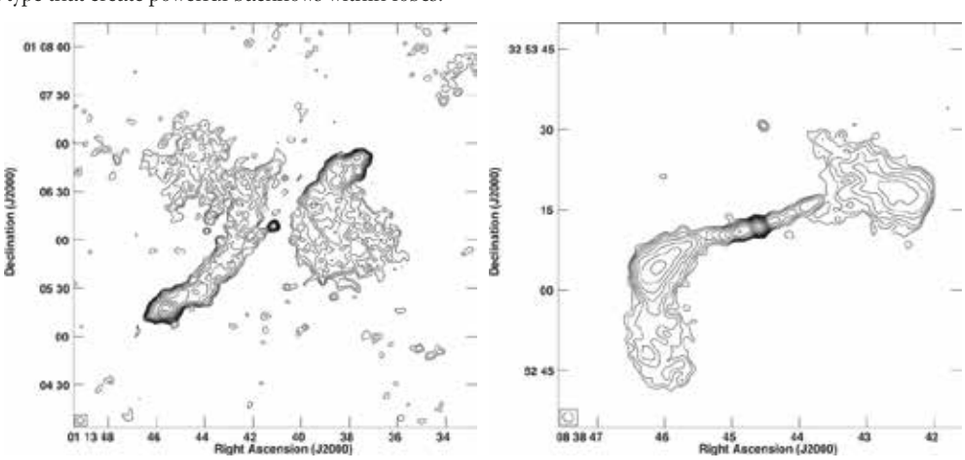


Figure. 2. Examples of inversion-symmetric off-axis emission structures in radio galaxies in the study: Left - off-axis emission originating from inner ends of radio lobes, Right - off-axis emission originating from outer ends of radio lobes.

Phase shifts in multi-frequency observations of the drift bands of J0034-0721

Avinash Deshpande and collaborators have observed single pulses PSR J0034-0721 (B0031-07) simultaneously at the MWA (185 MHz) and the Gaint Meterwave radio Telescope (GMRT) (610 MHz). Correlation analyses revealed that the phase difference of the average profiles at the two frequencies differs from the phase difference observed between individual sub-pulses, indicating that the individual emission columns above the pulsar's rotating carousel of sparks do evolve in frequency in the same way that the global magnetosphere does, hinting at a possible departure from the dipolar field geometry in this pulsar's emission region. Moreover, the discrepancy depends on the drift mode, suggestive of a way to constrain the emission heights associated with each drift mode.
[S. J. McSweeney (Curtin University, Australia), N. D. R. Bhat (Curtin University, Australia), S. E. Tremblay (Curtin University, Australia) and Avinash Deshpande]

Continuing projects that use Gauribidanur radio telescope and Ooty radio telescope

Targeted observations to search for pulsars and fast transients are continued at 34.5 MHz, using the Gauribidanur Radio Telescope. Following simulation of Lunar Occultation and estimation of dynamic spectral signature, actual lunar occultation observations were carried on a few sources using the Ooty Radio Telescope, and the data are being processed.
[H. A. Ashwathappa, Jigisha Patel, P. K. Manoharan (Tata Institute of Fundamental Research) and Avinash Deshpande]

Diffuse matter in galaxies

The initial mass function is an idea relevant for star formation and galaxy evolution. It describes the number distribution of stars with mass in a star formation event and is found to be a power-law. This stellar mass spectrum is likely to be determined by two processes: (a) turbulence, and (b) metallicity. Turbulence in hydrogen clouds is expected to set up the basic density fluctuation spectrum. Some of the high density regions may collapse into stars. Thus the fluctuation spectrum of turbulence is expected to lead to an universal IMF. Large scale turbulence may depend on the dynamical state of the galaxy indicated by the number of its spiral arms. Metallicity influences cooling, which is another key process in star formation. More the stars, more the metals (heavier than helium) and faster the cooling of the gas clumps. This is expected to reduce the fragmentation mass scales and steepen the IMF. This steepening hypothesis can be tested if the IMF slope in different galaxies with different metallicities is measured. While metallicities of late type galaxies are measured in optical band via the nebular lines, there exist no direct measures of IMF slopes for late type galaxies currently.
Thus motivated, Chandrasekhar Murugesan, Geethu Paulose and Ramesh Balasubramanyam have evolved proxy measures for bulk gas-phase metallicity which correlates well with measured (O/H) metallicities for late type galaxies. They tested the IMF slope proxy against the measured metallicities to find a negative correlation. Further, they also found good negative correlation between their metallicity proxies versus IMF proxy. The reasonably strong and tight correlation between the proxies indicates that metallicity is indeed a key driver of IMF slope in late type galaxies. The metallicity proxy relation can be inverted to estimate SHI and SCO for galaxies with measured metallicity and NIR flukes. This would be especially useful for intermediate redshift galaxies where direct measurements are time consuming. The manuscript reporting this work has been submitted to the MNRAS.

Given these new tracers, it would be interesting to study how they change among galaxies showing different dynamical states as reflected by the number of arms or their rotational speeds reflecting their dark-matter mass. A set of galaxies from the Galaxy zoo catalogue has been selected and relevant data collected from literature. Similarly, relevant data is being collected for a set of edge-on galaxies from literature. At the moment, it appears challenging to get a statistically significant set with relevant data in these categories.
[Chandrasekhar Murugesan, Geethu Paulose and Ramesh Balasubramanyam]

X-ray Astronomy

Compact X-ray binaries are composed of a compact object, a neutron star or a black hole and a companion 'normal' star. The intense gravitation field of the neutron star causes matter from the companion star to accrete onto the neutron star, producing X-rays. X-ray astronomy is a powerful tool to study such objects. A plethora of information about system parameters and dynamics like orbital period and radius evolution of X-ray binaries, structural evolution of the accretion disk and its time scales, and structure in the stellar winds can be obtained by a careful analysis of the X-ray output from compact X-ray binaries. A brief overview of various aspects of compact X-ray sources investigated by RRI astronomers during 2017-18 is given below.

Investigation of various aspects of compact X-ray sources

A co-variability study of X-ray and optical orbital modulation of EXO 0748-676 using XMM-Newton

Gayathri Raman and Biswajit Paul have carried out a multi-wavelength timing study of the eclipsing low mass X-ray binary EXO 0748-676 (UY Vol) using XMM-Newton when the source was in a hard spectral state. The orbital optical and X-ray light curves showed large intensity modulations in observations of 36 complete binary orbits of EXO 0748-676. While assessing the non-burst variability, simultaneously in the optical and X-ray light curves, they found that they are not correlated at reprocessing or orbital time-scales, but are weakly correlated at a few 1000s of seconds time-scales. Although a large fraction of the optical emission is likely

to be due to reprocessing, the lack of significant correlation and presence of large variability in the orbital X-ray and optical light curves is probably due to structures and structural changes in the accretion disk that produce, and sometimes mask the reprocessed signal in varying amounts. These disk structures could be induced, at least partly, by irradiation. From the observed modulations seen in the optical light curves, strong evidence of accretion disk evolution at time scales of a few hours was found.
[Gayathri Raman and Biswajit Paul]

Post-flare formation of the accretion stream and a dip in pulse profiles of LMC X-4

During the past year, Biswajit Paul and collaborator Aru Beri carried out a pulse profile evolution study of an accreting X-ray pulsar LMC X-4 during and after the large X-ray flares using data from the two observatories XMM-Newton and RXTE. During the flares, the pulse profiles were found to have a significant phase offset in the range of 0.2-0.5 compared to the pulse profiles immediately before or after the flare. Investigating the pulse profiles for about 10^5 s after the flares, it was found that it takes about 2000-4000 s for the modified accretion column to return to its normal structure and formation of an accretion stream that causes a dip in the pulse profile of LMC X-4. They also carried out a pulse phase resolved spectroscopy of LMC X-4 in narrow phase bins using data from EPIC-pn and spectroscopically confirmed the pulsating nature of the soft spectral component, having a pulse fraction and phase different from that of the power-law component.
[Aru Beri (University of Southampton, UK) and Biswajit Paul]

Supergiant fast X-ray transients versus classical supergiant high mass X-ray binaries: Does the difference lie in the companion wind?

Biswajit Paul and collaborators Pragati Pradhan and Enrico Bozzo have carried out a comparative study of stellar winds in classical supergiant high mass X-ray binaries (SgXBs) and supergiant fast X-ray transients (SFXTs) by analysing publicly available out-of-eclipse observations performed with Suzaku and XMM-Newton. They found that classical SgXBs are characterized by a systematically higher absorption and luminosity compared to the SFXTs, confirming the results of previous works in the literature. Additionally, they showed that the equivalent width of the fluorescence Kα iron line in the classical SgXBs is significantly larger than that of the SFXTs (outside X-ray eclipses). They conclude that the most likely explanation of these differences is ascribed to the presence of mechanisms inhibiting accretion most of the time in SFXTs, thereby leading to a much less efficient photoionization of the stellar wind compared to classical SgXBs. They also did not find evidence for the previously reported anticorrelation between the equivalent width of the fluorescence iron line and the luminosity of SgXBs.
[Pragati Pradhan (Penn State University, USA), Enrico Bozzo (University of Geneva, Switzerland) and Biswajit Paul]

Thermonuclear X-ray burst of MXB 1658-298 with NuSTAR

MXB 1658-298 is a transient Low-Mass X-ray Binary (LMXB), which shows eclipses, dips and bursts in its light curve. This source has undergone three active periods separated by long quiescent phases. The latest phase of enhanced X-ray emission was observed during 2015-2016. Biswajit Paul and collaborators have analysed broadband data from Swift/XRT and NuSTAR observations carried out in 2015. During NuSTAR observation, one thermonuclear X-ray burst took place. The X-ray emission during the burst was brighter by a factor of ~200, compared to the pre-burst emission. They carried out spectral analysis of MXB 1658-298 during the persistent and the burst phases using NuSTAR observation of 2015. They have also determined the temperature and radius evolution during the burst using the time-resolved spectroscopy. The burst phase showed mild Photospheric Radius Expansion (PRE).
[Rahul Sharma (Delhi University), Abdul Jaleel (Delhi University), Chetana Jain (Delhi University), Anjan Dutta (Delhi University) and Biswajit Paul]

Observation of variable pre-eclipse dips and disk winds in the eclipsing LMXB XTE J1710-281

Gayathri Raman, Biswajit Paul and collaborator Chandreyee Maitra have reported the first detection of highly ionized Fe species in the X-ray spectrum of an eclipsing and dipping Low Mass X-ray Binary XTE J1710-281. Using archival Chandra and Suzaku observations, they carried out a spectro-timing analysis of the source during three different epochs. They compared the average orbital profile and obtained differences in pre-eclipse dip morphologies between different observation epochs. They observed an orbit to orbit evolution of the dips for the first time in this source in both the Chandra observations, reflecting changes in the structure of the accretion disc in timescales of hours. They further performed intensity resolved spectroscopy for both the Chandra and the Suzaku data to characterize the changes in the spectral parameters from the persistent to the dipping intervals and found that the absorbers responsible for the dips, can be best described using a partially ionized partial covering absorber, with an ionization parameter, log(ξ) of ~2. The photon index of the source remained at ~2 during both the Chandra and the Suzaku observations. In the 0.6-9 keV Suzaku spectra, they detected a broad 0.72 keV Fe L-alpha emission line complex and two narrow absorption lines at ~6.60 keV and ~7.01 keV. The highly ionized Fe line signature, being an indicator of accretion disc-winds, has been observed for the first time in XTE J1710-281.
[Gayathri Raman, Biswajit Paul and Chandreyee Maitra (MPE, Garching)]

SUZAKU observation of the eclipsing high mass X-ray binary pulsar XTE J1855-026

Jincy Devasia and Biswajit Paul carried out study of an eclipsing supergiant high mass X-ray binary pulsar XTE J1855-026 observed

with the X-ray Imaging Spectrometer (XIS) on-board Suzaku Observatory. The time averaged energy spectrum of XTE J1855-026 in the 1.0-10.5 keV energy range was well fitted with a partial covering power law model modified with interstellar absorption along with a black-body component for soft excess and a gaussian for iron fluorescence line emision. The hardness ratio evolution during this observation indicated significant absorption of soft X-rays in some segments of the observation. For better understanding of the reason behind this, they performed time-resolved spectroscopy in the 2.5-10.5 keV energy band, which revealed significant variations in the spectral parameters, especially the hydrogen column density and iron line equivalent width with flux. The correlated variations in the spectral parameters was indicative of the presence of clumps in the stellar wind of the companion star accounting for the absorption of low energy X-rays in some time segments.
[Jincy Devasia, Biswajit Paul]

Neutron Stars in X-ray Binaries and their Environments

Neutron stars are fascinating objects and are cosmic laboratories to investigate some extremes of the physical universe like high density nuclear matter, extremely high magnetic field strength, different manifestations of strong gravity etc. Neutron stars in X-ray binary systems are fascinating objects that display a wide range of timing and spectral phenomena in the X-rays. Not only parameters of the neutron stars, like magnetic field strength and spin period evolve in their active binary phase, the neutron stars also affect the binary systems and their immediate surroundings in many ways.

Biswajit Paul, in a recent review article, has discussed some aspects of the interactions of neutron stars with their environments that are revealed from their X-ray emission. Additionally, recent developments involving the process of accretion onto high magnetic field neutron stars: accretion stream structure and formation, shape of pulse profile and its changes with accretion torque as well as various recent studies of reprocessing of X-rays in the accretion disk surface, vertical structures of the accretion disk and wind of companion star were discussed in the article.

The review further discusses X-ray pulsars which are excellent sources for accurate measurements of the orbital parameters and thus also evolution of the binary orbits that take place over time scale of a fraction of a million years to tens of millions of years. The orbital period evolution of X-ray binaries have shown them to be rather complex systems. The review discusses orbital evolution of X-ray binaries that have been gleaned from timing of the X-ray eclipses and highlights some surprising results, including orbital period glitches in two X-ray binaries and possible detection of the most massive circumbinary planet around a Low Mass X-ray Binary.
[Biswajit Paul]

ASTROSAT observations

During the past year, Varun, Jincy Devasia, Biswajit Paul, along with collaborators Chandreyee Maitra and Pragati Pradhan have analysed ASTROSAT-LAXPC data from many observations of various kinds of sources like: i) GRO J1008-57, to study its broad band characteristics during a transient outburst, ii) SXP 15.3, a transient X-ray pulsar in the SMC during an outburst to study its cyclotron line, iii) 4U 1538-52 and 4U 1907+09 for a detailed study of the cyclotron line.
[Varun, Chandreyee Maitra (MPE, Garching), Pragati Pradhan (Penn State University, USA), Jincy Devasia and Biswajit Paul]

Experimental Astronomy

Apart from carrying out observational astronomy with facilities, RRI astronomers do in fact built specialized telescopes designed to "see" in different frequency bands of radiation with focus on specific unsolved problems. The unrelenting quest for pushing the frontiers of knowledge about the observable universe and the need to see hitherto hidden regions of space has fuelled the need for better, efficient and sensitive telescopes and associated receivers and algorithms. AA research at RRI over the past year has focused on both these aspects and RRI astronomers and engineers have been involved in designing and constructing Radio and X-ray telescopes both nationally and internationally: the X-Ray polarimeter payload called POLIX, poised to be the first dedicated X-ray polarimeter mission in space, a precision radiometer called SARAS operating in the 40-230 MHz radio band dedicated to detecting spectral distortions in the cosmic radio background, an Efficient Linear Array Imager, a Supernova Search Engine, both operating at Radio wavelengths, and the Sky Watch Array Network (SWAN) that primarily aims at exploring the transient radio sky. Additionally, this aspect of astronomy research at RRI includes new methods and modelling aimed at extracting the signal of interest from confusing foregrounds and backgrounds.

Development of the Qualification Model of the Thomson X-ray polarimeter POLIX

X-ray polarimetry is an unexplored area in high energy astrophysics. X-ray polarization measurements can give valuable insights about (i) the strength and the distribution of magnetic field in the sources (ii) geometric anisotropies in the sources(iii) their alignment with respect to the line of sight (iv) the nature of the accelerator responsible for energizing the electrons taking part in radiation and scattering. During the past few years, RRI has been designing and building an Indian X- ray polarimeter (POLIX), as a payload for a dedicated small satellite mission of ISRO called XPoSat. During 2017-18 this project saw significant progress. An MOU between RRI and ISRO for POLIX on board XPoSat was signed in September 2017 and funding has been received for fabrication of the Qualification Model (QM) of POLIX. In collaboration with the XPoSat project office, most of the interfaces between the payload and the satellite have been defined. In addition, during the past year the following developments have taken place at RRI towards the QM of POLIX:

- POLIX design report has been prepared and Preliminary Design Review (PDR) of POLIX was conducted successfully in ISRO in December 2017.
- Finite element model and finite element analysis of POLIX payload

have been carried out.

- Several action items from the payload PDR have been completed.
- An X-ray beam-line for calibration of the collimator has been installed and tested.
- Collimator calibration has been initiated.
- Significant progress made in design of the payload telecommand-telemetry electronics.
- Significant progress made in identifying and procurement of components for flight electronics of POLIX.
- Several wire frames have been fabricated for the Flight Model (FM) and wiring work for remaining units is ongoing.
- Environmental (thermal and vacuum) tests have been carried out on one high voltage unit.
- A space qualified electronics housing has been fabricated.
- Design and development of a ground checkout system is in progress.
- Software development for POLIX data reduction and analysis has been initiated.

Most promising targets for POLIX are the accreting, high magnetic field neutron stars called X-ray pulsars. POLIX is poised to be the first dedicated X-ray polarimetry mission in the world and open a new window in high energy astrophysics by measuring X-ray polarisation in about 50 bright X-ray sources, ahead of the NASA and ESA space mission proposals for launching X-ray polarimeters.
[P. V. Rishin, M. R. Golapakrishna, Mohamed Ibrahim, Abhilash Kulkarni, Pooja Verma, G. Rajagopala, Aditya Murumkar, S. Dhilip, Vikram Rana, Nandini Sreeanand, T. S. Mamatha, P. Sandhya, H. N. Nagaraja, Varun, Biswajit Paul and many members of Mechanical Engineering Services at RRI]

Development and characterization of CdZnTe (CZT) detectors and X-ray Optics for high sensitivity hard X-ray applications in Astronomy

Vikram Rana has initiated experimental activities for fabrication of X-ray concentrators/Optics. This part of the research requires a dedicated clean room facility of 10,000 class, for which space has been allocated and the process of establishing a clean room facility for X-ray optics work has commenced. Vikram Rana and Biswajit Paul have submitted two proposals to ISRO to support future X-ray instrument development beyond POLIX, which would be aimed at the next X-ray astronomy mission beyond ASTROSAT and POLIX, and where RRI could play a key role.
[Vikram Rana and Biswajit Paul]

SARAS: Precision measurements of spectral distortions in the radio background at long wavelengths aimed at detecting signals from cosmic dawn and the epoch of reionization.

The gas in the expanding universe cooled to form neutral atoms of hydrogen and helium by about cosmic time of 400,000 years and the universe entered the "Dark Ages". First Light emerged at "Cosmic Dawn" when the First Stars formed and the Lyman-α, UV and X-rays from the ultrafaint galaxies transformed the thermal state of the gas, ultimately reionizing the neutral gas. A key probe of the timing and physics of the formation of first stars in the universe and the transformation of the universe from neutral gas to one with galaxies surrounded by an ionized intergalactic medium is the evolution of the hyperfine level populations and ionization state of hydrogen. This is observationally detectable in redshifted 21-cm from those cosmic times. The range of allowed parameters for the timing and physics predicts a range of 21-cm distortions in the spectrum of the cosmic radio background, which redshift to the frequency range 40-250 MHz.

The "Distortion" laboratory at RRI has built precision radiometers that may be deployed in remote radio-quiet sites to detect such redshifted 21-cm distortions from cosmic dawn and reionization. During 2017-18 the radiometer SARAS 2 was deployed in a radio quiet site at Timbaktu Collective in Andhra Pradesh, Southern India. SARAS has been the first radiometer to yield significant constraints on about 10% of currently allowed models, requiring a minimum X-ray emissivity in the first stars and ruling out models with rapid reionization. These first results were published in Singh, Subrahmanyan, Udaya Shankar et al. 2017, The Astrophysical Journal Letters, vol. 845, Issue 2, article id. L12, and in Singh, Subrahmanyan, Udaya Shankar et al. 2018, The Astrophysical Journal, vol. 858, Issue 1, article id. 54.

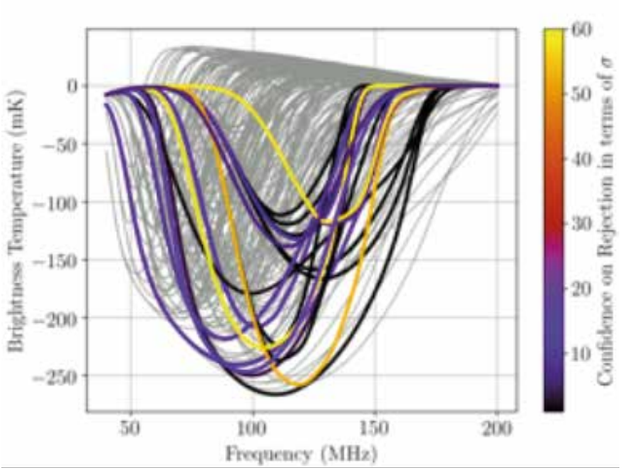


Figure. 3. The atlas of predicted 21-cm profiles are shown; these are plausible profiles, given constraints on cosmic dawn and reionization based on observations of galaxies and quasars at the highest redshifts and also the properties of the cosmic microwave background anisotropies. The highlighted profiles (in colour) are the family of profiles ruled out with high significance by SARAS 2 data.

Following the success with SARAS 2, the radiometer is being improved with better electronics, antennas and signal transport systems to be deployed during 2018-19 at the Indian Astronomical Observatory, Hanle, Ladakh, which is operated by the Indian Institute of Astrophysics (IIA).
[Saurabh Singh, Jishnu Nambissan, Mayuri S, Ravi Subrahmanyan, N Udaya Shankar, B S Girish, A Raghunathan, R Somashekar & K S Srivani]

An Efficient Linear-array Imager prototype for molecular astronomy

Imaging surveys covering large sky areas are important to advance astronomy. The 35 MHz continuum survey with the T-array at Gauribidanur was carried out by RRI decades ago. Recently, efforts are being made at the Gauribidanur field-station to build a cm-wave imaging telescope. This is a prototype of the new optics scheme proposed some years ago: ''An Efficient Linear-array Imager (ELI) for radio astronomy'', 2014, MNRAS, v.444 p.2212, which promises ease and economy of manufacturing.

In this novel optics scheme, given a certain number of receivers, one can image the sky for the same time, resolution and sensitivity with lesser reflector area than a corresponding single dish. Moreover, the smaller reflector area is shaped as parabolic cylinders, easy and economical to manufacture. The area reduction arises as follows: in a conventional paraboloidal telescope, say with 16 receivers, one can instantaneously observe over 16 circular beams on the sky. In the new optics scheme, the receivers make highly elliptical beams, which are arranged equally as adjacent rows and columns, as in a matrix. Then, by cross-correlating the outputs of the row receivers with the column receivers, one can obtain 64 pencil beams, corresponding to the cells of the matrix. The very process of making the beams elliptical reduces the reflector area to 70%!

Last year, Pavan M. S., Sandeep H., Charles Paul and Ramesh Balasubramanyam successfully designed and developed from scratch a light-weight and stiff backup structure for the 6.8 m x 6.8 m prototype cross telescope. The effort was primarily assisted by Swaroop Jois and Ashwini Prakash. A 1:3 scale model was built and installed at Gauribidanur in June 2017 and has been weathering for a year and is found to be strong. The below figure shows the CAD view model of the backup structure including the mirrors. The other figure is the photo of the scaled model of the backup structure under construction. The prototype backup structure weighs 225 kg for a maximum deviation of <1 mm when loaded with the primary and secondary panels, themselves weighing about 360 kg. This work was presented in IEEE Radio'17 conference in Cape Town, South Africa and the conference paper is reported in IEEE explore. The prototype construction continued in 2017-18 with design and fabrication of all the stainless steel joint parts completed using laser cutting, CNC bending and spot-welding processes in addition to requisite manual processes such as bending, boring etc. Currently, they are in the process of integrating one full side-section using the fabricated joint parts. To enable manufacturing of panels scaled versions of two special purpose machines (a) a hot-wire cutting tool to process Thermocol or PUF blocks; (b) a universal cylindrical profiler have been built.

Soon the construction of the full version will begin, to demonstrate the feasibility and utility of the concept. To demonstrate its working, a two-channel receiver is being built. Once demonstrated, the telescope will be equipped with 16 receivers and make 64 beams to undertake a spectral and continuum transit survey of the Galactic plane in the 7-11 GHz band. The ELI prototype project provides ample opportunity for many graduate students to be involved in technology development and thereby gain hands-on experience in doing high quality engineering.
[Pavan M. S., Sandeep H., Charles Paul and Ramesh Balasubramanyam]

Figure. 4. (Left) A CAD model view of the backup structure with mirrors in it. (Right) A photo of the scaled model of ELI 2.3m x 2.3m at Gauribidanur.

Supernova search engine

Massive stars explode as supernovae (SNe). In our Galaxy they are expected to happen once every 30 years on average. Such explosions produce prompt emission over the entire electromagnetic spectrum. However, the interstellar medium absorbs in most parts. Radio emission however can be seen from them even if they happen at the other end of the Galaxy. A typical SN exploding in our Galaxy at 30 kpc from us will be more than 100 Jy strong at its peak. At 11 GHz, a 120 cm dish antenna with a 150 K T_{sys} receiver for 8 min of overall integration time (time for source to transit across the beam) and 0.4 GHz bandwidth will achieve 10 Jy 3.5 σ sensitivity, adequate for this purpose. Therefore, radio search for supernovae in our Galaxy is a worthwhile goal. Lekshmi Nair and Ramesh Balasubramanyam have embarked to build and deploy a radio "Super-nova search engine (SnSE)" dedicated for this purpose. The instrument will use the scheme of One Element Interferometer (RB, 2014, MNRAS 444, 2018). This scheme cancels self-noise power and thereby enables a single dish to measure faint continuum sources.

The SnSE being constructed at RRI has four components: (a) a wavefront modulator to implement OEI; (b) 1.2m dish with a commercial low noise block converter (LNBC) operating at 12 GHz; (c) a triplexer-cum-detector module with its digitizer; (d) software to position the antenna, acquire and store data and a GUI to display essential information. During the past year the following activities were undertaken: A small prototype cam-based wavefront modulator was built, tested and found to work satisfactorily. A bigger full-scale one is yet to be fabricated and tested. Reducing vibrations induced by the cam arrangement will be important. A 60 cm satellite dish fitted with a commercial LNB has been purchased to carry out initial testing. A PCB for the detector module has been made and is being populated. The position control and a part of the acquisition software has been completed. Once the detector module is completed, receiver testing and characterisation will be undertaken, following which, OEI testing will be done. GUI to display essential information will also be developed. Once everything works well in parts and as a whole, the instrument will be commissioned at the Gauribidanur field station.

[Lekshmi Nair and Ramesh Balasubramanyam]

Sky Watch Array Network (SWAN) – Status update

The present focus in the SWAN project is active student participation in development of several observing modes in which the SWAN is proposed to be used. Interested students from various educational institutes have been engaged in developing python-based software to cater to dynamic spectral correlation analysis, RFI detection and excision, estimation of visibilities, delay estimation and correction, detection of dispersed pulsed signals, synchronization of time sequences from different recording pipelines, etc. Almost daily interaction (via telecons) with the student groups to discuss the analysis issues and methods is helping to make progress in this development on desired time-scales. Students have also made new test observations via remote access to the system.

The SWAN data on a few strong continuum sources are being used to test their software. Estimation of the geometric delays and comparison with their expected values, based on assumed locations of the tiles (measured GPS), shows differences growing only at the level of a few nanoseconds in an hour (Figure 5). The comparison has been used to even refine estimates of the related baseline length, and thus the locations of the tiles.

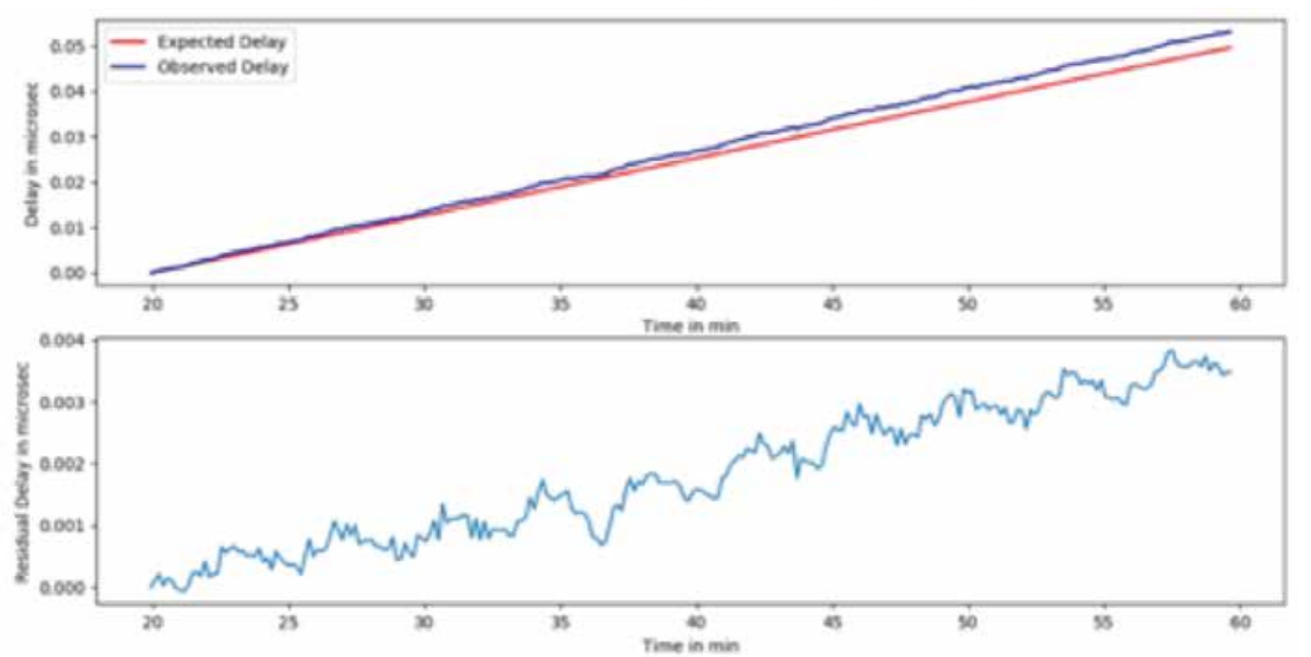


Figure. 5. Plot showing differences between observed and expected delay increasing at a level of a few nanoseconds in an hour.

As for the development on the hardware front, the different station hardware (originally housed together) has now been separated, and rearranged in sub-racks in their respective miniracks (Figure 6). Equipped with their separate power-supplies for respective tiles, along with independent beam controls, the re-wired units for the different station are now ready for future relocation to different institutes.

Figure. 6. Hardware units, rewired and ready for future relocation to different Institutes

Development of Broad-band Receiver System for SWAN:
A broad-band receiver system is being developed to operate in the frequency range 50MHz – 400MHz, and consists of low noise amplifiers, high-gain amplifier modules, a set of shaping filters and a digital receiver system. Evaluation of this system, capable of simultaneously catering to eight input signals (each of width 175 MHz), is in progress.
[Vinutha Chandrashekar, K. B. Raghavendra Rao, Rahul Kinger, H. A. Aswathappa, P. S. Sasikumar, T. S. Mamatha, Bhawana Bansal (IIT, Kharagpur), Harsh Grover (BITS, Pilani), H. N. Nagaraja, Sandhya, Indrajit Barve (IIA, Bangalore) and Avinash A. Deshpande]

Algorithms & Signal Processing

Research effort is also focused on developing methods and algorithms that would detect the required signal from background or place useful constraints on the parameter space of theoretical models.

Detecting Circular Patterns in Images

Understanding patterns and devising effective methods of their detection has been a theme of numerous scientific investigations, across various fields of research. Although there has been a push towards developing automated detection methods, prompted by large data volumes, given the diversity in parameters characterizing a given pattern, as well as the need to cater to partial delineation of the shapes to be searched, the existing methods are significantly expensive in terms of required computing power and hardware. The need, therefore, for efficient methods which can handle large data volumes without increasing the computational time to facilitate detection in real time applications cannot be overstated.

Focusing initially on circular feature detection, Avinash Deshpande along with collaborators Pratik Kumar and Joy Mitra have proposed a fast algorithm based on the Hough transform (noting its flexibility to incorporate other geometric shapes) to overcome the short-comings of the available approaches, providing a superior computational performance, and thus making it more attractive for real-time applications. Thier basic algorithm is readily applicable to other shapes as well.
[Pratik Kumar (IISER, Trivandrum), Joy Mitra (IISER, Trivandrum) and Avinash Deshpande]

Scintillation-based search for off-pulse radio emission from pulsars

Kumar Ravi and Avinash Deshpande have proposed a new method to detect off-pulse (unpulsed and/or continuous) emission from pulsars, using the intensity modulations associated with interstellar scintillation. The technique involves obtaining the dynamic spectra, separately for on-pulse window and off-pulse region, with time and frequency resolutions to properly sample the intensity variations due to diffractive scintillation, and then estimating their mutual correlation as a measure of off-pulse emission, if any. They describe and illustrate the essential details of this technique with the help of simulations, as well as real data. They also discuss advantages of this method over earlier approaches to detect off-pulse emission. In particular, they point out how certain non-idealities inherent to measurement set-ups could potentially affect estimations in earlier approaches, and argue that the present technique is immune to such non-idealities. They verify both of the above situations with relevant simulations.

They applied this method to observation of PSR B0329+54 at frequencies 730 and 810 MHz, made with the Green Bank Telescope and present upper limits for the off-pulse intensity at the two frequencies. They expect this technique to pave way for extensive investigations of off-pulse emission with the help of even existing dynamic spectral data on pulsars and of course with more sensitive long-duration data from new observations.
[Kumar Ravi and Avinash Deshpande]

A Minimal Space Interferometric Configuration for Low Frequency Radio Observations

Avinash Deshpande and Akhil Jaini explored a novel space interferometer system consisting of minimal number of satellites in Low Earth Orbits (LEO), and have examined the spatial frequency coverage it would provide. Such a system of three satellites in specific orbits would enable them to image the radio sky at frequencies under 10 MHz, which is not possible with earth-based telescopes due to ionospheric cut-off. This system would provide interferometer

baselines extending to diameter of the Earth, facilitating imaging with high angular resolution.
[Akhil Jaini (BITS, Pilani) and Avinash Deshpande]

Dipole Anisotropy induced diurnal pattern in the apparent spectrum of the Monopole Component of the Cosmic-Dawn: A critical test

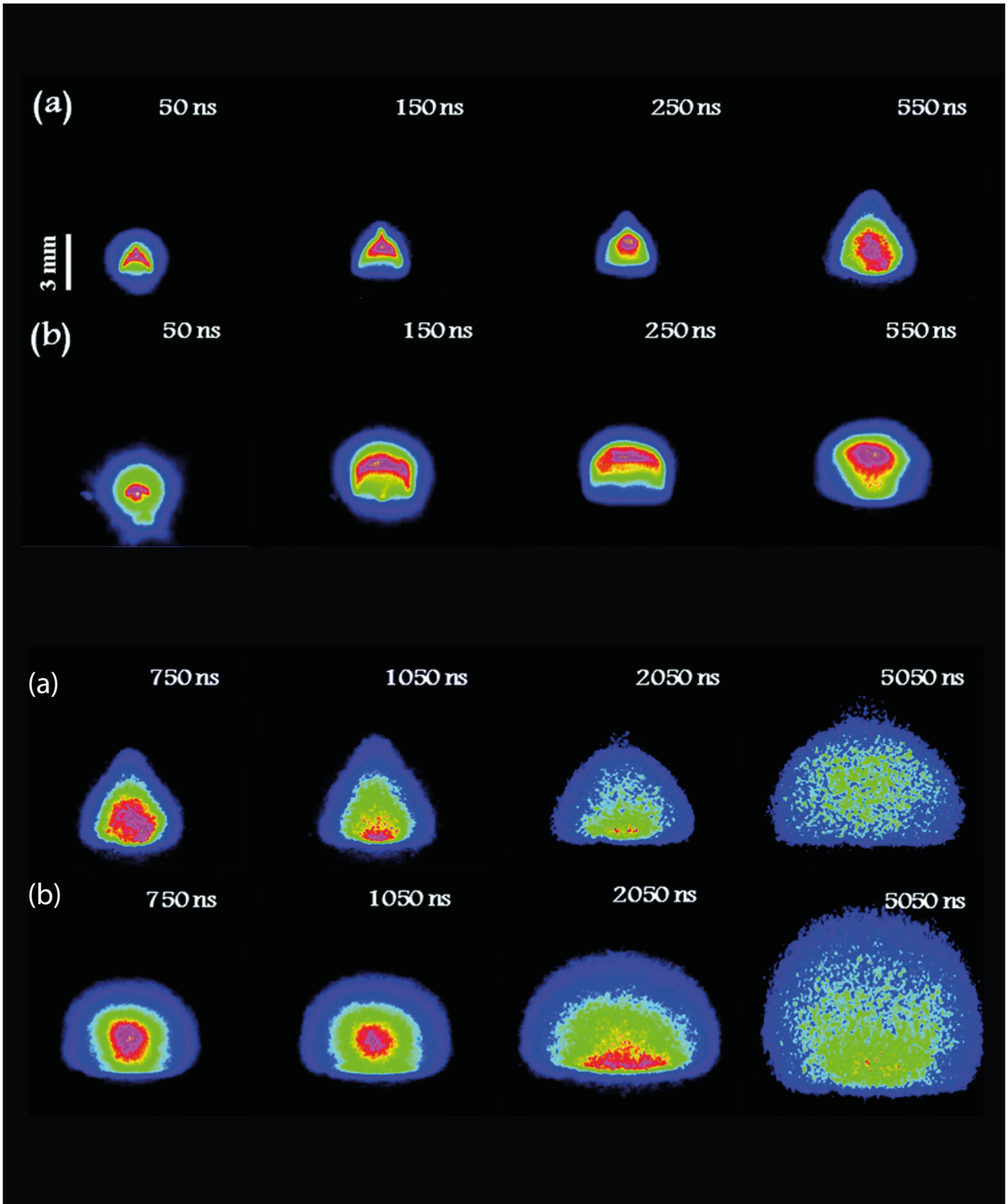
Avinash Deshpande has investigated an interesting manifestation of dipole anisotropy (of origin similar to that observed in the CMBR) in terms of a diurnal pattern in the apparent spectral signature of the Monopole component of HI line signal associated with the Cosmic Dawn. He has shown that the spectral manifestation of the dipole anisotropy gets amplified by a significant factor, depending on the monopole spectral slopes, rendering it feasible to measure. He has proposed a critical test, based on the above correspondence, for in situ validation of spectral signatures from early epochs, relevant to presently reported and future detections of EoR signal.
[Avinash Deshpande]

Analysis of MWA drift scan data

Akash Patwa, K.S. Dwarakanath and Shiv Sethi in collaboration with the International MWA team continued their work on the analysis of MWA Phase I and Phase II drift scan data. The main aim is to develop novel methods to extract the EoR power spectrum. During the past year, they have investigated the noise properties of the data, shown how foreground wedge weakens for a drift scan, an isolated extended source can essentially be removed from the data in such a scan, computed weights appropriate for a drift scan from the expected HI signal, estimated the two- dimensional power spectrum from the data using these weights, and are currently finishing work on determining the one-dimensional power spectrum.
[Akash Patwa, K. S. Dwarakanath, Shiv Sethi and International MWA team]

Baseline migration at two levels: intra-channel and inter-channel

The migration of interferometric baselines with frequency causes a flat spectrum source, that should have remained in the zeroeth delay (line-of-sight) mode, to appear to have power in higher modes. This is in addition to the smearing/spill-over of all modes, including the zeroth, of the order of reciprocal bandwidth due to finite band- width truncation. Magendran Sambasivam has approached the baseline migration and its mode-mixing effects at two levels: within a DFT spectral channel/bin and between the channels. Intra- channel effects occur since the finite-duration nature of DFT allows for contribution from frequencies adjacent to the channel being evaluated, resulting in a micro-level of baseline migration even in the absence of inter-channel migration. He has shown that if the DFT resolution becomes worse than a primary critical limit, the delay mode starts to smear beyond the reciprocal bandwidth order in a manner that increases with baseline and approaches infinity as it is further worsened towards a secondary critical limit. These limits relate the channel resolution to the ratio of maximum to minimum antenna separations and the maximum frequency. Inter-channel migration, on the other hand, would be completely eliminated if the gridding process could provide an accurate interpolation on a uniform grid of baselines and pixels, global to all frequencies. But inaccuracies are inevitable due to finiteness/quantization in visibility coverage - both in the number of samples and the sample spacing. These result in post-gridding residual ripples over frequency for a fixed baseline/pixel. To mitigate such line-of-sight oscillations due to inter-channel migration in redshifted cosmological signals, he has considered a per-pixel ripple suppression technique in the image domain, when the complex-envelope of any pixel's auto-correlation is expected to be monotonically decreasing and free of spurs at non-zero delays due to gradualness in redshift evolution.
[Magendran Sambasivam]



Research: Knowledge Creation

Light and Matter Physics

Light and Matter Physics

Overview

Light and matter interaction is at the heart of how scientists learn about the physical properties of objects ranging in size from that of the universe down to atomic scales. At the Raman Research Institute members of the Light And Matter Physics (LAMP) group are engaged in research on fundamental properties of electromagnetic (EM) waves and on the nature of interaction of EM waves with gaseous neutral atoms, ions, ultra-cold and exotic states of matter. The underlying theme of these studies is to unravel fundamental processes which will qualitatively improve our understanding of the studied phenomena and provide new guiding principles. The knowledge thus gained will help in utilization of these principles both at the fundamental and at the applied level.

Focus 2017-18

Ultra-cold Atoms Research

One major area of research in the LAMP group involves the cooling and trapping of atoms, ions and molecules in order to study interactions at low temperatures.

Quantum Simulation of Condensed Matter Physics using Degenerate Gases

Quantum Degenerate Mixture of Neutral Sodium and Potassium atoms

Following the impressive development of the field of "Ultra-cold atoms and Quantum gases" over the past two decades, an emerging sub-field of "Quantum simulations with ultra-cold atoms" has gained considerable importance in the past few years. The goal is to use the ultra-cold atomic system - where external parameters are easily tuneable - as a tool to simulate physics of complex physical problems such as those in condensed matter physics and gain deeper physical insights. Few such successful examples of "Quantum simulations with Ultra-cold atoms" include observation of Superfluid-Mott Insulator phase transitions, Observation of Anderson localization, BEC-BCS crossover, BKT phase transitions, etc. In the past, Saptarishi Chaudhuri has been associated with experimental investigations of disordered and interacting quantum gases and hetero-nuclear mixtures of ultra-cold Fermi gases. However, such experiments deal with "contact" interactions and a large class of phenomena involving long-range interactions cannot be reliably simulated using these set-ups. To overcome this limitation, Sagar Sutradhar, Sanjukta Roy, Maheswar Swar and Saptarishi Chaudhuri have designed and started setting up a new experiment facility at the Institute, towards creating a Sodium-Potassium gas mixture at nano-Kelvin temperature. At this very low temperature, well below the critical temperature for Bosonic species and Fermi temperature of Fermionic species, the behaviour of the trapped cloud can be completely described by quantum theory and thermal fluctuations can be ignored. Therefore, the system can be an ideal test bed for investigating purely quantum mechanical phenomena.
Moreover, their experimental facility is expected to evolve to produce quantum degenerate ground state molecules with a permanent electric dipole moment. These molecules can, in turn, be trapped in periodic potential created by interfering trapping light and the magnitude of the effective dipole moment can be manipulated using external electric fields. Therefore, effects of true long-range interactions in the quantum gas can be investigated in this experimental system.

During the past two years, careful design and implementation of the experimental facility were performed. They have built the laboratory from scratch in an existing space in the old telescope building at the Institute and completed the following tasks:
(i) Anti-static, self-levelling epoxy flooring and installation of the clean-room facility with temperature and humidity control were completed.
(ii) Three research grade optical tables were procured and installed in the facility.
(iii) The ultra-high vacuum design – one of the critical parts of the experimental facility was designed, and components were ordered from various sources. They will install the vacuum system once all the components arrive at RRI. A 3D design of the vacuum system is presented in figure 1.

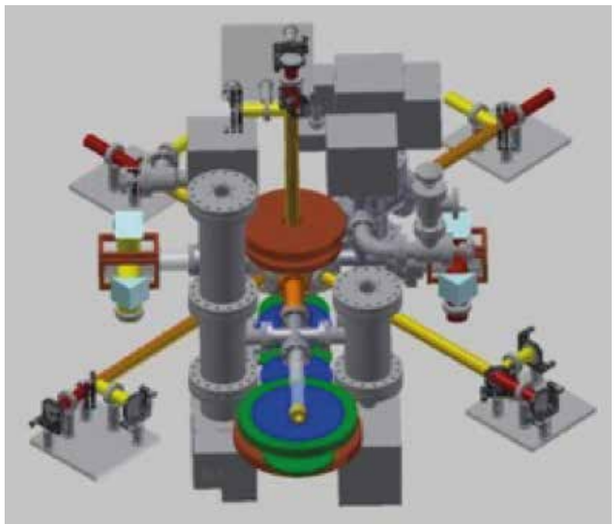


Figure 1. Vacuum design of the Sodium- Potassium Mixture Experiment

(iv) The laser systems for laser cooling and trapping of both Sodium and Potassium atoms as well as a wavelength meter with +/- 1 MHz frequency accuracy for absolute frequency calibration of the laser systems were procured and installed.
(v) Ultra-high precision atomic spectroscopy based on saturation absorption spectroscopy technique was performed for Potassium atoms and the laser, in turn, was frequency stabilized using this spectroscopy signal. Figure 2, displays a Doppler-free spectrum of Potassium atoms.

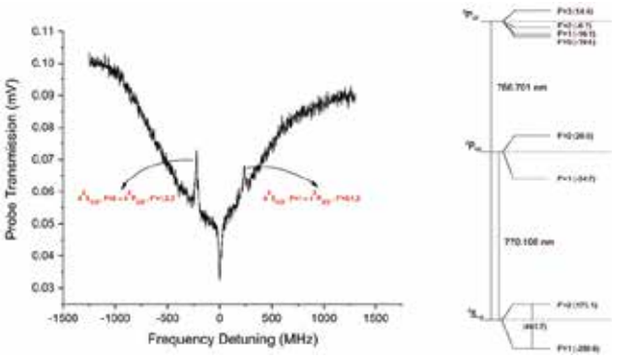


Figure 2. Doppler-free spectrum of Potassium atoms

(v) Optomechanical and Optical components required for their future experiments were carefully selected and purchase procedures were initiated. Most of the purchased optomechanical components have reached their laboratory. A significant number of the optomechanical components were designed in-house keeping in mind the improved capability of RRI workshop and some of those "home-built" optomechanics have already been tested in their laboratory. Subsequent to the arrival of critical optical components the installation of the experimental facility will be completed.

(vi) They have designed a magnetic transport scheme where ultra-cold atoms will be trapped in a quadrupole magnetic field and the field centre will be transported by varying currents in pairs of coils placed adjacent to each other (Figure 3). Numerical simulation and design of those "transport coils" were performed and some of the coils are already fabricated in the Institute's workshop as per their design. After laser cooling and trapping of the two species cloud, they will transport these cold atoms through ultra-high vacuum ports to a glass cell with very high optical access for further experimentation.

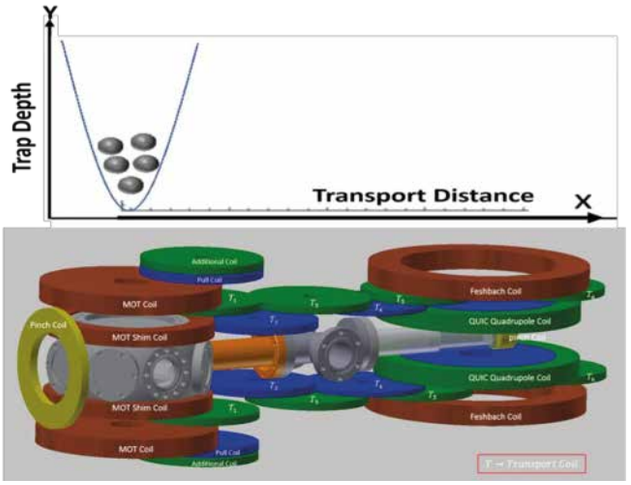


Figure. 3 . The Magnetic transport scheme of the ultra-cold neutral atoms.

(vii) A novel, IGBT and varistor based, high-current, fast switching circuit has been designed and tested which will be a critical component of the magnetic trapping transport procedures. The performance of this switching circuit was satisfactory and they were able to switch-off reasonably high magnetic fields in less than 100 microseconds.

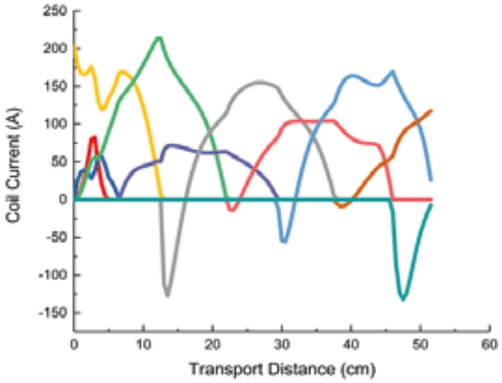


Figure 4 . Numerically simulated current profile through the transport coils for optimum transfer of ultra-cold atoms to science cell.

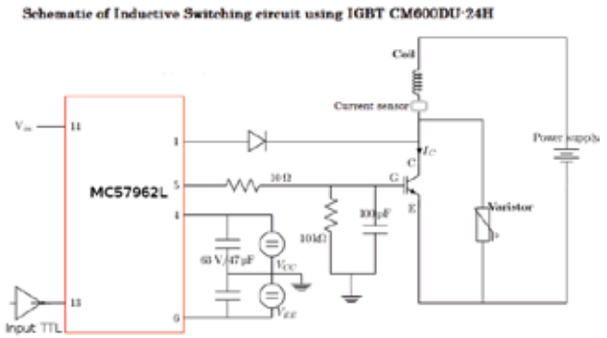


Figure 5. Fast Magnetic field switching circuit

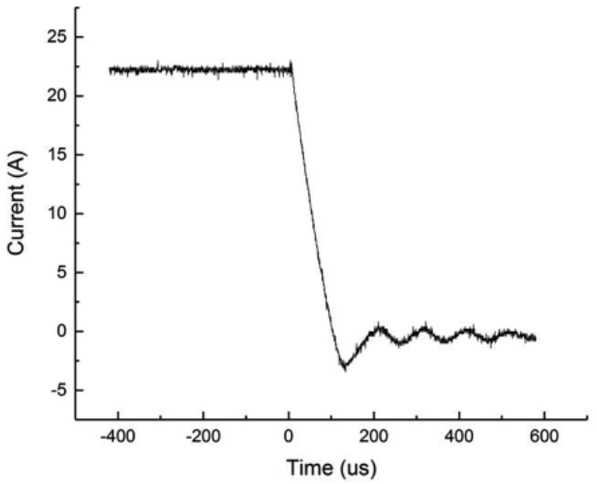


Figure 6. Fast switching of the magnetic fields

In conclusion, a major part of actual design and implementation of the quantum gas mixture experiment was completed in the above mentioned period. This laboratory is poised to conduct and report actual measurements and results in the near future.
[Sagar Sutradhar, Sanjukta Roy, Maheswar Swar and Saptarishi Chaudhuri]

Quantum Diffusion

Quest for Observation of Quantum diffusion with ultra-cold atoms

Motivation: Members of the Theoretical Physics (TP) Group, Supurna Sinha, Urbashi Satpathi along with the Institute's Adjunct Professor Rafael Sorkin had in one of their recent works analysed the diffusion law at low temperatures using the fluctuation dissipation theorem (FDT) in a physical system with viscous response-function R(t). They found several regimes of time and temperature, namely the classical, intermediate and quantum regime where the diffusion in the medium manifests qualitatively different behaviour. The striking aspect of these results is the logarithmic time-dependence of the mean-square displacement in the quantum regime, which has never been explored so far experimentally. After discussions with TP group members, Sanjukta Roy came up with an idea to observe the diffusion in the various regimes in cold atom experiments: 3D Optical molasses can provide the diffusive medium and atoms have to be cooled to various temperature range via laser cooling and evaporative cooling for investigating the diffusion in the various time and temperature regimes.

Progress:
The measurement of low temperature diffusion in the classical regime was done in the single atom experiment and the observation agrees very well with the theoretical predictions and gives an accurate value of the Diffusion constant.

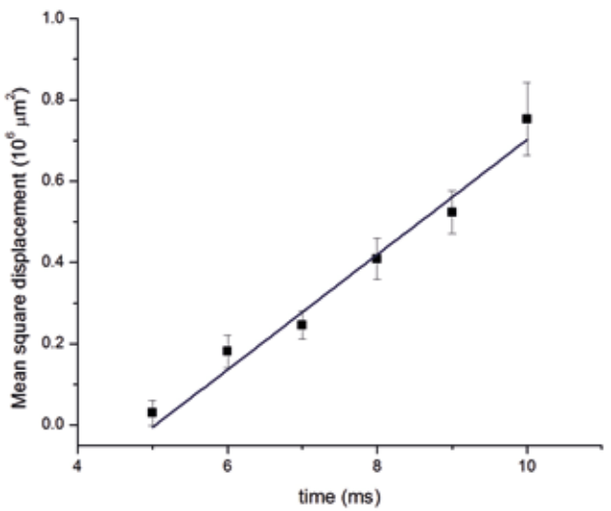


Figure 7. Low temperature diffusion in a 3D optical molasses in the classical regime

The temperature of around 10 μK required for exploring the intermediate regime has already been achieved in the BEC experiment via Sub-Doppler cooling. Sanjukta Roy along with Hema Ramachandran and Saptarishi Chaudhuri are in the process of measuring the diffusion in this regime.

Future direction: To explore the quantum regime, temperatures around 10-100 nK are required which can be achieved via evaporative cooling in a conservative trap like a magnetic trap or an optical dipole trap. For this purpose, they will be installing a magnetic trap in the experiment where the cold atoms will be loaded after sub-Doppler cooling and spin-polarisation. Thereafter, an RF evaporative cooling will be done to cool down the temperature of the atom cloud in the nano-Kelvin regime to explore the quantum regime of the low temperature diffusion.
[Sanjukta Roy, Hema Ramachandran, Saptarishi Chaudhuri, Supurna Sinha, Rafael Sorkin (Perimeter Institute, Canada and Adjunct Professor, RRI), Urbashi Satpathi]

Cavity QED related experiments

Lasing by driven atoms-cavity system in collective strong coupling regime

The interaction of laser cooled atoms with resonant light is determined by the natural linewidth of the excited state. An optical cavity is another optically resonant system where the loss from the cavity determines the resonant optical response of the system. The near resonant combination of an optical Fabry-Pérot cavity with laser cooled and trapped atoms couples two distinct optical resonators via light and has great potential for precision measurements and the creation of versatile quantum optics systems. Rahul Sawant and Sadiq Rangwala have shown how driven magneto-optically trapped atoms in collective strong coupling regime with the cavity leads to lasing at a frequency red detuned from the atomic transition. They experimentally demonstrate lasing via the observation of a lasing threshold accompanied by polarization and spatial mode purity, and line-narrowing in the out-coupled light. Spontaneous emission into the cavity mode by the driven atoms stimulates lasing action, which is capable of operating as a continuous wave laser in steady state, without a seed laser. They also modelled the system theoretically, and found qualitative agreement with experimentally observed lasing. Their result has opened up a range of new measurement possibilities with this system.
[Rahul Sawant and Sadiq Rangwala]

Precision Atom-Light Interaction and Spectroscopy

Demonstration of a high-contrast, phase-sensitive optical switch in a Delta system

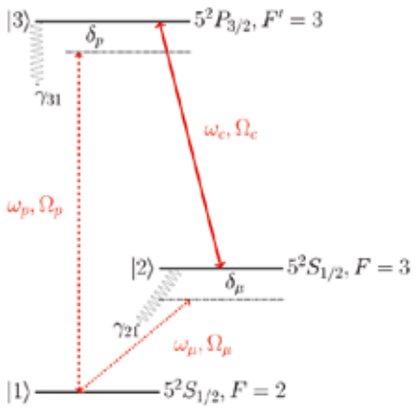


Figure. 8. Three-level atom in a Delta configuration

For the past few years, Asha Karigowda, Megha Ghosh, Ayyapan Jayaraman, Meena M. S. and Andal Narayanan, along with collaborators Barry Sanders and Fabien Bretenaker have been experimentally studying an atom-light interaction scheme which involves light fields and atomic energy states interacting with each other in a cyclic and closed fashion as shown above. Such cyclic interactions lead to phase sensitive refraction and absorption properties of the bulk atomic medium to all the interacting light fields. The phase being the relative phase of all the fields. In their system, they have two optical fields and one microwave field.

In a novel application of such an interaction present in an atomic Delta scheme shown in Figure 8, they have experimentally demonstrated a very high contrast amplitude switch in one of their optical field controlled by a change in the phase of the microwave field. The switching action in the time domain is shown in Figure 9:

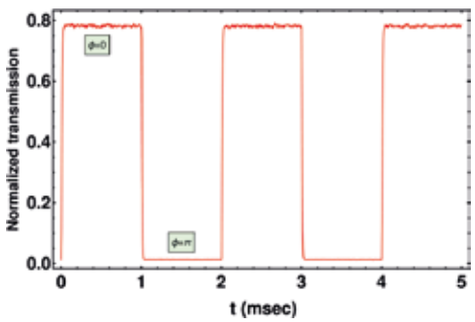


Figure 9. Intensity Switching of an optical probe in the time domain

The novelty of their switching scheme is in the following features:
(i) The switch demonstrated to function within a band-width of 1 MHz is embedded within an inhomogeneously broadened line-width of about 550 MHz arising from the random thermal motion of the atoms which are at room temperature. The central frequency of the switch can be glided over this broad line-width.

(ii) The contrast is the highest reported for such systems so far and in the off-state of the switch the light level is reduced to the ambient dark-count of the detector.

(iii) At idealized low photon light levels the switch utilises one optical photon and one microwave photon accompanied by a Pi phase change for switching a single optical photon from a bright state to a dark state.

Thus their scheme is a promising candidate for a single optical photon operated switch.
[Asha Karigowda, Megha Ghosh, Ayyappan Jayaraman, Barry Sanders (University of Calgary, Canada and Adjunct Professor, RRI) Fabien Bretenaker (Laboratoire Amie Cotton, Paris, France and Adjunct Professor, RRI), Meena M.S and Andal Narayanan]

Coherent generation of an infra-red optical field from a microwave field using three-wave mixing phenomena in an atomic Delta system

Nonlinear frequency conversion from microwave to optical frequencies has garnered a lot of attention in the past decade. This is owing to the ease of transport and detection of Giga-Hertz signals in the optical domain and the essentially noise-free nature of frequency conversion process. The later attribute has been central to proposing high-fidelity classical and quantum conversion of signals between microwave and optical frequencies. Many devices demonstrate this frequency conversion phenomenon. In atomic systems, beginning with the demonstration of lasing without inversion (LWI), a range of experiments have been performed which combine atomic coherence effects with non-linearity such as a four-wave-mixing process to coherently convert microwave signals to the optical domain maintaining the relative phase. Most of these experiments have been in the all-optical regime, demonstrating noiseless amplification and squeezing.

In a recent work, Adwaith K. V., Asha Karigowda, Charudatta Manwatkar and Andal Narayanan in collaboration with Fabien Bretenaker have experimentally demonstrated coherent generation of a near infrared optical field using a three-wave mixing process in a room temperature gaseous atomic vapor of ^{85}Rb atoms. The three-wave process combines transitions in optical and microwave frequency domains to coherently generate an infrared frequency. To the best of their knowledge, this experiment is the only system, which uses a magnetic dipole interaction between the microwave field and the atomic levels during a new-field generation process. The advantage of this system lies in the fact that it allows them to circumvent the symmetry constraint of an electric-dipole interaction and make use of the highest order non-linear response of their atomic system for the generation process. A plot (Figure 10) showing the generated infra-red optical field as a function of microwave power is shown below.

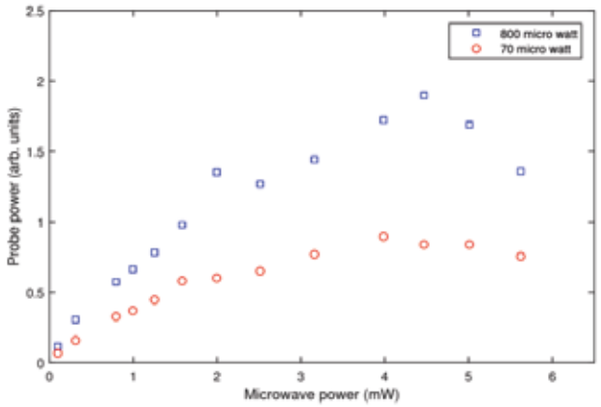


Figure 10. Generated optical probe light as a function of input microwave power

[Adwaith K. V., Asha Karigowda, Charudatta Manwatkar, Fabien Bretenaker (Laboratoire Amie Cotton, France and Adjunct Professor, RRI) and Andal Narayanan]

Demonstration of phase sensitive amplification using an atomic Delta system

Amplifiers are indispensable elements in amplifying low amplitude signals. Along with amplifying the signal the noise is also amplified in any amplifying device. Phase sensitive amplifiers show amplification, which is dependent on the quadrature in which the signal is present. They amplify signals and de-amplify noise in orthogonal quadrature thus maintaining the same signal to noise ratio both at the input and the output end of an amplifier giving a noise figure of unity in the ideal case.

The atomic Delta system being studied by Asha Karigowda, Adwaith K.V, Charudatta Manwatkar and Andal Narayanan with collaborator Fabien Bretenaker can also act as a phase sensitive amplifier. They have demonstrated phase sensitive amplification of a signal in the optical domain with the input signal in the microwave domain. The amplification (Gain- G) and de-amplification (1/G) are very similar in their numerical value for a range of microwave powers. This implies that the amplifier is operating in the ideal limit of a near-unity-noise-figure amplification.

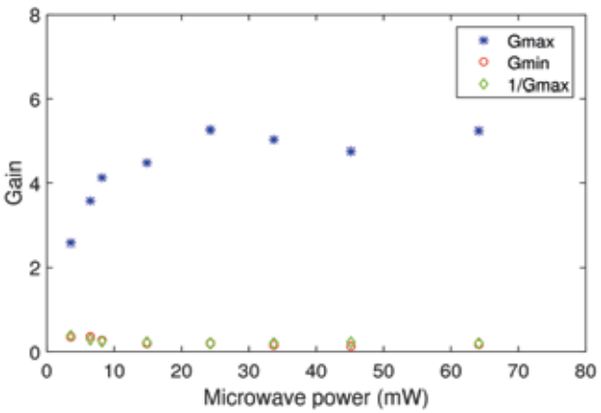


Figure 11. Gain (G) and inverse gain (1/G) as a function of microwave power

[Asha Karigowda, Adwaith K.V., Charudatta Manwatkar, Fabien Bretenaker (Laboratoire Amie Cotton, France and Adjunct Professor, RRI) and Andal Narayanan]

Spin noise spectroscopy of neutral thermal Rubidium atoms

Non-perturbative detection of true many-body states is of fundamental importance especially in condensed matter physics and quantum optics. Recently there is renewed interest in the non-perturbative measurement of ultra-cold atoms via polarization rotation measurements. However, the fluctuations in the rotation of polarization reveal further dynamic quantities relevant to the system under investigation. To develop and understand such a non-perturbative detection scheme, Maheswar Swar, Dhanalakshmi D, Sanjukta Roy, Hema Ramachandran and Saptarishi Chaudhuri with theoretical inputs from Dibyendu Roy have performed experiments on spin fluctuations in a thermal vapour investigated by the probe beam polarization fluctuation measurements. Such fluctuations in far-detuned probe laser passing through a thermal vapour in the presence of an orthogonal magnetic field reveal intrinsic spin fluctuations in the system. This technique has promising applications in many other similar systems such as ultra-cold quantum gases. During the past year, they developed a polarization sensitive precision detection technique in their laboratory and spectrum of polarization fluctuation was measured and interpreted as intrinsic spin noise from thermal atomic vapour. They have been able to detect extremely small spin-noise signal with a very high signal to noise ratio.

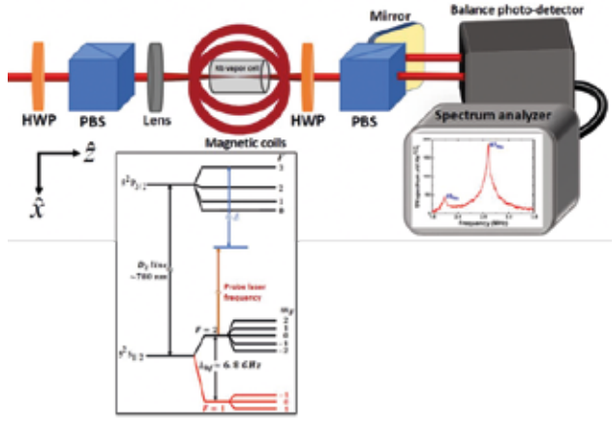


Figure 12. Experimental Set-up to detect intrinsic spin noise from thermal atomic vapor

Using this technique, they were able to measure the following:
(i) Intrinsic atomic and chemical properties such as atomic g- factor, isotope abundance etc. of the system under investigation.

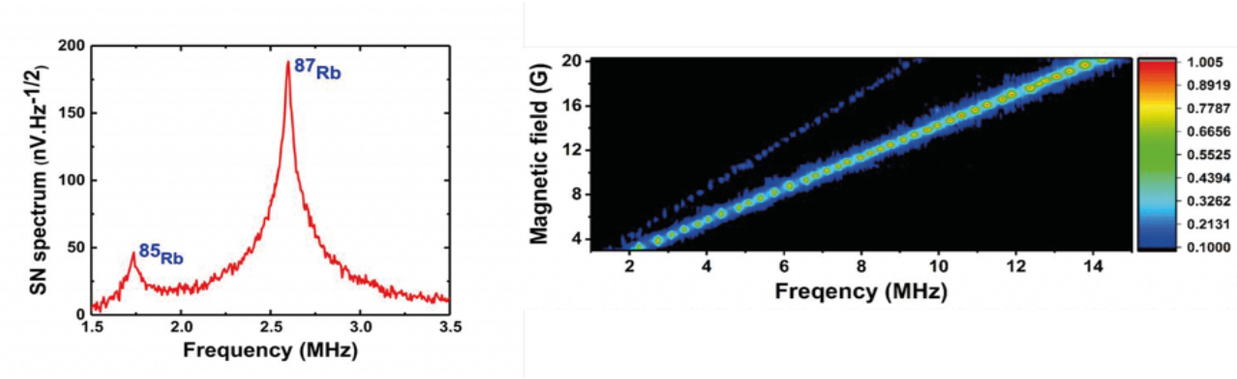


Figure 13. Measurements of atomic g-factor and detection of isotope abundance using spin-noise spectroscopy

(ii) Careful measurements and analysis, led to the detection of the nuclear g-factor as well as very high precision measurements of hyperfine constant using spin noise spectroscopy technique.

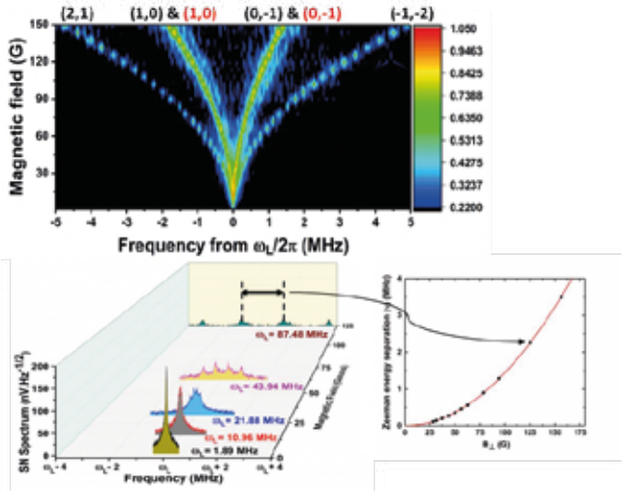


Figure 14. Observation of the energy splitting due to nuclear magnetic moment and measurement of hyperfine constant using Spin Noise Spectroscopy

(iii) They have also employed the spin noise spectroscopy technique for the first time to non-perturbative measurements of the real-time spin population of different hyperfine states by performing a pump-probe experiment. This is a very useful result since in a large number of atomic physics experiments including those related to atomic clocks, atom interferometry etc. a knowledge of the spin state population without destroying the state will lead to extreme simplification of such experiments

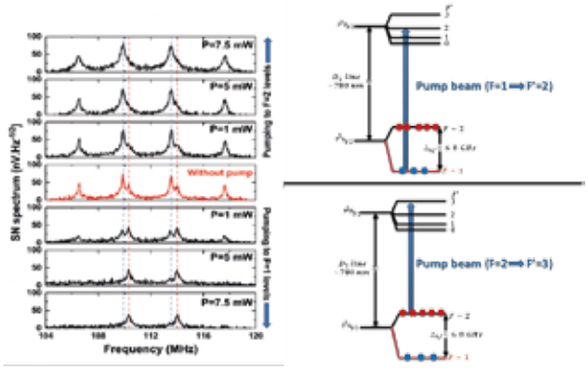


Figure 15. Non-perturbative detection of spin state populations using spin noise spectroscopy

(iv) From the measurements, they also show that they can easily isolate the spin noise signal obtained from separate hyperfine states of the atom. This result manifests the control over separate quantum states and has deep implications in the context of atomic physics experiments.

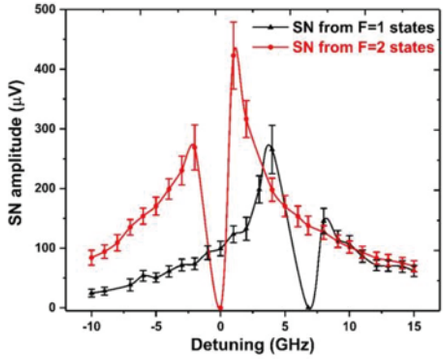


Figure 16. Spin noise signals from separate hyperfine states of atoms being isolated using their pump-probe measurements

An even more fundamental demonstration of "quantum control" and "Quantum non-demolition measurements" will be evident when these experiments will be repeated in cold atom systems. Their current efforts are directed towards that goal with refinement of electronics and measurement techniques.

[Maheswar Swar, Dibyendu Roy, Dhanalakshmi D, Sanjukta Roy, Hema Ramachandran and Saptarishi Chaudhuri]

Intense Light - Matter Interactions

At low light levels the optical response of a material scales linearly with respect to incident intensity. However, when the intensity of the incoming radiation is sufficiently high, the material may respond in a nonlinear fashion. The study of the interaction of intense light with matter is known as nonlinear optics. Research during the past year has been on studying nanostructured and other materials capable of nonlinearly transmitting light at high input intensities.

Optical nonlinearity in novel materials of nano and other size domains

Overview: Optical limiters are devices designed to keep the power transmitted by an optical system well below some specified maximum value, regardless of the magnitude of the input. In other words, optical limiters maintain a high transmittance at low input powers, but not the same high transmittance at high input powers. By keeping the output below a maximum specified value, the optical limiter will be able to protect sensitive optical detectors and human eyes from damage due to intense laser beam exposure.

Motivation and current challenges in the field: Nonlinear optical nanostructured materials are gaining increased interest as optical limiters for various applications. However, many of them suffer from reduced efficiencies at high light powers due to photo induced sample degradation. In this context, Sreekanth Perumbilavil, Gaurav Kumar Tiwari and Reji Philip in collaboration with Josep Nogués investigated the nonlinear optical properties of ferrite core/shell nanoparticles, and have shown that they are robust for ultrafast optical limiting applications.

Description of the research work [Perumbilavil et.al., Small 14, 1701001 (2018)]: They excited Ferrite core/shell nanoparticles using ultrashort (100 fs) laser pulses and found that the effective two-photon absorption (2PA) coefficient shows a non-monotonic dependence on the shell thickness, with a maximum value obtained for thin shells. In view of the local electric field confinement, this indicated that core/shell is an advantageous morphology to improve the nonlinear optical parameters, exhibiting excellent optical limiting performance with effective 2PA coefficients in the range of 10^{-12} cmW^{-1} (100 fs excitation), and optical limiting threshold fluences in the range of 1.7 J cm^{-2}. They found that these values are comparable to or better than most of the recently reported optical limiting materials. The quality of the open aperture Z-scan data recorded from repeat measurements at intensities as high as 35 TW cm−2 is indicative of their considerably high optical damage thresholds, ensuring their robustness in practical applications. The high photo-stability combined with the remarkable nonlinear optical properties makes these nanoparticles excellent candidates for ultrafast optical limiting applications.

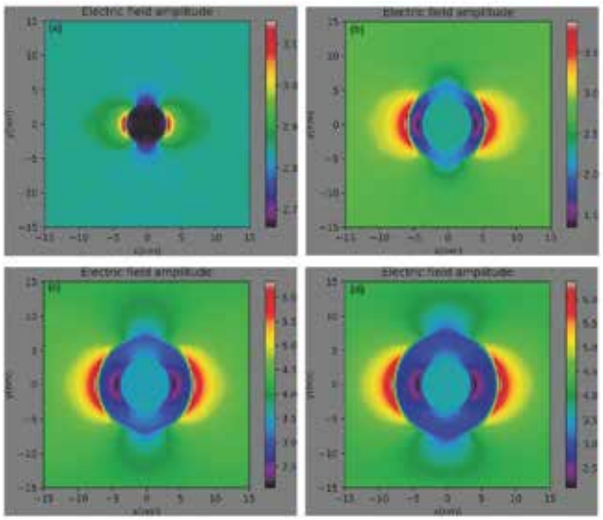


Figure 17. FDTD simulation results for Co (top left image) and Co@Mn (other images) nanoparticles periodically dispersed in the dielectric medium toluene, with an inter-particle separation of 30 nm. The electric field amplitude within the nanoparticle and its vicinity are plotted in a colour scale, where the input field has been taken as unity. The core diameter is 6 nm for all samples, while the shell thickness varies from 0 to 3 nm.

[Sreekanth Perumbilavil, Gaurav Kumar Tiwari, Josep Nogues (Universitat Autònoma de Barcelona, Spain) and Reji Philip]

Laser produced plasmas: properties and applications

Overview: The interaction between a pulsed laser beam and a given substance is quite complex. The nature of the interaction depends on laser characteristics (fluence, pulse duration, wavelength, beam quality), target composition and surface character, and the background gas in which the plasma forms (pressure and composition). Due to its various applications, the field of laser-induced plasmas is very active with more than about hundred publications appearing every year in high-impact international publications.

Motivation and current challenges in the field: Very few papers have been devoted to the influence of laser pulse duration, and particularly to the ultrashort laser pulses, on the LIBS (Laser induced breakdown spectroscopy) performance. One important application of femtosecond laser pulses is material removal or ablation. Laser ablation with femtosecond pulses can be used for the deposition of droplet-free thin films, including semi-conductors, superconductor, magneto-resistive materials, and the creation of new alloys. They can also be used for micro-machining, for the fabrication of nanomaterials, and even in the arts for picture restoration and

cleaning. Femtosecond laser ablation has an important advantage in such applications compared with ablation using nanosecond pulses because there is little or no collateral damage due to shock waves and heat conduction produced in the material being processed.

Work done: P. Sankar, Jijil J. J. Nivas, N. Smijesh, G. K. Tiwari and Reji Philip investigated species dynamics in aluminium plasmas generated by femtosecond and nanosecond laser pulses [P. Sankar et.al., Journal of analytical atomic spectrometry 32, 1177 (2017)], for different ambient pressures [P. Sankar et.al., Applied Physics A 124, 26 (2018)]. Their studies have provided valuable insights into the composition and expansion of Al plasmas produced by ultrashort and short laser pulses respectively, which could be of importance for a number of applications including EUV and X-ray generation, pulsed laser deposition, cluster production, and nanoparticle formation and growth.

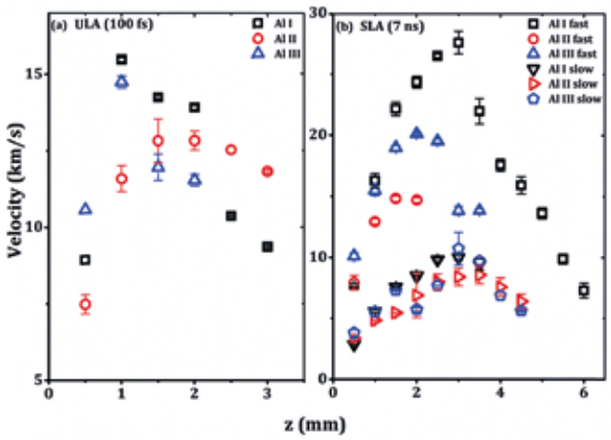


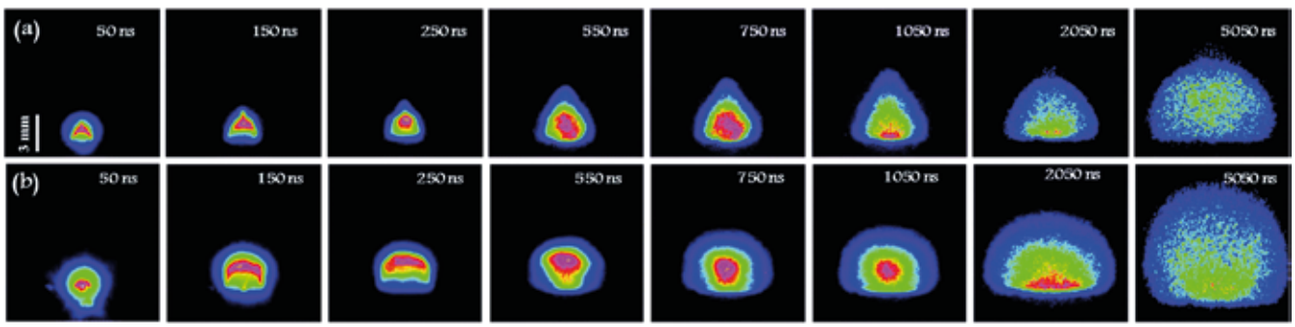
Figure 18. Top - Peak velocities of atomic and ionic species in ultrafast (left image) and short pulse (right image) laser ablation, at different distances in the plasma plume from the target surface. Bottom - Time resolved ICCD images of expanding plasma plumes produced by ultrashort (top image) and short (bottom image) pulse laser ablation.

Surface nanostructuring using ultrafast lasers

Overview: During the past decade, laser beam processing has been very successful in fabricating diverse surface features, including polarization directed periodic surface structures, cone arrays, submicron spikes, random patterns, and many more. Laser induced periodic surface structures (LIPSS) in the form of "ripples" and "grooves" are formed from the interference between incident laser light and surface scattered electromagnetic waves (SEWs). LIPSS provides a fast and effective way to functionalize a material by altering its surface morphology and consequently tailoring properties like wetting, light absorption and emission, adhesion, etc.

Motivation and current challenges in the field: Most of the experimental investigations on fs laser surface structuring, especially for silicon, are based on laser irradiation with an 800 nm wavelength, while very few are dedicated to LIPSS formation at shorter wavelengths, in particular at 400 nm. Therefore, Jijil Nivas, K. K. Anoop and Salvatore Amoruso collaborated with Reji Philip towards elucidating the characteristics of the process at the 400 nm laser wavelength, which is rarely investigated.

Work done: In this work, they analysed the effects of the laser pulse wavelength (400 nm) on femtosecond laser surface structuring of crystalline silicon [J.J.J. Nivas et.al., Applied Physics Letters 112, 121601 (2018)]. They investigated the features of the produced surface structures as a function of the number of pulses, N, and compared it with the surface textures produced by more standard near-infrared (800 nm) laser pulses at a similar level of excitation. Their experimental findings highlighted the importance of the light wavelength for the formation of the supra-wavelength grooves, and, for a large number of pulses (N 1000), the generation of other periodic structures (stripes) at 400 nm, which are not observed at 800 nm. Their results provide interesting information on the generation of various surface textures, addressing the effect of the laser pulse wavelength on the generation of grooves and stripes.



[P. Sankar, Jijil J. J. Nivas, N. Smijesh, G. K. Tiwari and Reji Philip]

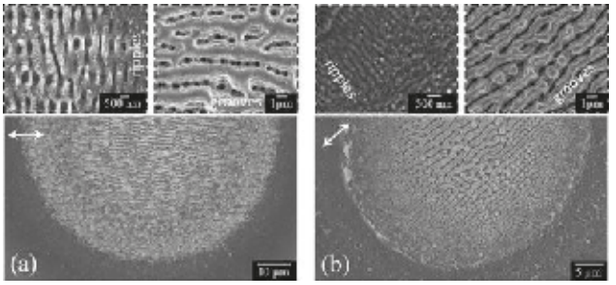


Figure 19. SEM (scanning electron microscope) images of a silicon surface after irradiation with 50 laser pulses: (a) fundamental beam at 800 nm with energy 30 microJoules; (b) second harmonic beam at 400 nm with energy 5 microJoules. Upper panels report zoomed views of ripples (left) and grooves (right) for each. Arrows indicate the direction of laser polarization.

[Jijil Nivas, K. K. Anoop, Salvatore Amoruso (University of Naples, Italy) and Reji Philip]

Light transport in random media

Light, that normally travels ballistically (i.e., in straight-line paths) turns diffusive when traversing a medium with randomly placed refractive-index inhomogeneities. An example of this is atmospheric fog. Light gets multiply scattered, making it difficult to view or image through. Several schemes have been devised, that either require long data acquisition times, or long computational times. Recently, Sriram Sudarsanam, James Mathew, Hema Ramachandran along with collaborators Swapnesh Panigrahi, Julien Fade, Mehdi Alouini had shown real-time imaging through strongly scattering media – where images were obtained through simulated fog instantaneously. They had devised a new algorithm, and had utilized the parallel processing capabilities of a Graphical Processing Unit in a standard desktop to achieve more than a thousand-fold speed-up in processing. In this manner they obtained images, even of moving objects, within milliseconds, and with frame-refresh rates faster than the flicker-frequency of the human eye, such that the scene appears as it would have in the absence of the scattering medium. They have now gone a step further, and devised a means of data-acquisition, so that even the computational aspect is not required – that is, the algorithm is implemented optically. In this manner, a fully processed image is obtained directly upon recording a single camera frame. This technique is now being patented. Preliminary experiments have yielded encouraging results.
[Patent: Hema Ramachandran, Julien Fade (University of Rennes, France), Mehdi Alouini (University of Rennes, France);
Preliminary Experiments: M.S. Meena and Hema Ramachandran]

Quantum information, computing and communication

During the past few years RRI has accumulated infrastructural capability and intellectual knowhow to conduct cutting edge research in the fields of quantum information, quantum computing and quantum communication using quantum optics based tools. It is worth pointing out that the Institute has pioneered the manufacture and applications of single, heralded and entangled photon sources in India which were hitherto unexplored in our country. Any truly quantum application of light requires harnessing it at a single particle (photon) level and this requires dedicated resources and technology to materialize, which has been established at the Institute. During the past year, LAMP group members have used the infrastructure developed to further our knowledgebase in these research areas. Another area of research is towards realization of entanglement scalability via mesoscopic entanglement of large number of ultra-cold Rydberg atoms with the end goal being the realization of a fast mesoscopic quantum gate.

Quantum Information

Manipulation of entanglement sudden death in an all optical set up

An investigation of the phenomenon of Entanglement Sudden death in an all optical set-up was undertaken by Urbasi Sinha, at the Institute during the past year. The theory work was done in collaboration with A.R.P Rau, Ashutosh Singh and Siva Pradyumna. They have established the entangled photon source necessary for this experiment and also made good progress with the setting up of the experiment.

Entanglement is a quantum correlation that serves as a resource in several quantum information, computation and communication protocols. However, when entangled systems interact with their environment, it can lead to degradation of the entanglement and in some situations, the entanglement can disappear completely at a finite time. If this happens, then the correlation is not available any more for quantum operations. In this work, they propose a way of holding on to the entanglement for longer so that useful operations may be performed with more time available in hand. The investigations have led to an experimental proposal using an all optical experimental set up which in fact is currently being set up in their lab right now.

The unavoidable and irreversible interaction between an entangled quantum system and its environment causes decoherence of the individual qubits as well as degradation of the entanglement between them. Entanglement sudden death (ESD) is the phenomenon wherein disentanglement happens in finite time even when individual qubits decohere only asymptotically in time due to noise. Prolonging the entanglement is essential for the practical realization of entanglement-based quantum information and computation protocols. For this purpose, the local NOT operation in the computational basis on one or both qubits has been proposed. In this work, they have formulated an all-optical experimental set-up involving such NOT operations that can hasten, delay, or completely avert ESD, all depending on when it is applied during the process of decoherence. Analytical expressions for these were derived in terms of parameters of the initial state's density matrix, whether for pure or mixed entangled states. They discuss the schematics of the

experiment, theoretically analyse the problem and present simulation results of such manipulations of ESD.
Their work has been published in Journal of Optical Society of America B. During the past year, they have established a 96% visibility Entangled Photon Source for this experiment and have also nearly finished setting up the experiment.

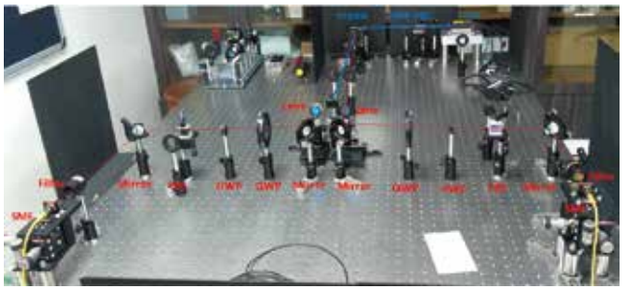


Figure 20. Entangled Photon Source set up for the experiment

[Ashutosh Singh, Siva Pradyumna, A.R.P Rau (Louisiana State University, USA) and Urbasi Sinha]

The Quantum Cheshire Cat effect

The Quantum Cheshire Cat [New J. Phys. 15, 113015, 2013] (QCC) is an effect defined within the Weak Measurements framework by which a property of a quantum particle appears to be spatially separated from its position. The status of this effect has however remained unclear, as claims of experimental observation of the QCC have been disputed by strong criticism of the experimental as well as the theoretical aspects of the effect. In an appraisal paper published this past year, Urbasi Sinha and collaborators Q. Duprey, S. Kanjilal, D. Home and A.Matzkin have clarified in what precise sense the QCC can be regarded as an unambiguous consequence of the standard quantum mechanical formalism applied to describe quantum pointers weakly coupled to a system. In light of this clarification, the raised criticisms of the QCC effect were rebutted. They further point out that the limitations of the experiments performed to date imply that a loophole-free experimental demonstration of the QCC has not yet been achieved.

Surya Narayan Sahoo, Sanchari Chakraborti and Urbasi Sinha in collaboration with Alexandre Matzkin and Dipankar Home have established an experiment in the lab this year to investigate the effect using photons. The experiment is being pursued at both the semi-classical and quantum domain and various capacities being developed for the same. It is expected to yield exciting results in the coming year.
[Q.Duprey (Université de Cergy-Pontoise, France), S.Kanjilal (Bose Institute), D.Home (Bose Institute), A.Matzkin (Université de Cergy-Pontoise, France), Surya Narayan Sahoo, Sanchari Chakraborti and Urbasi Sinha]

Towards Quantum Entanglement with ultra-cold Rydberg atoms

Quantum Entanglement is a key feature of Quantum mechanics in which two or more particles are generated or interact in such a way that their quantum states are correlated and cannot be described independently even though the individual particles may be separated spatially. The quantum correlations exhibited by entangled states have no classical analog. Quantum entanglement has important applications in emerging quantum technologies such as quantum information processing, quantum cryptography and teleportation.

Control and manipulation of ultra-cold Rydberg atoms with long-range dipole-dipole interaction offer a promising avenue for quantum information processing. Rydberg states are highly excited atomic states with a large principal quantum number n near the ionization threshold. Atoms in Rydberg states exhibit interesting characteristic features such as large dipole moments. For example, Rydberg states with a principal quantum number n ~ 50 has a dipole moment few thousand times that of water molecule. This makes the Rydberg atoms highly polarizable with the static polarisability scaling as n^7 and hence very sensitive to DC or AC electric fields. Such large dipole moment possessed by Rydberg atoms gives rise to large interaction between them via dipole-dipole coupling which scales as $1/R^3$ where R is the inter-atomic distance. The interaction energy between two Rydberg atoms exhibit a strong dependence on the principal quantum number n and can be tuned from the Van der Waals regime to the $1/R^3$ regime by using an electric field or by varying the inter-atomic distance. Rydberg interactions between ultra-cold Rydberg atoms can enable the generation of entangled states via Rydberg blockade effect and enables Quantum information processing via realization of fast quantum gates. While the generation of quantum entanglement and the realization of a Quantum gate with two single Rydberg atoms has been achieved elsewhere, for the purpose of scalability of Quantum information processing, it is desirable to realize mesoscopic entanglement with a large number of atoms which can be created very fast with high fidelity.

Towards this direction, the planned experimental strategy is to use an ensemble of ultra-cold atoms in the 'blockade sphere' of a single control Rydberg atom, with mesoscopic quantum entanglement being generated via the Rydberg blockade mechanism. The entanglement will be implemented in a single step with high fidelity within a time-scale of one micro-second by combining long-range Rydberg interactions with the quantum interference phenomena of Electromagnetically Induced Transparency (EIT). This would eliminate the need for individual addressing of the ensemble of atoms and hence would enable the realization of a fast mesoscopic quantum gate. Such a mesoscopic Rydberg quantum gate would work like a single atom transistor or a quantum amplifier and has important applications in quantum information processing and entanglement-based many particle interferometer. It is planned to

explore adiabatic transport of quantum entanglement via the Rydberg blockade effect analogous to momentum transfer in Newton's cradle in 1D and 2D arrays of single Rydberg atoms. (March 2018)

Progress: In this direction, during the past year, the following has been achieved by Sanjukta Roy, Silpa B.S. and Hema Ramachandran, along with Sukanya Mohapatra and Monika. The experimental setup, which consists of a magneto-optical trap (MOT) with a superposed optical dipole trap has been built, and the various steps towards trapping and detecting a single atom have been automated. The MOT is a non-standard one with steeply inclined beams so as to incorporate within the ultra-high vacuum cell, a pair of lenses with high numerical aperture that are used to achieve tight focusing of the dipole trap beam to form a micron sized optical dipole trap. The optics has to be aligned to a micron precision or better to obtain efficient trapping and collection of fluorescence emission from the single atom. A novel technique using a knife-edge beam profiler along with a Michelson interferometer had been reported in the literature to measure sub-micron spots. We have used this idea to devise a simple yet very precise method for ensuring optimal alignment and overlap of the beams of different wavelengths to sub-micron precision.

A detailed calculation was carried out to select the specific Rydberg levels to be addressed in the experiment to realise mesoscopic quantum entanglement with Rydberg atoms. Thereby, the range of wavelength and all the relevant options required for the laser was finalized. A state-of-the-art tunable laser with a bow-tie shaped frequency doubling cavity that was procured has been frequency tuned to desired wavelength, and steps are under way to frequency-lock the laser to a spectroscopic feature.
[Sanjukta Roy, Shilpa B. S., Sukanya Mohapatra, Monika and Hema Ramachandran]

In the MOT, the collection of cold atoms is thermal, and thus the light emitted is classical and bunched. When the number of atoms trapped is reduced to a few, countable atoms (e.g., 1, 2, 3…), the collection is said to be in a Fock (number) state, and is quantum. The statistics of emission changes, and anti-bunching is seen. This is most evident in the second-order correlation of intensity of emission from the source – the g2 function. B.S. Girish, A.M. Rashmi and Hema Ramachandran had recently built a FPGA-based photon arrival time archival system, APODAS that enabled post-processing of the data to obtain the second-order correlation function. (Publication -1). They have now developed another system – FORCEPS – FPGA-based Optimised Realtime CorrElated Photon-counting System. This system continuously acquires the output of two Avalanche Photo-detectors, and passes it to a series of multiply-and-accumulate units with appropriate delays to obtain the g2 function. This is evaluated in realtime, and with a 6 ns time resolution, and displayed on a screen in realtime, obviating the need for post-processing of the data. Such an instrument, which would be very useful in a variety of fields from quantum optics studies to biology, is not commercially available. It is currently being thoroughly evaluated, prior to patenting and transfer of technology to an Indian industry.
[B.S. Girish, A.M. Rashmi and Hema Ramachandran

Quantum Computation and Communication

The quantum information and computation community is collectively working towards systems with large number of qubits in coherent superposition. As the exponential advantage of quantum computers goes like 2n where "n" is the number of qubits, more the number of qubits, more the speed up. However, it becomes increasingly difficult to increase n beyond a point due to onset of Decoherence. What could be an alternative approach? Change the base! Instead of two dimensional qubits, one could conceive of using higher dimensional qudits where the "2" is replaced by 3,4,5 and so on. Then, for a smaller "n", one could envisage similar speed up.

At the Institute efforts are towards exploring a qudit architecture based on spatial degree of freedom of a single photon. During the past year, Debadrita Ghosh and Urbasi Sinha in collaboration with Thomas Jennewein and Piotr Kolenderski established near perfect spatial correlations in their experimentally generated bipartite qutrit system.

Higher dimensional quantum systems have a very important role to play in quantum information, computation as well as communication. In photonic systems, it is common to use the photon's polarization degree of freedom for various investigations. However, this restricts us to only two orthogonal states, hence qubits for manipulation. In a recent publication, they have theoretically analysed and experimentally demonstrated a system of two photonic qutrits that are correlated in the spatial degree of freedom. The qutrits were generated by modulating the pump beam in a spontaneous parametric down conversion process using an aperture based system. In principle, this system can be scaled up to generation of even higher dimensional correlated qudits with possible application for quantum communication and computation implementations.

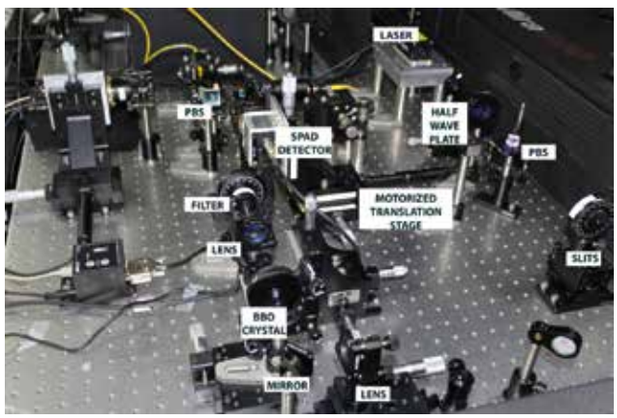


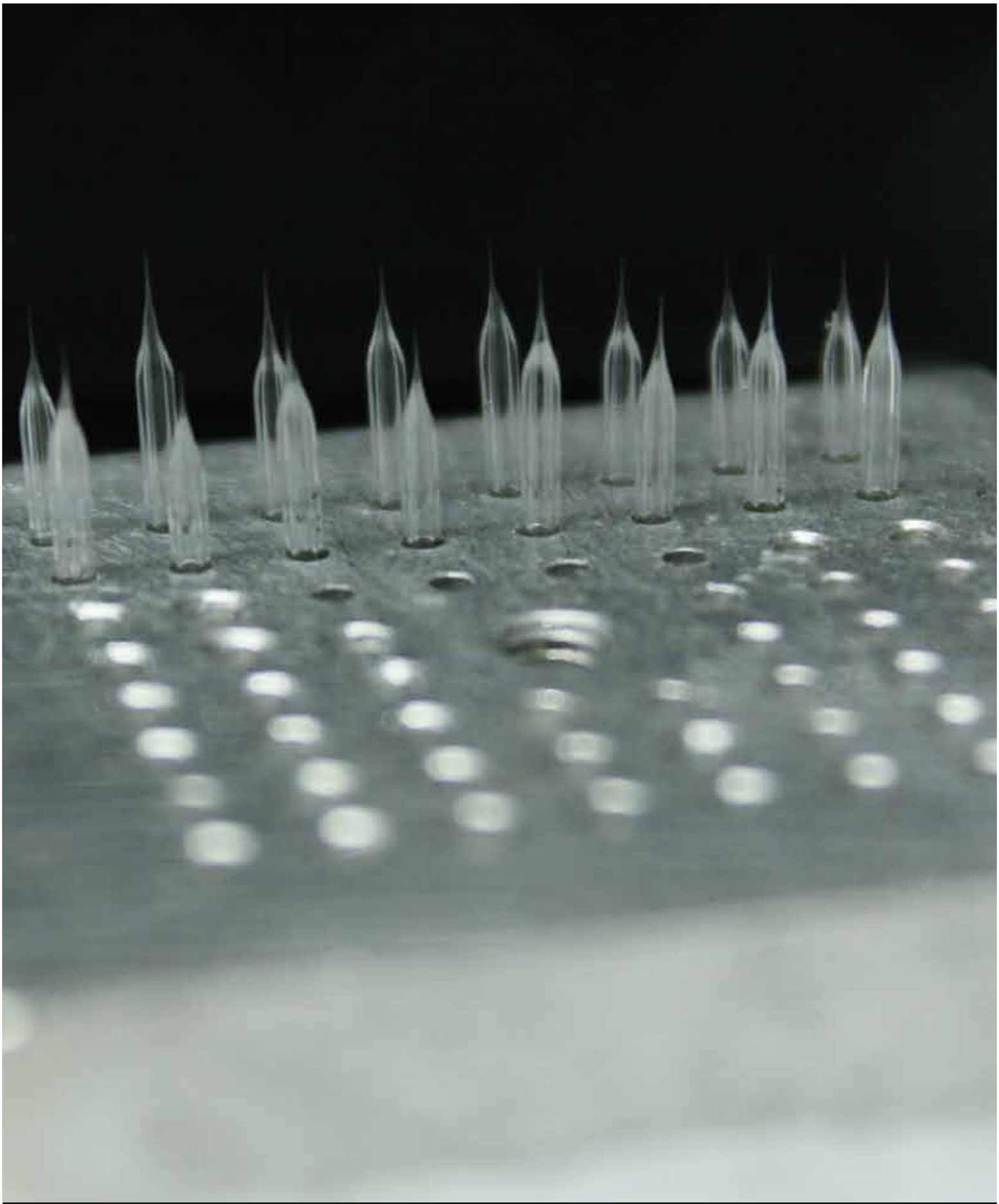
Figure 21. The experimental set up in QuIC lab which is used to generate spatially correlated bi-partite qutrits.

Quantification of the spatial correlations between a pair of qutrits can in principle also have applications in quantum communication whereby now they can explore a different degree of freedom i.e. spatial compared to the more conventional polarization degree of freedom.

This year they have gone several steps forward. While spatial correlations were established last year, how does one know if these correlations are classical or quantum? A novel theoretical measure of entanglement was established in collaboration with theory collaborators C. Jeberathinam and Dipankar Home, which makes use of the well-known measure of classical correlations, the Pearson correlation coefficient, in a novel quantum setting. They are also in the process of experimentally testing this measure using their indigenous bi-partite qutrit system in the lab.
[Debadrita Ghosh, Thomas Jennewein (IQC, Canada), Piotr Kolenderski (NCU, Poland), C Jebarathinam (Bose Institute), Dipankar Home (Bose Institute) and Urbasi Sinha]

The area of quantum communications is an exciting new area not only for RRI but also for the Indian community. The currently prevalent means of secure communication is through classical cryptography. When the information to be communicated needs to be kept secure for instance in defence, banking and other such strategic sectors, the information is encoded by the sender in what is called a ''key'' which is then decoded by the receiver by using the key in their possession. The distribution of the key forms the basis of the security and one of the common techniques used is based on the algorithmic hardness of problems for instance the factorization problem. For instance, multiplying two numbers has a lower class of ''hardness'' in terms of algorithmic complexity than factorization of a number into its two prime factors. Factorization has long been used as the basis of security in public key distribution algorithms like the RSA algorithm. In what is called ''Private Key'' distribution, one still needs to rely on trusted human carriers. The imminent onset of small quantum registers jeopardizes the security of classical key distribution, as they would be able to run what are called Shor's algorithm, which can break the hardness of the factorization problem. What is needed is a ''quantum'' solution to the problem where the basis of the security is laws of nature and not mathematical hardness of problems or algorithmic complexity. This brings us to ''Quantum Key Distribution'' or QKD. QKD uses laws of quantum mechanics to ensure ''absolute'' security of key distribution.

In the Quantum Information and Computing lab at RRI, Kaushik Joarder, Rishab Chatterjee, Debadarita Ghosh, A. Nagalakshmi, Rakshita R.M. and Urbasi Sinha have embarked on an ambitious multi-year project to demonstrate free space quantum key distribution over different distance domains in varying environmental conditions. This project is in collaboration with the Indian Space Research Organization (ISRO) and will involve demonstrating quantum key distribution over large distances using a satellite as a trusted node. This is India's first project in satellite based quantum communication and RRI is extremely excited by its prospects and look forward to reporting on different milestones in the years to come.
[Kaushik Joarder, Rishab Chatterjee, Debadrita Ghosh, A. Nagalakshmi, Rakshita R.M. and Urbasi Sinha]



Research: Knowledge Creation

Soft Condensed Matter

Soft Condensed Matter

Overview

Soft matter, as the name implies, encompasses materials that are easily deformed by thermal fluctuations and external forces. Some common examples of soft matter that we use in our day-to-day life include lotions, creams, milk and paint. The building blocks of these materials are macromolecules with typical size ranging anywhere from few nanometers to few micrometers and are held together by weak inter macromolecular forces and exhibit complex structures and phase behavior. The SCM group at RRI actively studies colloids, complex fluids, liquid crystals, nanocomposites, polyelectrolytes, self-assembled systems, polymers and biological materials. A fundamental understanding of the structure-property correlations, phase behavior of these systems, and response to external stimuli form a major part of the experimental research activities in the SCM group. Theoretical work carried out by the group broadly concerns developing phenomenological theories of elasticity and topological defects in soft matter.

Focus 2017-18

Liquid Crystals

As the name implies, liquid crystals (LCs) is a state of matter that has properties intermediate between those of conventional liquids and solid crystals. An LC exhibits many of the physical attributes of a liquid, whereas its molecular units exhibit some form of order. LCs can be divided into thermotropic LCs in which transitions into an LC phase occur with change in temperature, and lyotropic LCs that are formed by dissolving surfactants - amphiphilic materials composed of a polar head group and non-polar chain - in a solvent.

Thermotropic LCs are further subdivided into calamitic LCs made of rod-like molecules and discotics composed of disc-like molecules. More recently a new class of LCs made of bent-core molecules has also been discovered. An attractive feature observed in this type of LC is the interplay between polarity and chirality, which leads to various chiral effects despite the molecules being achiral.

LCs display a variety of phases characterized by the type of molecular ordering, the simplest among them being the nematic phase in which the molecules have no positional order, but they self-align tohave long-range orientational order with their long axes roughly parallel, and the smectic A phase in which the molecules are parallel to one another and are arranged in layers with the long axes being perpendicular to the layer plane.

Since their discovery, considerable work has gone into understanding their structure-property relationships, which hold the key for the myriad applications involving LCs. Researchers within the SCM group at RRI have done pioneering work in LCs and that tradition still continues today with research in various aspects of LCs being undertaken. The interesting physical properties resulting from a careful tuning of the molecular shape, concentration, constituents and phase, while expanding the LC knowledge base, serve to open potential avenues for technological applications.

Research focus during 2017-18 was on developing new building blocks for novel LCs, phase transitions, self-assembly and pattern formation in LC's, structure-property relationships of noble metal nanoparticle-LC hybrids and phenomenological theory of elasticities and topological defects in fluid membranes.

Design, synthesis and physical studies of liquid crystalline materials

Synthesis and characterization of some new chalcone liquid crystals

H.T. Srinivasa and Sandeep Kumar have synthesized and characterized a series of new chalcones with four aromatic rings. The chemical structures of chalcones were evaluated by Fourier

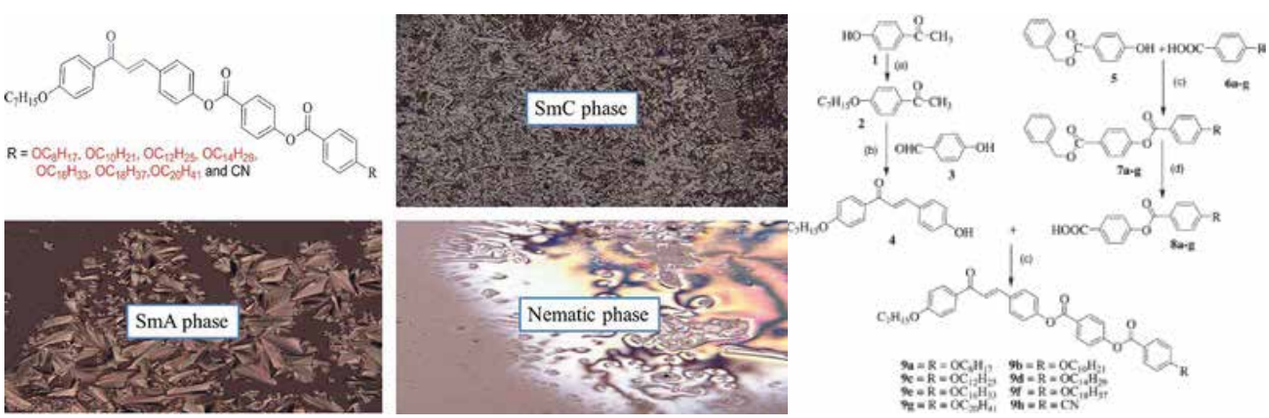


Figure 1. Synthesis of unsymmetrical chalcone target compounds 9a–g and 9h. Reagents and conditions: (a) $C_7H_{15}Br$, K_2CO_3, butanone, 90°C, 12 h; (b) 3.6 mol KOH in minimum amount methanol, rt, 12 h; (c) DCC, DMAP, dry CH_2Cl_2, rt, 6 h; (d) H_2–gas, 5% Pd–C, 1,4-dioxane, 60°C, 12 h.

transform-infrared spectroscopy, elemental analysis and 1H and 13C nuclear magnetic resonance spectroscopic techniques. They investigated the compounds for liquid crystalline properties using differential scanning calorimetry and polarizing optical microscopy with hot stage and found that the formation of mesophase type is dependent on the alkyl chain length at one end of the molecule. It was found that compounds 9a–d with relatively shorter chains showed SmA and nematic mesophases, whereas 9e–g exhibit SmC and SmA mesophases whereas compound 9h having a cyano group at one end, exhibited SmA and nematic mesophases.
[H. T. Srinivasa and Sandeep Kumar]

Synthesis and mesomorphism of ionic self-assembled complexes of anthraquinones

Anthraquinones are known to exhibit mesomorphism upon appropriate substitutions. During the past year, Swamynathan K., Raghunathan V. A. and Sandeep Kumar applied the concept of ionic self-assembly to design and synthesize new anthraquinone-based liquid crystals. They used four different anthraquinone polyelectrolytes which form ionic complexes with double-tail ammonium surfactants and characterized their chemical structures by spectral techniques and elemental analysis. The thermal behaviour of the complexes was investigated by polarizing optical microscopy, differential scanning calorimetry, thermogravimetric analysis and X-ray diffraction studies and it was found that these complexes display lamellar mesomorphism. Additionally, they also studied the amphotropic nature of the complexes.

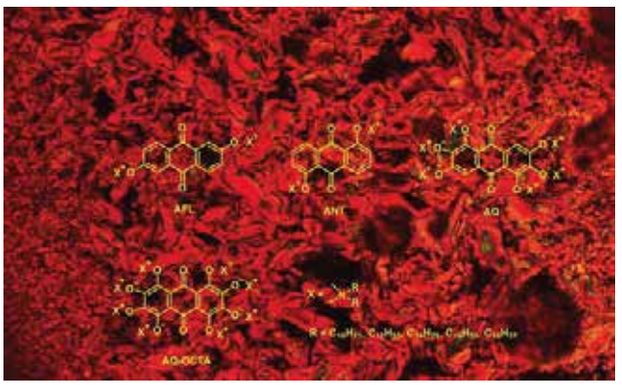


Figure 2. Chemical Structure of the complexes

[Swamynathan K., Raghunathan V. A. and Sandeep kumar]

Phase Behavior of a New Class of Anthraquinone-Based Discotic Liquid Crystals

Sandeep Kumar and collaborators Joydip De, Santosh Prasad Gupta, Indu Bala, and Santanu Kumar Pal have synthesized five novel columnar liquid crystalline compounds (4.1–4.5) consisting of a central anthraquinone core carrying four alkoxy chains (R = n-C_6H_{13}, n-C_8H_{17}, n-$C_{10}H_{21}$, n-$C_{12}H_{25}$, and 3,7-dimethyl octyl) with two diagonally opposite 1-ethynyl-4-pentylbenzene units, and have investigated their phase transitions between changes in the molecular structure and their self-assembly into the columnar mesophases. They performed small and wide-angle X-ray scattering (SAXS/WAXS) studies to deduce the exact nature of the mesophases, and their corresponding electron density maps were derived from the intensities of the peaks observed in the diffraction patterns. A comparison of compounds with different alkoxy chains indicated that the soft crystal columnar rectangular (Cr_{colrec}) phase was stable at lower temperature for the shortest peripheral alkoxy chain (4.1; R = n-C_6H_{13}) and was found to exhibit the columnar hexagonal (Col_h) phase and then the discotic nematic (ND) phase with increasing temperature. In contrast, increasing the peripheral chain length to n-C_8H_{17} or the branched one (4.2 and 4.5) stabilized the Col_h phase at lower temperature and showed the ND phase at higher temperature. Further increase in chain length (4.3 and 4.4; n-$C_{10}H_{21}$, n-$C_{12}H_{25}$) demonstrated the formation of the ND phase. Conductivity measurement in the Col_h mesophase was found to be almost 10 times higher in magnitude than the corresponding Cr_{colrec} phase. The HOMO–LUMO band gap of all the compounds was found to be in the range from 2.79 to 2.82 eV, which is quite less and comparable with the optical energy band gap.

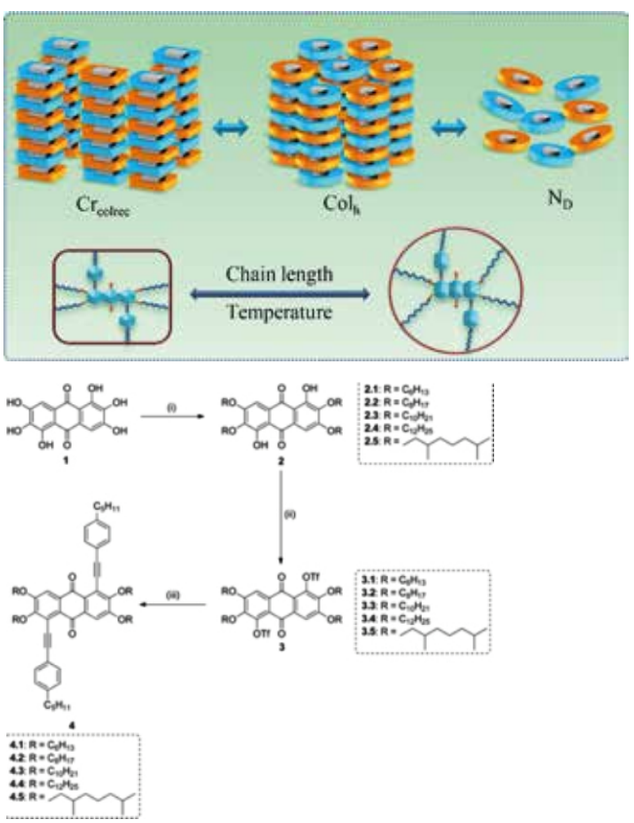


Figure 3. (Top) Schematic representation of the phase sequence observed in compounds 4.1–4.5. (b) Schematic of the change in the shape of the compound with increasing temperature/periphery chain length. (bottom) Synthesis of Anthraquinone Derivatives: Reagents and conditions: (i) NaOH, RBr, DMSO, 70 °C, 18 h; (ii) Tf_2O, pyridine, dry DCM, RT, 24 h; (iii) Pd(PPh3)2Cl2, PPh3, CuI, Et_3N, reflux, 18 h.

[Joydip De (IISER, Mohali), Santosh Prasad Gupta(IISER, Mohali), Indu Bala(IISER, Mohali), Sandeep Kumar and Santanu Kumar Pal (IISER, Mohali)]

Tri-s-triazine (s-heptazine), a novel electron-deficient core for soft self-assembled supramolecular structures

Self-assembled supramolecular structures formed by disc-shaped molecules, commonly known as discotic liquid crystals (DLCs), have attracted tremendous interest during the past decade due to their potential applications in wide-viewing liquid crystal displays, sensors, photovoltaic solar cells, light emitting diodes, thin film transistors, etc. Since the discovery, only about sixty different core molecules have been explored to prepare about 3500 DLCs. During the past year, Irla Siva Kumar and Sandeep Kumar have realized a new heterocyclic aromatic molecular motif, s-heptazine, which functions as a core fragment for the synthesis of discotic liquid crystals on appropriate functionalization.

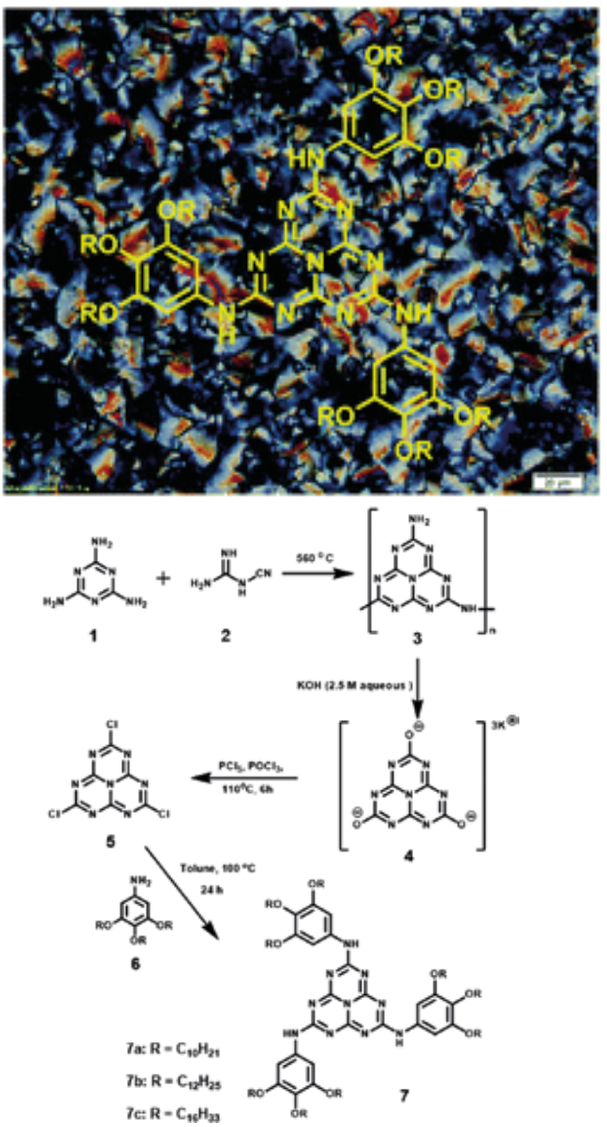


Figure 4. Synthesis and chemical structure of trisubstituted heptazine derivatives

[Irla Siva Kumar and Sandeep Kumar]

irconia-Supported Cu(I)-Stabilized Copper Oxide Mesoporous Catalyst for the Synthesis of Quinazolinones Under Ambient Conditions

Although there are many reports on the synthesis of quinazolinones, the use of high boiling solvents and high temperature restricts their scale-up to the industrial level. Sandeep Kumar and collaborators L. Parashuram, Swamy Sreenivasa, S. Akshatha and V. Udaya Kumar have developed a simple protocol for the catalytic synthesis of quinazolines in the presence of a cost-effective and reusable mesoporous ZrO_2-supported Cu_2O (Cu_2ZrO_3) catalyst. The catalyst was prepared by simple co-precipitation and characterized using techniques like XRD, TGA, BET, SEM and TEM. They reused the catalyst for five cycles without significant loss in the activity and the catalyst was truly heterogeneous. The present synthesis utilizes environmentally benign H_2O_2 as an oxidant. The protocol showed good tolerance for various substituted aldehydes and good yields for quinazolinone derivatives. Their method followed a simple workup procedure and no column chromatography was needed.
[L. Parashuram (Tumkur University, Tumkur), Swamy Sreenivasa Tumkur University, Tumkur), S. Akshatha,V. (Tumkur University, Tumkur), Udaya Kumar (Tumkur University, Tumkur) and Sandeep Kumar]

Synthesis, structural and mesophase characterization of isoindoline-1,3-dione based mesogenic Schiff bases

Two homologous series of mesogenic Schiff-bases, [4-(((4-(1,3-dioxoisoindolin-2-yl)phenyl)imino)methyl)-3-hydroxyphenyl-4-(alkoxy)benzoate, HL_1^n, (Series I), which is an estererivative of HL and 2-(4-((4-(alkoxy)-2-hydroxybenzylidene)-amino)phenyl)isoindoline-1,3-dione, HL_2^n, (Series II), which is an alkoxy derivative of
HL where HL = 2-{4-[(2-Hydroxy-benzylidene)-amino]-phenyl}-isoindole-1,3-dione) and n = C_8H_{17}, $C_{10}H_{21}$, $C_{12}H_{25}$ and $C_{14}H_{29}$] have been prepared by Sandeep Kumar and collaborators R. Dubey, R. Yerrasani , M. Karunakar, A.K. Singh and T.R. Rao and their molecular structures and thermal behaviour studied by FTIR, NMR and ESI-MS spectrometry, DSC, POM and variable temperature PXRD techniques. They found that all these derivatives displayed an enantiotropic liquid crystalline behaviour with Nematic texture while few of them also exhibited SmA phase. They also investigated the influence on thermal behaviour and mesomorphic properties upon changing the spacer in both the series. The HOMO and LUMO band gaps were found to be 2.89 and 3.26 eV for the two series respectively, in reasonable agreement with theoretical calculations (by DFT) made on optimized structure of one representative compound of each series.
[R. Dubey (BHU, Varanasi), R. Yerrasani (BHU, Varanasi), M. Karunakar(BHU, Varanasi), A.K. Singh(BHU, Varanasi), S. Kumar and T.R. Rao (BHU, Varanasi)]

Rapid Formation and Macroscopic Self-Assembly of Liquid-Crystalline, High-Mobility, Semiconducting Thienothiophene

A synergistic approach to enhance charge-carrier transport in organic semiconductors along with facile solution processing and high performance is crucial for the advancement of organic electronics. In recent work, Ashwathanarayana Gowda, Sandeep Kumar and collaborators Manish Pandey, Shuichi Nagamatsu, Wataru Takashima, Shuzi Hayase, and Shyam S. Pandey used the floating film transfer method (FTM) as a facile and cost-effective method for the fabrication of large-scale, uniform, highly oriented poly[2,5-bis(3-tetradecylthiophen-2-yl)thieno[3,2-b]thiophene] (pBTTT C-14) films under ambient conditions. Utilization of such oriented films as the active semiconducting layer in organic field-effect transistors (OFETs) results in highly anisotropic charge-carrier transport. They characterized the highly oriented, FTM-processed pBTTT C-14 thin films by polarized electronic absorption and Raman spectroscopy, atomic force microscopy, out-of-plane X-ray diffraction, and grazing incident X-ray diffraction (GIXD) measurements. The GIXD data indicated an edge-on orientation, which is highly desirable for planar devices such as OFETs. The OFETs built by them using the oriented films displayed a mobility anisotropy of 10 with highest mobility of 1.24 $cm^2 V^{-1} s^{-1}$ along the backbone orientation, which is among the highest value reported for this class of materials using a similar device configuration.

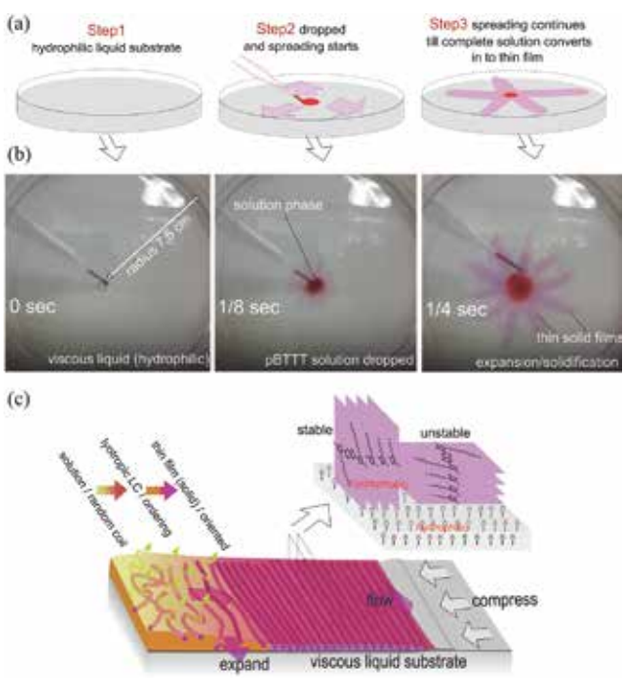


Figure 5. Schematic illustration of the steps a) with photographs and b) for the processes involved during film formation; c) schematic representation of the possible mechanism for polymer orientation during pBTTT film formation on a liquid substrate.

[Manish Pandey (Kyushu Institute of Technology, Japan), Ashwathanarayana Gowda, Shuichi Nagamatsu (Kyushu Institute of technology, Japan), Sandeep Kumar, Wataru Takashima (Kyushu Institute of technology, Japan), Shuzi Hayase (Kyushu Institute of technology, Japan), and Shyam S. Pandey (Kyushu Institute of technology, Japan)]

Thermal and nonlinear optical studies of newly synthesized EDOT based bent-core and hockey-stick like liquid crystals

Ashwathanarayana Gowda, Litwin Jacob, Nithin Joy, Reji Philip, Pratibha R and Sandeep Kumar have designed and synthesized via the Sonogashira coupling reaction, novel EDOT based bent-core and hockey-stick shaped mesogens bearing terminal alkyl chains and alkoxy terminal chains, respectively. Molecular structures of these new compounds were determined using spectral and elemental analysis. They investigated the mesomorphic behaviour of all the novel compounds by a combination of polarising optical microscopy (POM), differential scanning calorimetry (DSC) and X-ray diffraction studies (XRD) and observed that all of the compounds exhibit an enantiotropic nematic phase in lower homologs. However, a smectic A phase at a lower temperature along with the high temperature nematic phase was observed in higher homologs of BC and hockey-stick LCs. A density functional theory study was carried out to investigate the stable configuration. The bent angle of these molecules was found to be intermediate between calamitic LCs and banana LCs. Studies of the photophysical properties of all the compounds in anhydrous chloroform solvent revealed absorption patterns around 370–395 nm and emission between 418–465 nm. They have also reported large effective two-photon absorption in these novel compounds when measured under excitation by nanosecond laser pulses at 532 nm. All of the mesogenic compounds are nonlinear materials, which make them suitable candidates for optical limiting applications.
[Ashwathanarayana Gowda, Litwin Jacob, Nithin Joy, Reji Philip, Pratibha R and Sandeep Kumar]

Parameters of LC molecules' movement measured by dielectric spectroscopy in wide temperature range

Dielectric properties of a nematic liquid crystal (NLC) mixture ZhK-1282 in the frequency range of 102–106Hz and a temperature range of −20 to 80°C was investigated by Sandeep Kumar and collaborators D.N. Chausova, A.D. Kurilova and V.V. Belyaeva. On the basis of the Debye's relaxation polarization model, dielectric spectra of temperature dependence of the orientational relaxation time τ and the dielectric strength δe were numerically approximated at the parallel orientation of a molecular director relative to alternating electric field. They found that the influence of ester components in the mixture plays a crucial role in relaxation processes at low temperature and external field frequency. They measured the activation energy of the relaxation process of a rotation of molecules around their short axis in a temperature interval of −20 to +15°C in which the dispersion of a longitudinal component of the dielectric

constant takes place. They also calculated the energy of potential barrier for polar molecules rotation in the mesophase and obtained the value of the transition entropy from the nematic to isotropic phase. Further, they obtained the values of the coefficient of molecular friction and rotational diffusion by different methods and have shown satisfactory agreement between experimental data and existing theoretical models.

[D.N. Chausova (Moscow Region State University, Russia), A.D. Kurilova (Moscow Region State University, Russia), V.V. Belyaeva (Moscow Region State University, Russia), and Sandeep Kumar]

Phase transition and electro-optics of liquid crystals

Novel smectic phases exhibited by bent core hockey stick shaped molecules

In continuation of their work on novel smectic phases exhibited by bent core hockey stick shaped (BCHS) molecules, Deepshika Malkar and Arun Roy in collaboration with Veena Prasad have further studied a new series of BCHS molecules in collaboration with chemists. Their studies not only confirmed the existence of novel pseudopolar smectic phases earlier reported by them but has also shown new phases and provided information on the stability of these phases on the chain length of the homologous series of compounds. The molecular structure of a typical BCHS molecule is shown in Figure 6. A BCHS molecule consists of two rigid rod-like arms of different lengths joined end to end and making an angle of about 120 degrees between them. There are flexible aliphatic chains attached to both ends of the rigid core of the molecule

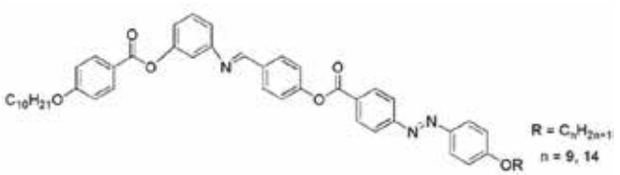


Figure 6. Molecular structure of a typical BCHS molecule.

They studied two BCHS compounds of an azo substituted series which were showing unusual phase behavior. They studied the observed phases by various experimental techniques such as Polarizing Optical Microscopy (POM), X-Ray Diffraction (XRD), Differential Scanning Calorimetry (DSC), Switching-Polarization Current measurements and Dielectric-Optic measurements. Based on these experimental studies they have established that one of the BCHS compound shows an unusual Smectic A to Smectic A' phase transition on cooling the sample from isotropic phase. Figure 7 shows the variation of layer spacing with temperature in the Smectic phases obtained from XRD.

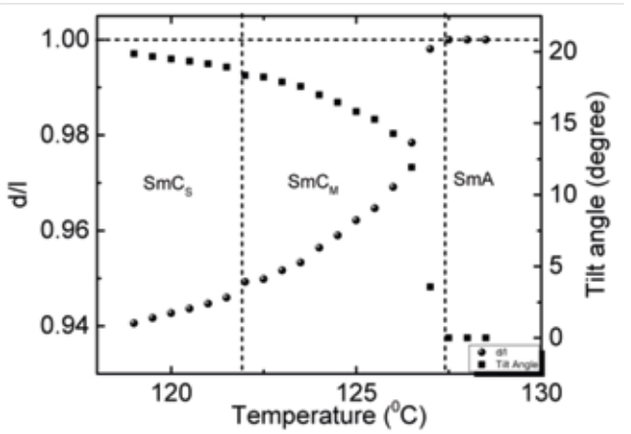


Figure 7. The temperature variation of layer spacing and tilt angle in the smectic phases for BCHS molecule studied.

The other compound studied with longer chain length exhibited two pseudopolar tilted smectic phases which confirmed the results reported by them earlier for another compound. With the motivation to understand the interplay of molecular shape on the thermodynamic properties of binary mixtures of these two different kinds of shapes of liquid crystals molecules they have also studied the phase behavior of binary mixtures of BCHS and rod-like molecules. They constructed a detailed phase diagram in the temperature concentration parameter plane to establish the stability of the different phases. Interestingly, they found that layer spacing in the Smectic A phase of the pure rod-like molecules can be tuned continuously on increasing the concentration of the BCHS compound in the mixture. The variation of layer spacing with the molar concentration of BCHS molecules in the smectic A phase is shown in Figure 8

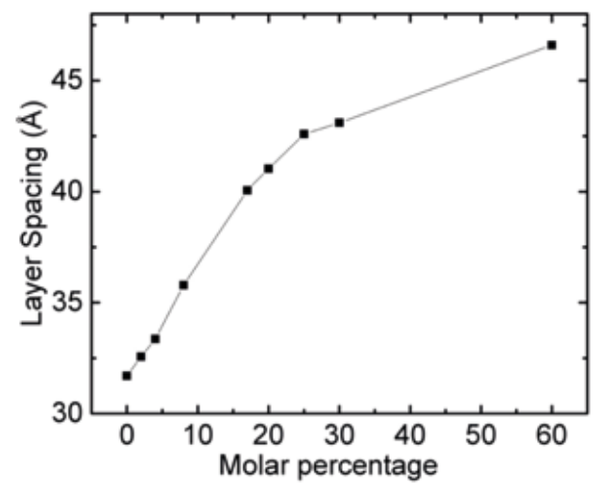


Figure 8. Layer spacing variation in the Smectic A phase as a function of molar percentage of BCHS compound in a pure rod-like molecule

[Deepshika Malkar, Veena Prasad (CeNS, Banagalore) and Arun Roy]

Shape-transforming fluid membranes and elastomer sheets

Nematic films, membranes, and vesicles with vector order are some of the examples of 2D soft material with in-plane orientational-order. Because of their extremely small elastic moduli, these materials offer an ideal testing ground for the interplay between shape, order and topological defects (vortices). It establishes that Gaussian curvature of membranes acts as a source of defects in the orientational-order. Conversely, defects tend to bend flat, deformable membranes. Positive and negative defects of equal strength prefer locally positive (sphere-like) and negative (saddle-like) Gaussian curvatures. Using Nelson-Peliti formalism of membrane elasticity, C Saichand, Yashodhan Hatwalne and Arun Roy have studied the equilibrium properties and energetics of helicoidal and catenoidal membranes with in plane orientational-order. These shapes are easy to produce experimentally, since they are minimal surfaces. In this study, they deal with membranes which have in-plane nematic order, tilt order, tetratic order and hexatic order.
[C. Saichand, Yashodhan Hatwalne and Arun Roy]

Orientational Order and Molecular Organization of 3-Cyano Thiophene based π–Conjugated Mesogens in de Vries Smectic A Phase.

The mesophase properties and the molecular order of 3-Cyano thiophene centered π-conjugated mesogens with alkoxy phenyl/biphenyl rings were investigated by Arun Roy in collaboration with T. Narasimhaswamy. The mesogens synthesized by them mostly exhibited smectic A mesophase and the XRD studies revealed de Vries like phase. Despite structural simplicity, the observation of de Vries smectic A phase was attributed to location of dipole axis across the long axis of the molecules due to the presence of polar cyano at 3-position of central thiophene ring. Interestingly, they found that the order parameters determined from 13C-1H dipolar couplings from 13C NMR to be low further supporting the de Vries like nature of the smectic A phase for the mesogens. Further, due to the manifestation of π-conjugated core, the mesogens exhibited photo luminescence in solution with emission maxima in the range 425-460 nm. They performed density functional theory and time dependent density functional theory calculations on representative mesogens to gain more insight on the nature of the electronic transition and frontier molecular orbital distributions. The results indicated possibility for the intramolecular charge transfer transition between the biphenyl to 3-cyanothiophene units. The observation of de Vries smectic A phase in structurally simple and π-conjugated mesogens is of considerable importance as layer contraction across the smectic A to smectic C transition is very low in contrast to usual smectic A to smectic C phase transition.
[T. Narasimhaswamy (CLRI, Chennai) and Arun Roy]

Structured liquid crystalline gels

Periodic grating-like patterns induced by self-assembly of gelator fibres in nematic gels

Self-assembly of fibrillar networks formed by molecular gelators can form novel nano structured materials. As the nature of the solvent can influence the self-assembly, the combination of anisotropic materials like thermotropic liquid crystals (LCs) and low molecular weight gelators can lead to a different class of gels with new functions and improved properties. During the past year, Neha B. Topnani, Prutha N. and Pratibha R. have succeeded in obtaining self-assembly of elongated fibrous aggregates of a simple alkanoic acid organogelator 12-Hydroxy stearic acid (12-HSA) within the nematic (N) phase formed by E7, a mixture of four cyanobiphenyls, which led to a very interesting grating-like structural motif composed of LC rich and fibre rich regions whose dimensions can be varied depending on the relative concentration of the NLC and the gelator.

They used polarized optical microscopy (POM) to study the microphase separation process in the N-gels and found that the fibres which grow parallel to the plane of the substrate tend to collect together leading to well segregated LC rich regions and regions with mainly self-aligned gelator fibres (Figure 9). As the fibrous structures disturb the underlying LC alignment, fibre rich regions appear bright. The overall optical texture therefore consisted of alternate dark and bright domains with a well-defined periodicity. While the emergence of the pattern formation in the N-gels is by itself not affected by cell thickness, the width of the fibrous domains was found to increase with increase in cell thickness. The structural patterns were stable at room temperature and remained unaltered for months. The segregation process into LC rich and fibre rich regions was observed even with cells treated for homeotropic alignment where the LC director is orthogonal to the substrates showing that it owes its origin to molecular interactions and not due to any surface effects.

They carried out further investigations using XRD, SEM and vibrational spectroscopic studies. X-ray data showed evidence for coexistence of the N phase along with helical fibres in the N-gels. Small angle x-ray scattering measurements showed reflections corresponding to the first and second order peaks at 46.8 and 15.7 Å related to the multilamellar arrangement within the helical fibre with a layer thickness equivalent to the bimolecular length of 12-HSA. A third peak present at 26 Å can be attributed to the E7 molecules which form a structure consisting of an overlapping of the aromatic cores with a quasi smectic A like arrangement due to the molecules having a highly polar cyano end group with a large dipole moment. Wide angle x-ray scattering study of the N-gels showed peaks at 4.5, 4.2, 3.9 and 3.8 Å related with the subcell of 12- HSA, in addition to the broad and diffuse peak related with the liquid like

order in the N phase. The N-gel imaged by Cryo-SEM in situ without removing LC as is normally done, showed well-defined long twisted helical fibers due to the inter-molecular hydrogen bonding (Figure 9). Energy dispersive x-ray analysis also revealed the segregation between the LC rich and fiber rich regions, consistent with the optical observations. Raman and IR spectra of the N-gels exhibit bands around ~2882 and 3200-3400 cm^{-1} respectively corresponding to the intermolecular hydrogen bonding between the secondary hydroxyl groups. The IR spectra also shows a band at ~1690 cm^{-1} indicating the cyclic dimerization of carboxylic acid group resulting in the self-assembly of the helical fibrous network. All the N-gels displayed a sharp band at ~2200 cm^{-1} related with the cyano group similar to the pure E7.

Based on experimental studies, they understood the periodic macroscopic segregation between the LC rich and gelator fibre rich regions as follows. The gelation process depends on solvent-solvent and gelator-gelator interactions and various intermolecular forces. Efficient gelation can occur when the interaction between solvent and gelator is minimal and self-assembled fibrillar networks (SAFiNs) are formed by the gelator fibres. As shown by XRD studies, there is a strong association in the form of antiparallel dimers even in the N-gel. Although these molecules have strong permanent dipole-dipole attractions as well as Van der Waals dispersion forces, they usually cannot form hydrogen bonds. However, despite strong molecular polarity, the blend of E7 and 12-HSA forms a gel. This is mainly because of the strong association between the molecular dimers of the cyano biphenyl compounds in E7, which remain unaltered even in the N-gels and in turn encourages enhanced gelator-gelator interactions via intermolecular hydrogen bonding rather than the solvent-gelator interactions. This leads to a macroscopic segregation of the gelator fibres. The extent of this association depends on the relative concentration of the LC and gelator. As the LC molecules are well aligned owing to the polyimide coated substrates this segregation process encourages the spontaneous self-alignment of the fibrillar aggregates within the LC state leading to the periodic orientation patterns and stability of the N-gel by confining the N between the fibrillar aggregates.

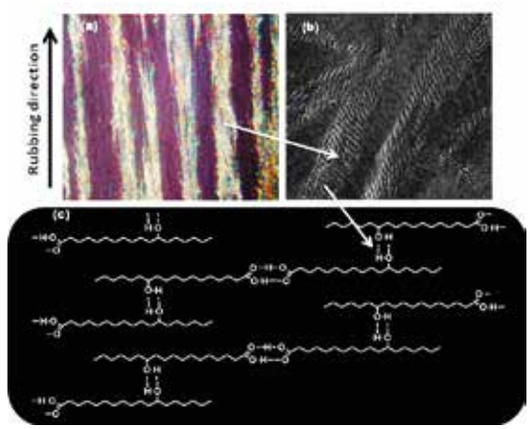


Figure 9. (a) Periodic orientation patterns formed by LC rich and fibre rich domains observed under POM with the N-gel when the N is planar aligned (b) SEM images of N-gel revealing helical morphology of fibrous aggregates (c) Schematic representation of inter-molecular hydrogen bonding within the helical fibres.

Such a periodic organization of the bundles of fibres can act as a template for positioning nanoparticle arrays in an LC matrix which may have the potential to form novel devices.
[Neha B. Topnani, Prutha N., Pratibha R.]

Frustrated liquid crystalline phases

Induced blue phases in mixtures of chiral calamitic and achiral bent-core liquid crystals

Liquid crystalline blue phases occurring in highly chiral systems have evoked immense interest, both from a fundamental perspective and their more recently discovered potential in applications like large-screen flat panel displays and tunable photonic band gap materials. Blue phase (BP) structures typically consist of double-twist cylinders, stacked in three dimensions. Topological constraints restrict the smooth variation of the director in the region between the double twist cylinders leading to the formation of disclination lines. The usual blue appearance is because the spacing between the defects lies in the visible region. Three distinct types of BPs have been observed. Among these, BPI and BPII are more highly ordered, with their disclination networks forming body-centered cubic and simple cubic lattices respectively. On the other hand, BPIII has an amorphous structure. The Kerr effect leading to an induced birefringence depending on the square of the applied electric field is an interesting electro-optic phenomenon associated with BPs. However, utilization of BPs for technological purposes is severely constrained because of their short temperature range of existence.

One of the strategies employed to widen the temperature range of BPs is to induce these phases by doping chiral materials in liquid crystals made of achiral bent-core molecules. Bent-core liquid crystals (BCLCs) have been found not only to enhance the temperature range of the BPs but also contribute to an enhanced Kerr constant. In spite of these developments, several factors like high temperature range of occurrence and high operating voltages have to be overcome in order to make BP liquid crystals to be easily viable for commercial applications. This also necessitates a more detailed understanding of the BP structures and the relation to factors influencing their stability. The earlier studies usually consisted of doping a BCLC exhibiting a nematic (N) phase with a chiral nematic (N*) LC or a non-mesomorphic chiral dopant.

The B7 phase formed by BC molecules is a special type of lamellar phase consisting of periodically modulated layers with the direction of modulation being retained through the lamellar stacks. An earlier geometrical analysis has shown that such an arrangement with the layer spacing being preserved can result in a frustrated structure which may have some analogy with the blue phase double twist structure. It is therefore interesting to investigate the effect of using a BCLC exhibiting the lamellar B7 phase on the BP ranges instead of BC nematics as has been done earlier.

Prutha N. and Pratibha R. have therefore undertaken studies on BPs induced in mixtures of a ferroelectric smectic C* liquid crystal made of chiral rod-like (R) molecules and a BCLC made of achiral molecules and exhibiting two variants of the B7 phase (Compound synthesized by S Umadevi and B K Sadashiva in RRI). Their studies show that for certain concentration ranges, the BP range is substantially enhanced, but on decreasing the temperature the BCLC separates out in the form of clusters of helical filaments which are somewhat different from the filaments that form at the isotropic-B7 phase transition of the pure BCLC (Figure 10). The phase separation process is being investigated by studying selective reflection spectra and monitored by differential scanning calorimetry, dielectric spectroscopy, X-ray diffraction and electro-optic studies. These results have shown that while the stabilization of BPs may owe its origin to smectic nano-clusters formed by the BC molecules, layer undulation occurring within the clusters with decrease in temperature, leads to an incompatibility of the helical structures resulting in phase segregation into the N* phase and the B7 filaments. They are presently investigating the effect of electric fields on these induced blue phases. Their study aids in providing new insights from a molecular point of view for understanding structural requirements and mechanism of obtaining stable induced BPs for optoelectronic applications.

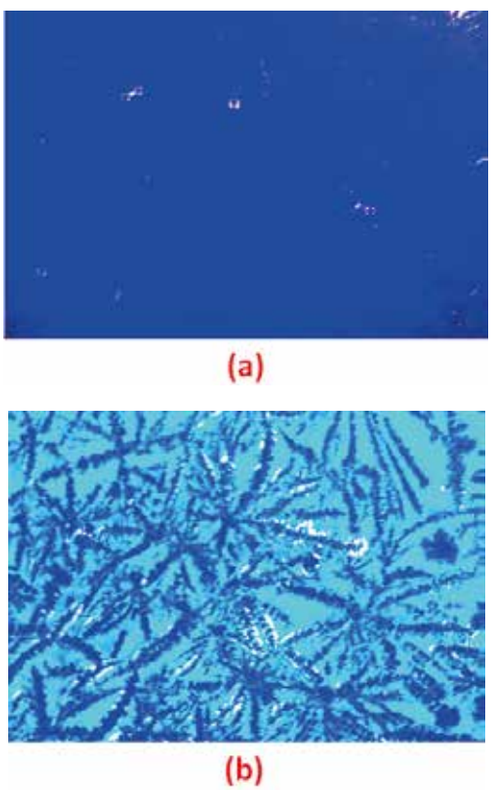


Figure 10. Optical textures exhibited by a mixture of a chiral calamitic liquid crystal and a bent-core liquid crystal made of achiral molecules (a) induced blue phase (b) radial interfacial pattern formed by helical B7 filaments.

[Prutha N. and Pratibha R.]

Liquid crystal nanoscience

Anomalous ordering of single-walled carbon nanotubes in a nematic liquid crystal near the clearing temperature

Carbon nanotubes possess high aspect ratio, high tensile strength and exhibit anisotropic electrical and thermal conductivities. Due to their unique features, they are expected to find applications in solar cells, sensors and mechanical and electrical nano devices. However, to realize most of these applications, uniform alignment of carbon nanotubes is necessary. One way of aligning carbon nanotubes is to disperse them in liquid crystals as it is expected that the liquid crystals impose their orientational order on CNT guests. Uniform nanotube alignments were reported in the literature by dispersing CNTs in thermotropic liquid crystals. However, most of these studies are carried out only at room temperature. The temperature dependence or the dynamics of the CNT alignment in the LC matrix is not reported so far. Motivated by the belief that investigating CNT alignment/ordering in a liquid crystal matrix as a function of temperature will give interesting results, Vijayaraghavan D. and Sandeep Kumar have carried out polarized optical microscopy (POM), X-ray diffraction (XRD), magnetic susceptibility, electrical conductivity and optical birefringence studies as a function of temperature on single-walled carbon nanotubes dispersed nematic liquid crystal 6CHBT and found that on heating, close to the nematic-isotropic (NI) transition temperature of the host LC, the ordering of the carbon nanotubes in the sample increases and exhibit Smectic B, Smectic C and Cholesteric liquid crystalline phases. The temperature dependence of the lateral spacing between the liquid

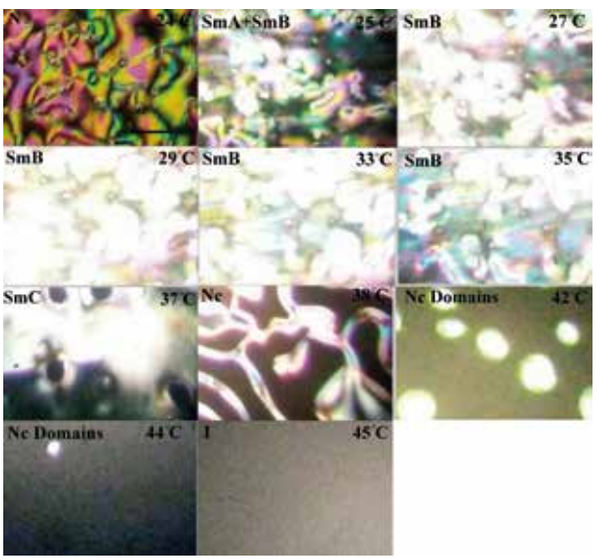


Figure 11. Polarised optical microscopy (POM) textures of the sample (6CHBT+0.25wt.% SWCNT) as a function of temperature. The liquid crystalline (LC) phases corresponding to the textures are also specified in the figure (image size 850x700 µm). The LC phases are identified based on the reports in the literature. They find Nematic (24 °C), Smectic B (27-35°C), Smectic C(37°C), Cholesteric (38°C), Cholesteric domains (42-44°C) and Isotropic (45°C)

crystal molecules close to the NI transition temperature derived from XRD data showed many discontinuous changes. They believe that the density fluctuations very close to the NI transition temperature in the liquid crystal matrix may be responsible for the observed anomalous ordering of carbon nanotubes in the system. They find that the temperature dependence of the optical birefringence, magnetic susceptibility, electrical conductivity and permittivity of the composite showed peaks in Cholesteric phase of the carbon nanotubes indicating a marked enhancement in the ordering of the nanotubes in the Cholesteric phase with respect to the ordering in the other CNT phases. Interestingly, the peaks occur at the LC NI transition temperature.
[Vijayaraghavan D. and Sandeep Kumar]

Soft discotic matrix with 0-D silver nanoparticles: Impact on molecular ordering and conductivity

The interplay between liquid crystals and nanostructures is fascinating as well as challenging to understand the dispersion effect of nanomaterials onto liquid crystals. To gain a better understanding, Shalaka Varshney, Manish Kumar, Ashwathanarayana Gowda and Sandeep Kumar have dispersed zero-dimensional silver nanoparticles (Ag NPs) in two discotic liquid crystals; the columnar stacks of 1,5-dihydroxy-2,3,6,7-tetrakis(3,7-dimethyloctyloxy)-9,10-anthraquinone (RTAQ) and 2,3,6,7,10,11-hexabutoxytriphenylene (HAT4) discotics were self-assembled with silver nanoparticles in a hexagonal manner at different weight concentrations. They observed that the dispersion of NPs reduced the lattice parameter, intracolumnar packing and increased the electrical conductivity by order of four to five in HAT4 DLC.
[Shalaka Varshney, Manish Kumar, Ashwathanarayana Gowda and Sandeep Kumar]

Time-Resolved Fluorescence and Absence of Förster Resonance Energy Transfer in Ferroelectric Liquid Crystal-Quantum Dots Composites

The interaction of octadecylamine(ODA) capped cadmium selenide quantum dots (CdSeQDs) and two ferroelectric liquid crystals (FLCs) having different values of spontaneous polarization (Ps) was studied by Sandeep Kumar and collaborators D.P. Singh, S. Pandey, R. Manohar, G.H. Pujar and S.R. Inamdar. They investigated the pristine FLCs and FLCQDs composites by using steady-state and time-resolved fluorescence spectroscopic techniques and found that Stokes shift and the preferred alignment of FLC molecules in the presence of QDs depends on the secondary order parameter of FLCs (i.e.Ps).They also found that the secondary fluorescence emissions to be strongly influenced by the concentration of QDs and that the Förster Resonance Energy Transfer (FRET) was absent in both the composites. Their work revealed the role of various factors, like relative orientation, dipolar interaction between donor and acceptor and the proximity of QDs (410nm), which might be responsible for the absence of FRET. They conclude that FLC-QDs composites do not form a new class of luminescent material though the fluorescence properties of host FLCs are tailored in the presence of QDs by means of the change in molecular alignment.
[D.P. Singh (Université du Littoral Côte d'Opale, France), S. Pandey (University of Lucknow, Lucknow), R. Manohar (University of Lucknow, Lucknow), S. Kumar, G.H. Pujar (Karnatak Unversity, Dharwad), S.R. Inamdar (Karnatak Unversity, Dharwad)]

CdTe quantum dot dispersed ferroelectric liquid crystal: Transient memory with faster optical response and quenching of photoluminescence

The effect of dispersing Octadecylamine capped Cadmium Telluride quantum dots (CdTe QDs) on the memory behaviour, physical parameters and dielectric relaxations of ferroelectric liquid crystal (FLC) W-327 with the variation of dopant concentration and applied voltage was examined by Sandeep Kumar and collaborators Shivani Pandey, Dharmendra Pratap Singh, Kaushlendra Agrahari, Atul Srivastava, Michal Czerwinski and Rajiv Manohar. They observed significant changes in visible light absorbance, photoluminescence (PL), spontaneous polarization, optical response and relative permittivity of the FLC material with the addition of QDs. An average of 19% (Mix.1) and 28% (Mix.2) fastening of optical response in QDs dispersed FLC mixtures was one of their remarkable findings. Enhancement in visible absorbance along with the quenching in PL intensity was also noticed in FLC/QD mixtures in comparison to pure FLC. The study of tan δ curves confirmed the reduction of ionic impurities in the presence of QDs. Pure FLC as well as FLC/QD mixtures showed time dependent memory effects. The memory behavior of mixtures significantly depended upon the concentration of dopant CdTe. The memory effect was confirmed with the help of dielectric spectroscopy, polarizing optical micrographs and electro-optical study. They attribute the observed memory effect to minimization of the depolarization field and ionic charges. Through this work, they have shown that QDs dispersed FLC plays a major role to enhance memory effects by trapping the impurity ions under the application of bias voltage. Their studies would be helpful to provide an idea for ionic impurity free memory devices having micro-second optical response and in security coded transmission.
[Shivani Pandey (University of Lucknow, Lucknow), Dharmendra Pratap Singh (University of Lucknow, Lucknow), Kaushlendra Agrahari(University of Lucknow, Lucknow), Atul Srivastava(University of Lucknow, Lucknow), Michal Czerwinski (Military University of Technology, Poland), Sandeep Kumar, Rajiv Manohar(University of Lucknow, Lucknow)]

Silver Nanodisks in Soft Discotic Matrix: Impact on Self-assembly, Conductivity and Molecular Packing

In a related work, Manish Kumar, Shalaka Varshney, Ashwathanarayana Gowda and Sandeep Kumar found that two-dimensional functionalized silver nanodisks self-assembled in the columnar mesophase of discotic liquid crystals in a layered forest

of "disk-in-discotic" like pattern. By using cryo-scanning electron microscopy and polarized optical microscopy, they observed signature of molecular self-assembly of hydrophobic silver nanodisks in supramolecular structures of discotic liquid crystals at both room temperature as well as at higher temperature. In their proposed model, the columnar stacks of 1,5-dihydroxy-2,3,6,7-tetrakis (3,7 dimethyloctyloxy) -9,10-anthraquinone (RTAQ) discotic are self-assembled over silver nano-disk in a hexagonal manner at 3% by weight which reduces the lattice parameter and intracolumnar packing. Both scanning electron microscope images and X-ray diffraction patterns showed that when cooled from isotropic phase to columnar hexagonal phase, discotic molecules self-assembled over and in-between nanodisks to form a large layered forest of discotics.
[Manish Kumar, Shalaka Varshney, Ashwathanarayana Gowda and Sandeep Kumar]

Pico-ampere current sensitivity and CdSe quantum dots assembly assisted charge transport in ferroelectric liquid crystal

Sandeep Kumar and collaborators D.P. Singh, Yahia Boussoualem, Benoit Duponchel, Sahraouj Abdelak Hadj, Rajiv Manohar and Abdelylah Daoudi have studied the properties of Octadecylamine capped CdSe quantum dots (QDs) dispersed 4-(1-methyl-heptyloxy)-benzoic acid 4′-octyloxy-biphenyl-4-yl ester ferroelectric liquid crystal (FLC) deposited over gold coated quartz substrate using dip-coating. The topographical investigation showed that the homogeneously dispersed QDs adopt face-on to edge-on assembly in FLC matrix owing to their concentration. They performed current–voltage (I–V) measurement using conductive atomic force microscopy (CAFM) which yielded ohmic to critical diode like I–V curves depending upon the concentration of QDs in FLC. They recorded pico-ampere (pA) current sensitivity in FLC-QDs composites, which they have attributed to micro-second drift time of electron due to weak electronic coupling between the π-electrons on the FLC and s-electrons on the metal surface. The observed pico-ampere sensitivity is the least current sensitivity recorded so far. For FLC-QDs composites, they observed almost 24% faster electro-optic response in comparison to pure FLC. The pico-ampere current sensitivity reported in this work can be utilized in touch screen displays whereas the change in polarization for low applied electric field ameliorates the increased electrical susceptibility which counteracts the internal electric field and could have potential applications in electronic data storage and faster electro-optical devices.
[Singh, Dharmendra Pratap (Université du Littoral Côte d'Opale, France), Boussoualem, Yahia (Université du Littoral Côte d'Opale, France), Duponchel, Benoit (Université du Littoral Côte d'Opale, France), Hadj Sahraoui Abdelak (Université du Littoral Côte d'Opale, France), Kumar, Sandeep, Manohar, Rajiv (University of Lucknow, Lucknow), Daoudi, Abdelylah (Université du Littoral Côte d'Opale, France)]

Discotic Liquid Crystals with Graphene: Supramolecular Self-assembly to Applications

In past decades many breakthroughs have been witnessed in research on liquid crystals (LCs) and the application of LCs has spread. On another side graphene is considered as a rapidly rising star on the horizon of materials science, soft condensed matter physics with promising applications. Supramolecular chemistry of LCs and graphene together is described as "chemistry beyond the molecule". A new class of 2D colloidal graphene oxide liquid crystalline material consisting discotic liquid crystallinity and their interactions with LCs present a platform for number of versatile properties and applications. In a review article, Manish Kumar, Aswathanarayana Gowda and Sandeep Kumar have focused on discotic liquid crystalline (DLC) behavior of graphene oxide/reduced graphene oxide in various solvents, their characterization and application for energy storage, wet-spinning fibers, electro-optical devices, and displays etc. In the first part of this review, they have given a brief introduction of discotic graphene oxide liquid crystals (GOLCs), their fundamental, synthesis process, supramolecular structures of graphene-DLC composites. In the second part, some important physical studies and application of this largest polycyclic aromatic core of DLCs were discussed. Finally, they have provided an outlook on this emerging two dimensional material in liquid crystal field with relevant scientific application background.
[Manish Kumar, Ashwathanarayana Gowda and Sandeep Kumar]

Trapping of inorganic nanowires in supramolecular organic nanoribbons

Self-assembly of semiconductor nanowires into three-dimensional network implicates a new era of nanoelectronics applications. Avinash. B. Shivanandareddy, Manish Kumar, Ashwathanarayana Gowda and Sandeep Kumar have demonstrated the incorporation of cadmium sulphide (CdS) nanowires in the supramolecular order of discotic liquid crystal. They studied the sample using polarized optical microscopy, differential scanning calorimetry, X-ray diffraction, FE-SEM and EDAX. Results indicate that CdS nanowires were trapped in ribbon like structures of hexahexyloxy-triphenylene discotic liquid crystal. They observed a 3-4 orders of magnitude increase in conductivity of the system on doping CdS nanowires.

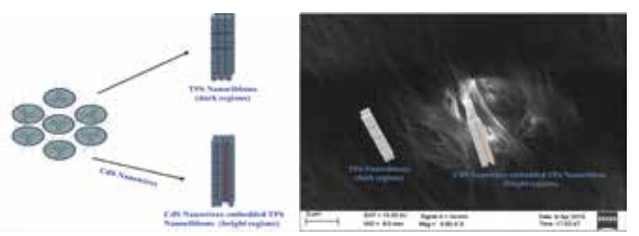


Figure 12. (Top) Schematic illustration of trapping of CdS nanowires in nanoribbons of triphenylene. (Bottom) FE-SEM images incorporation of cadmium sulphide nanowires in the supramolecular order of discotic liquid crystal. These nanocomposites may be useful for many device applications.

[Avinash. B. Shivanandareddy, Manish Kumar, Ashwathanarayana Gowda and Sandeep Kumar]

Effect of metallic silver nanoparticles on the alignment and relaxation behaviour of liquid crystalline material in smectic C phase*

The influence of silver nanoparticles dispersed in a Ferroelectric Liquid Crystal (FLC) on the properties of the resultant composite system was investigated by Sandeep Kumar and collaborators Tripti Vimal, Swadesh Kumar Gupta, Rohit Katiyar, Atul Srivastava, Michal Czerwinski, Katarzyna Krup and Rajiv Manohar using thermal, electro–optical, and dielectric methods. They have shown that the concentration of thiol capped silver nanoparticles is a critical factor in governing the alignment of nanoparticles (NPs) in the host FLC and that the orientation of NPs in composite samples affects the ordering of the LC phase and consequently changes the various phase transition temperatures of the host LC. They further observed the formation of self-assembled 2D (two dimensional) arrays of nanoparticles for high concentration of dopant in the LC, oriented perpendicular to the direction of rubbing and propose that the molecular interaction between the thiol capped NPs and LC molecules is the key factor behind such an arrangement of NPs. Orientation of NPs has affected the relaxation behaviour and various other material parameters, significantly. A noteworthy change in DC conductivity articulates their proposed idea of the formation of 2D array of NPs perpendicular to the direction of rubbing. This comprehensive study endorses the importance of dopant concentration in modifying the properties of the host LC material.
[Tripti Vimal (University of Lucknow, Lucknow), Swadesh Kumar Gupta (IIT, Delhi), Rohit Katiyar (University of Lucknow, Lucknow), Atul Srivastava (University of Lucknow, Lucknow), Michal Czerwinski (Military University of Technology, Poland), Katarzyna Krup (Military University of Technology, Poland), Sandeep Kumar, and Rajiv Manohar (University of Lucknow, Lucknow)]

The optical properties of quantum dots in anisotropic media

The optical properties of cadmium selenide quantum dots were investigated by Sandeep kumar and collaborators U.B. Singh, Deepa Singh, R. Dhar , M.B. Pandey in nematic liquid crystals, which were used as an anisotropic medium. They studied the effects of anisotropic media on the optical properties of immersed quantum dots through ultra-violet absorption/transmission spectroscopy and calculated the optical band gap and refractive index of immersed quantum dots for isotropic and anisotropic medium. They have also discussed the influences of anisotropic medium on the optical properties of quantum dots in terms of anchoring of liquid crystals molecules on the surfaces of immersed quantum dots.
[U.B. Singh (University of Allahabad, Allahabad), Deepa Singh (University of Allahabad, Allahabad), S. Kumar, R. Dhar (University of Allahabad, Allahabad), M.B. Pandey (Vikramajit Singh Sanatan Dharama College, Kanpur)]

Recent Advances in Discotic Liquid Crystal-Assisted Nanoparticles

In a recently published review article, Ashwathanaryana Gowda and Sandeep Kumar have summarized recent advancement in the field of discotic liquid crystal (DLC) nanocomposites. Discotic liquid crystals are nanostructured materials, usually 2 to 6 nm size and have been recognized as organic semiconducting materials. Recently, it has been observed that the dispersion of small concentration of various functionalized zero-, one- and two-dimensional nanomaterials in the supramolecular order of mesophases of DLCs imparts negligible impact on liquid crystalline properties but enhances their thermal, supramolecular and electronic properties. In this article, they discuss the synthesis, characterization and dispersion of various nanoparticles in different discotics.
[Ashwathanarayana Gowda and Sandeep Kumar]

Liquid crystals – phenomenological theory

Interplay between elasticity and topological defects on orientationally ordered, minimal-surface configurations of fluid membranes

Using the equations of equilibrium, C Saichand, A Jaya Kumar, Arun Roy and Yashodhan Hatwalne have considered the Thomson problem for the arrangement of disclinations (vortices) on catenoids and helicoids for nematic, vector, tetratic, as well as hexatic orientational order. They are currently preparing a manuscript based on this work.
[C. Saichand, A Jaya Kumar (IISc, Bangalore), Arun Roy and Yashodhan Hatwalne]

Mechanical properties of soft materials

Nonlinear mechanics and memory effects in in-vitro biopolymer networks

Overview:

Designing smart and adaptable materials that can modify their mechanical properties widely and in a controlled manner in response to external cues remains an outstanding challenge in material science. Such materials modify their properties in response to external cues like, stress, temperature, electric and magnetic fields, pH etc. Examples of such materials include, shape memory alloys, bio-mimetic materials, piezoelectric materials, and ferrofluids.

In the last couple of decades there has been an upsurge in interest in the study of a new class of materials known as ‘soft materials’ which are intermediate between Newtonian liquids and crystalline solids. In recent years, ‘soft materials’ such as, colloids, polymers, liquid crystals, granular-materials, emulsions, and biological materials are rapidly becoming important building blocks for various designer

materials and center of focus of interdisciplinary research. In these materials the constituents are generally held together by weak inter-molecular entropic forces that can easily be manipulated for various design purposes without going into the actual atomic and molecular details.

Apart from serving as design motifs for adaptive materials, these systems also pose variety of interesting fundamental questions and serve as the testing grounds for many non-equilibrium and many body phenomena which are extremely difficult to probe experimentally in atomic systems due to the fast relaxation processes and extremely short length scales.

Nonlinear mechanics and memory effects in in-vitro biopolymer networks:

The cellular cytoskeleton is a highly dynamic network of cross-linked protein filaments that gives the cell its rigidity. The cytoskeleton also takes part in cellular motility, signaling and other active mechanical processes. The versatility of the cytoskeleton networks in controlling the mechanical response of a cell under widely varying conditions also motivates material design strategies. The bio-polymer F-actin is the most abundant protein in the cell cytoskeleton and the essential determinant of the mechanical behaviour of eukaryotic cells. These filaments are semi-flexible with thermal persistence length orders of magnitude higher than that of flexible synthetic polymers (e.g. polyethylene). The semi-flexibility of these filaments together with the highly dynamic nature of physiological cross-linkers displays striking non-linear properties.

Ongoing projects and recent findings:

Deformation history dependent mechanical response in polymeric materials had been discovered more than fifty years ago in filled rubber-like materials showing cyclic-softening or Mullin's effect. Recently, such history dependent effects in the form of both cyclic-hardening (in bundled F-actin networks) as well as softening have been observed in bio-polymers. Importantly, all these effects are irreversible: Mullin's effect arises from the permanent breakage of chemical bonds in filled synthetic polymers and cyclic hardening in bio-polymers arises from the formation of permanent bundles under large strain. Such irreversibility limits the potential of these systems in designing adaptable materials.

Sayantan Majumdar and collaborators Louis C. Foucard, Alex J. Levine, and Margaret L. Gardel have recently discovered a novel type of mechanical adaptation in cross-linked networks of F-actin. They found that shear stress changes its nonlinear mechanical response even long after that stress is removed. The duration, magnitude and direction of forcing history all impact changes in mechanical response. The `memory' of such forcing history is long-lived, but can be erased by stress application in the opposite direction. They have also shown using numerical simulation and confocal microscopy that the observed mechanical adaptation is consistent with stress-dependent changes in the nematic order of the constituent filaments. This study demonstrates that F-actin networks can encode analog read-write mechano-memories, which can be used for adaptation to mechanical stimuli. As a continuation of this project, Danielle Scheff, Sayantan Majumdar and Margaret L. Gardel are investigating the role of cross-linker rigidity in tuning such mechanical memory.

Furthermore, in an ongoing work Sayantan Majumdar has found that the long-lived mechanical memory in these networks is related to the glassy dynamics and slow logarithmic relaxation processes. Such slow logarithmic relaxation has been observed for a variety of non-equilibrium systems. A few examples include current relaxation in MOSFET devices, flux creep in superconductors, structural relaxation in colloidal glasses, and compaction in agitated granular materials. Sayantan Majumdar and M.K. Firoz (NIT, Rourkela) are currently trying to model this behavior in biopolymer networks using simple visco-elastic components.

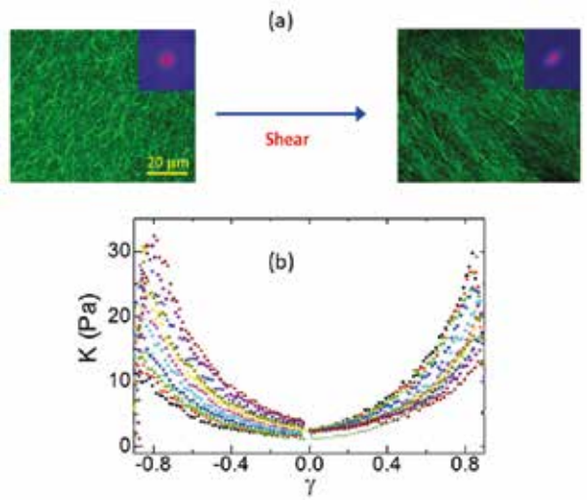


Figure 13. (a) Fluorescence confocal images showing shear induced nematic ordering in actin networks giving rise to mechanical memory; insets show the corresponding Fourier transform images. (b) Memory induced tuning of non-linear shear modulus in actin networks. In all cases, the concentration of actin is 1 mg/ ml with 5% Filamin cross-linkers.

[Sayantan Majumdar, Louis C. Foucard (University of California, USA), Alex J. Levine (University of California, USA), Margaret L. Gardel (The University of Chicago, USA)]

Structure, dynamics and rheology of non-Newtonian fluid

Transient jamming dynamics in dense particulate suspensions

When we add solid particles to a Newtonian liquid like water or oil, the viscosity of the suspension increases with increasing particle volume fraction as first studied by Einstein more than hundred years back. At very high volume fractions (> 0.5) the particles start to strongly interact through lubrication and contact forces and the

suspension becomes significantly non-Newtonian. Apart from fundamental interests, understanding flow behaviour of dense suspensions is crucial for many large scale industrial processes. Importantly, the viscosity of many dense suspensions increases discontinuously by orders of magnitude under applied stresses (known as discontinuous shear thickening or DST). Under high enough applied stress some suspensions can even form a solid-like jammed state that has a finite yield stress. In light of recent interests in designing flexible shock absorbing / impact mitigating materials using such liquid to solid transition under force, understanding the dynamics of jamming transition is extremely important. Although, jamming transition has been extensively studied in the context of dry granular materials, similar phenomenon is much less understood for suspensions mainly because of the complexity arising from the interplay between the hydrodynamic and frictional interactions.

Ongoing projects and recent findings: Recently, Sayantan Majumdar along with collaborators Ivo R. Peters, Endao Han and Heinrich M. Jaeger have probed the transient jamming dynamics under non-compressive deformations like, extension and simple shear. Using force measurements, high speed optical and ultrasound imaging, they found that the jamming transition is mediated by a propagating dynamic jamming front travelling much faster than the applied external drive. They have explicitly showed that strong localized shear at the front region converts the fluid-like suspension ahead into a solid like material in their wake. Understanding the transient dynamics of this 'jamming front' is extremely important in light of the recent interests in designing flexible shock absorbing materials as mentioned before. To get further insight into this interesting mechanical response, Sayantan Majumdar and Sebanti Chattopadhyay are currently trying to understand the surface properties and inter-particle interactions using SEM and AFM techniques.

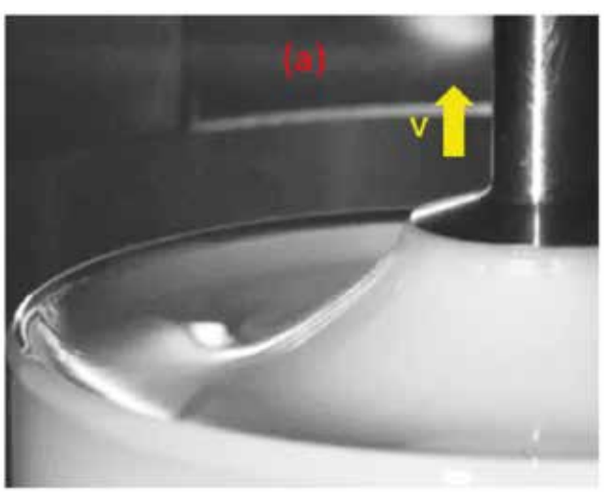
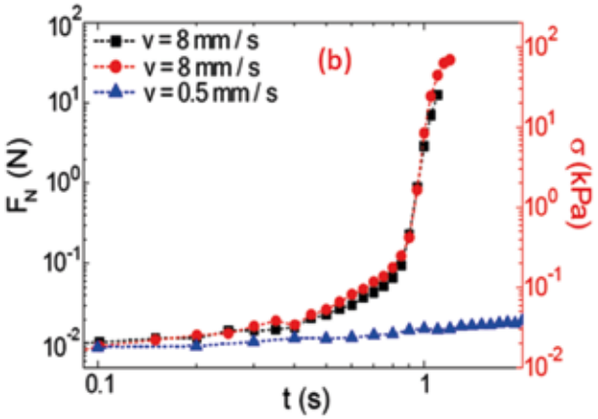


Figure 14. (a) Optical image showing the tensile stress induced transformation of dense corn-starch suspension (volume fraction~0.5) from a fluid-like to a solid-like state under sufficiently high pulling velocity. (b) Force response under different pulling velocities. The formation of the frustum shape [shown in (a)] correlates with huge increase in force / stress on the pulling plate.



[Sayantan Majumdar, Ivo R. Peters (University of Southampton, UK), Endao Han, (The University of Chicago, USA) and Heinrich M. Jaeger (The University of Chicago, USA)

Electric field induced gelation in colloidal nanoclay suspensions

Theme:

Paramesh Gadige and Ranjini Bandyopadhyay reported the irreversible transformation of fluid-like Laponite nanoclay aqueous suspensions into soft solids due to the application of DC electric fields. They investigated the rheological behavior of these solids and their microstructures using rheometric techniques and cryo-scanning electron microscopy(cryo-SEM), respectively.

Detailed summary:

Aqueous colloidal Laponite clay suspensions transform spontaneously to a soft solid-like arrested state as its aging or waiting time increases. In a recent experimental work, they have reported the rapid transformation of aqueous Laponite suspensions into soft solids due to the application of a DC electric field. They observed a substantial increase in the speed of solidification at higher electric field strengths. The electric field was applied across two parallel brass plates immersed in the Laponite suspension. The subsequent solidification that takes place on the surface of the positive electrode was attributed to the dominant negative surface charges on the Laponite particles and the associated electrokinetic phenomena. With increasing electric field strength, they observed a dramatic increase in the elastic moduli of the samples. These electric field induced Laponite soft solids demonstrated all the typical rheological characteristics of soft glassy materials. They also exhibited a two-step shear melting process similar to that observed in attractive soft glasses. The microstructures of the samples, studied using cryo-scanning electron microscopy (SEM), are seen to consist of percolated network gel-like structures, with the connectivity of the gel network increasing with increasing electric field strengths. In comparison with salt induced gels, the electric field induced gels

studied here are mechanically stronger and more stable over longer periods of time. This article is being reviewed for publication in Soft Matter.
[Paramesh Gadige and Ranjini Bandyopadhyay (with help using the cryo SEM from Yatheendran K. M. and Dhason A.)]

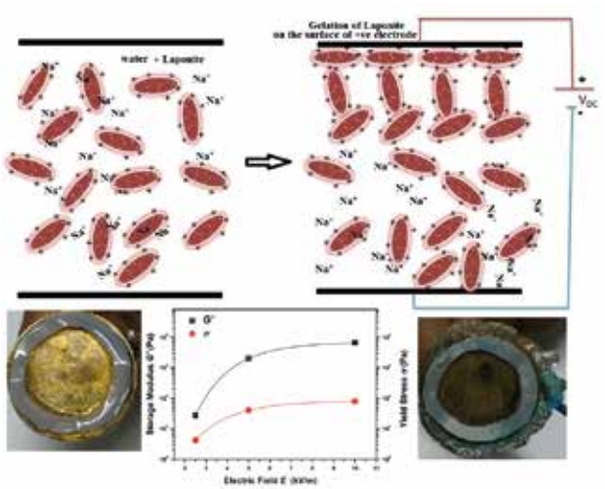


Figure 15. The cartoon shows disk-like Laponite colloids diffusing freely in the aqueous medium in the absence of an electric field and the initiation of a house of cards aggregation mechanism immediately upon the application of a DC field. The application of a DC voltage gives rise to the formation of a jelly like (gel) material on the positive electrode (photo on the bottom right). A gel is not formed when an AC voltage is applied (phone on the bottom left). The plot shows the formation of Laponite gels of progressively higher rigidities with increase in the strength of the DC electric field E.

Physics of Lipid Membranes and Polyelectrolytes

Chiral structures of surfactant-DNA complexes

DNA forms complexes with oppositely charged surfactants. X-ray diffraction studies have shown that they have a two dimensional hexagonal structure. Anindya Chowdhury and V. A. Raghunathan have recently observed that these complexes exhibit circular dichroism (CD), indicating that their structure is chiral. Further, the CD signal is found to change with salt concentration in the solution. They are currently probing associated structural changes using small angle x-ray scattering and cryogenic electron microscopy.
[Anindya Chowdhury and V. A. Raghunathan]

Interaction of mononucleotides with lipid membranes

According to the RNA world hypothesis of the origin of life on earth, RNA-like self-replicating polymers can be synthesized non-enzymatically from mononucleotides in a lipid environment. Motivated by this Sreeja Sasidharan and V. A. Raghunathan in collaboration with Sudha Rajmani and Himanshu Khandelia have been studying the interaction of uridine monophosphate (UMP) with phosphatidylcholine (PC) lipid membranes. They recently used computer simulation studies to understand the interaction of UMP with lipid membranes and have confirmed that the UMP molecules bind to the membrane and increase its fluidity. Interestingly, they observed this behaviour only with the acid form of UMP. On the other hand, the sodium salt of UMP was found not to bind to the membrane, but to form small clusters loosely attached to the membrane. These results help in understanding the significant differences in the effects of UMP and its sodium salt on the membrane, observed in x-ray diffraction experiments.
[Sreeja Sasidharan, Sudha Rajmani (IISER, Pune), Himanshu Khandelia (University of Southern Denmark, Denmark) and V.A. Raghunathan]

Biophysics

Nanoscale biophysics of biological systems

Gautam Soni's Nano-Biophysics lab's research interests are primarily guided by the role of force in biophysical structure formation and its synergy with functional dynamics. They try to understand mechanisms of force-sensing as well as force-response of cells and molecules. They study this in biological model systems of protein-assembly, DNA-protein complexes as well as whole cell mechano-sensing. They use, as well as develop, novel bio- nano and micro scale tools to decipher biophysical principles governing role of forces in cellular as well as molecular assemblies.

The lab members are currently looking at three aspects:

(1) Deciphering chromatin structure- function relationships from a biophysical point of view. In the lab, they are focusing on measuring the structural interactions that underlie molecular function in biological systems using a plethora of single molecule nanoscience tools (Nanopore platform, AFM, Optical tweezers, fluorescence microscopy etc). Changes in chromatin structure are a key element in epigenetic gene control. Activation and/or transcriptional-silencing of genes via condensation-decondensation of chromatin are its ubiquitous features. Defects in how chromatin is locally condensed are relevant to physiological and pathological processes. However, the molecular mechanisms that establish and maintain functionally distinct chromatin compaction states are poorly understood. Nucleosome formation is the primary element of chromatin fiber and the nucleosome-nucleosome interactions sets the primary phase of chromatin compaction. The lab has customized the Atomic Force Microscope to quantitatively measure these inter-nucleosome interactions. To establish single molecule resolution in their measurement technique, the lab has measured protein-protein (biotin-streptavidin) interactions at resolution of single bond rupture.

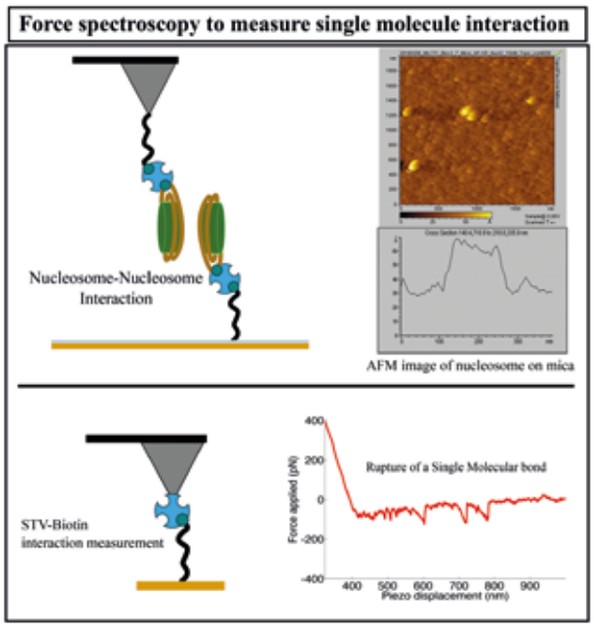


Figure 16. Force spectroscopy to measure single molecule interactions.

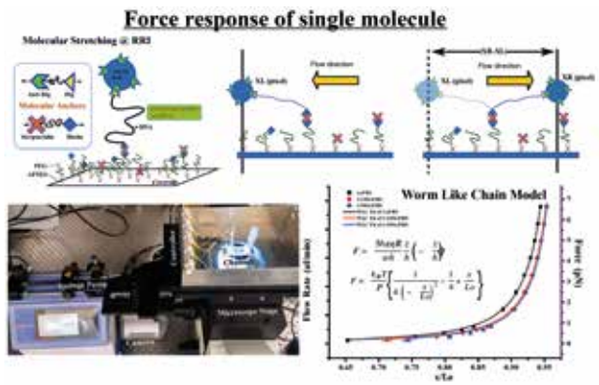


Figure 17. Force response of a Single DNA molecule using fluid-flow method.

To address DNA mechanics, the lab has also applied the existing microfluidics facility to build a fluid-force device. With this device, fluid force is applied on single tethered DNA molecules and their elastic response is measured under various salt conditions.

(2) Mechanism of force transduction across the cell nucleus: External mechanical cues are transmitted across the cell membrane, through the cytoplasm, across the nucleus and all the way to the cell's chromatin, to seek a response. However, mechanisms of transmission of force inside the cell is not well understood. They are addressing this problem at the cell nucleus by isolating the mechanical transducers across the cell nucleus and studying their mechanical properties.

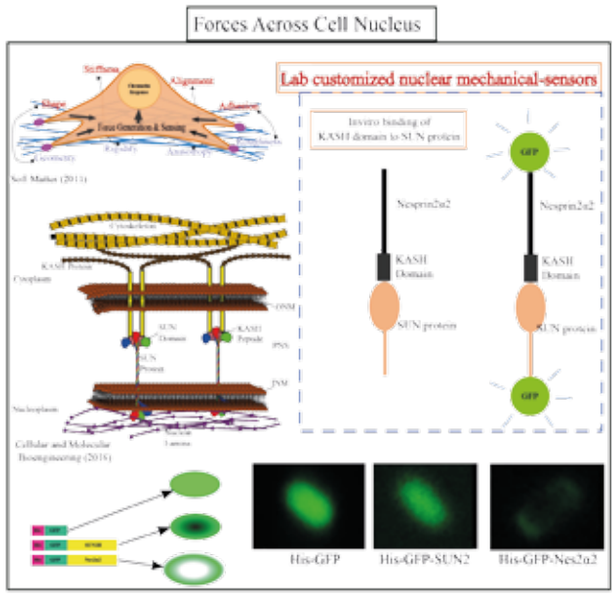


Figure 18. Lab customized nuclear mechano-sensors molecules are being isolated to measure force sensing across cell nucleus.

3) Developing novel tools for measuring cell volumes and whole-cell stiffness (WCS): They use single-cell microfluidics and custom electronics to find ways of turning mechano-sensing mechanisms of cells into physiological markers of diseases. This will allow translational applications of their research into early diagnostics field.
[Gautam Soni, Cecil Ross (St. Johns Hospital, Bangalore) and Feroz Meeran (C-CAMP, Bangalore)]

Optical Tweezer as force sensor - construction and optimization:

Gautam Soni's lab is also building a custom single molecule manipulation system. The recent developments on laser optical tweezer allows convenient manipulation and quantitative measurements of mechanical properties of biological objects without any damage to the cells. Laser optical tweezer based on ultra-stable IR laser source was designed and built by Durai Murugan Kandhasamy and Gautam Soni on the optical isolation table (Figure 19). The source is a Diode pumped solid state laser operating at 1064 nm in CW mode. The trapping beam intensity is modulated by a combination of half-wave plate and polarizing beam splitter cube. The laser beam was expanded to 8X by using a telescope set-up in order to fill the back aperture of the objective. The beam position and size are manually manipulated by a 1x beam steering assembly. The trapping laser is passed to the back aperture of the objective and imaging is done by using a white light Kohler illumination. A beam splitter before the 45° reflecting mirror directs illumination light to camera. The laser optical tweezer set up is complete and they are currently in the process of force calibration.

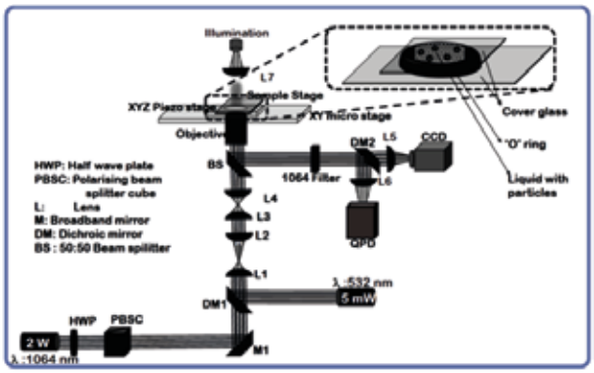


Figure 19. Schematics of the optical tweezer setup.

Biophysics of Axons

Neuronal cells are "extreme cells" as they have to span very long distances in order to conduct electrical signals across an organism. For this they generate tubular extensions called axons and dendrites. The lengths of axons in a human body range from 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. Apart from their amazing ability to conduct weak electrical signals as action potentials, they also possess unique mechanical properties which are only beginning to be appreciated. In the brain and during early development, axons are highly dynamic capable of making fresh connections and retracting redundant or wrong ones. This necessitates a dynamic structure. At the same time, they also have to be mechanically stable as they underdo large localised deformations during normal limb movement or shear deformations of the brain resulting from impacts. To withstand such mechanical stresses and to recover their original length they should possess special elastic properties. They can also generate contractile stresses like muscle cells. Formation of cortical folds in the brain is suspected to be the result of a mechanical instability resulting from axonal contraction. During early development axons often take convoluted paths to their targets and the subsequent length minimisation (for faster signal transmission) is believed to be driven by contractile stress generation. How do axons incorporate these varied responses into the same tubular structure?

It has been shown in recent years that axons show different response to mechanical stresses depending on timescale. Under fast deformations (~ 1 min.) they show a viscoelastic response. At intermediate timescales they exhibit contractile responses, and at long time scale (tens of minutes) they exhibit tension-induced growth where the axon switches on its protein synthesis machinery and extends maintaining a constant diameter in response to tension. Recently, research in Pramod Pullarkat's lab has shown that the axonal mechanical response can be understood based on a non-linear viscoelastic model which invoke contractile stresses generated by molecular motors. However, the microscopic structural aspects and mechanisms which give rise to these properties are mostly unknown. In order to understand these members in Pramod Pullarkat's lab develope new quantitative measurement techniques and combine them with biological and genetic tools to specifically perturb or modify structural elements within the axon. The data thus obtained are used to develop theoretical models to elucidate the physical principles governing such responses. Thus this is an inter-disciplinary collaborative effort involving neurobiologists from IISER-Pune, experimental physicists from RRI and theoreticians from Institut Curie and University of Paris, France. A few examples of ongoing and recently completed projects are discussed below.

Probing mechanical properties of Axons

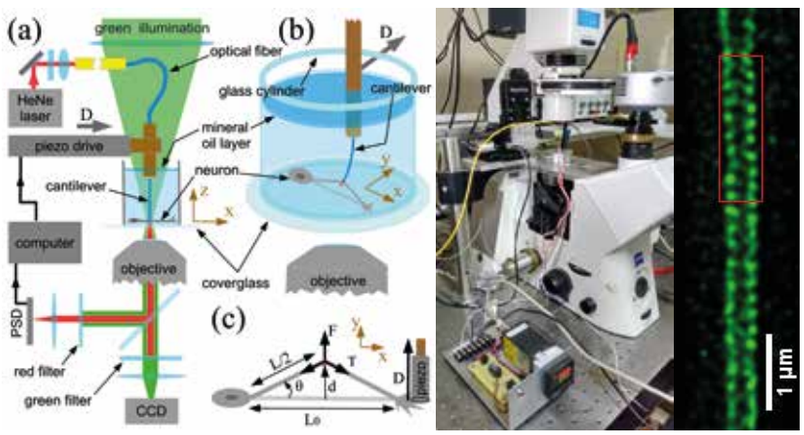


Figure 20. (Left) (a) A schematic diagram of the optical fiber force apparatus designed and developed at RRI (published in Rev. of Sci. Instr., 2013; RRI-NCL-Pune joined patent). This technique uses an etched and calibrated optical fiber as cantilever to apply nano-scale deformations to live axons and to measure forces in the range of nano-Newton. A computer feedback mechanism allows for strain controlled perturbations. This device can also perform Micro-Extension Rheology of samples like polymer melts and silk (published in Acta Rheol., 2017). (b, c) Schematics showing how an axon is stretched and the various parameters that are measured. (Middle) A photograph of the setup. (Right) A super-resolution image of the periodic spectrin arrangement in an axon taken using a STED microscope in collaboration with IISER-Pune.

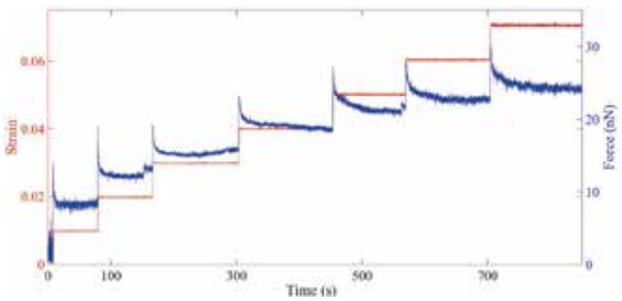


Figure 21. An example of the imposed strain and axonal force response recorded using the Micro-Extension Rheometer. The plot shows non-linear viscoelastic response and analysis reveals a strain softening of the elastic modulus.

Sushil Dubey, Nishita Bhembre, and Pramod Pullarkat along with collaborators Aurnab Ghose and Andrew Callan Jones have probed the mechanical properties of axons using an optical fiber force apparatus they have designed and developed at RRI (see figures). They have performed rheological measurements on axons using the constant-strain mode and have shown that axons exhibit a strain softening response as opposed to strain stiffening seen in other cell types. By performing genetic knock-down or pharmacological blocking experiments to delete specific protein components, they have shown that this softening response is due to the force induced unfolding of spectrin repeat domains. Thus, spectrin which is organised as a 1D lattice along the axon acts as a tension buffer or "shock absorber" allowing axons to undergo large reversible deformations without rupture. [work to be published].

[Sushil Dubey, Nishita Bhembre, Aurnab Ghose (IISER, Pune), Andrew Callan Jones (University of Paris, France) and Pramod Pullarkat]

Anagha Datar, Jaisha Bhanu, Roli Srivastava, Alka Bhat and Pramod Pullarkat in collaboration with Jacques Prost, Andrew Callan-Jones have performed experiments and developed theoretical models that aims to understand the shape stability of axons. They use specific biochemical agents to depolymerise actin-filaments or microtubules (biopolymers present inside the axon) and study the resulting shape evolution. They observed two distinct responses. (i) After microtubule depolymerisation the axon develop peristaltic radius modulations (see images on left). (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 (see images in the middle). Using experimental data and theoretical analysis they show that these morphological transitions are akin to the well-known Rayleigh-Plateau instability of fluid jets and is driven by axonal membrane tension. Microtubules, which form a polar filamentous bundle along the length of the axon, are central to the stability of the axon and the nature of its degradation dictates the shape evolution under perturbed conditions. Such shape evolutions are commonly observed in a wide range of neurodegenerative conditions like Alzheimer's and nerve injury and these results may provide clues as to how to stabilise axons against shape transitions. [work to be published].

[Anagha Datar, Jaisha Bhanu, Roli Srivastava, Alka Bhat, Jacques Prost (University of Paris, France), Andrew Callan-Jones (University of Paris, France) and Pramod Pullarkat]

Axonal shape instabilities

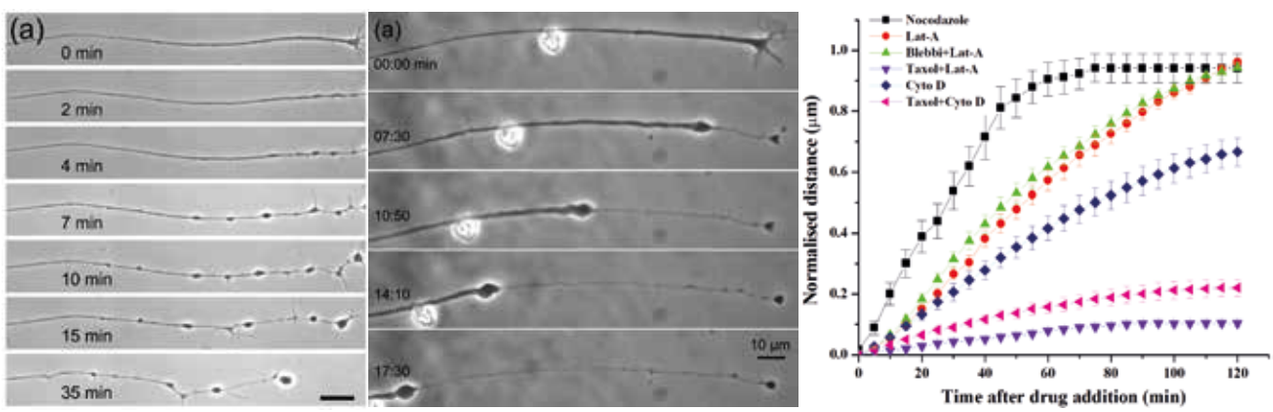


Figure 22. (Left, Middle) Two distinct shape transformations seen in axons after disruption of specific biopolymer elements within the cell. On left, a peristaltic mode develops progressively from the tip when microtubules are perturbed (scale bar 20 micron). The middle image shows axon response via a single travelling front when actin filaments are perturbed. Both cases lead to eventual axonal atrophy and such shape evolutions are commonly seen to result from neurodegenerative diseases. (Right) Quantification of the axonal dynamics like the ones shown in the image sequences.

Cell adhesion studies using a home-developed fluid shear device

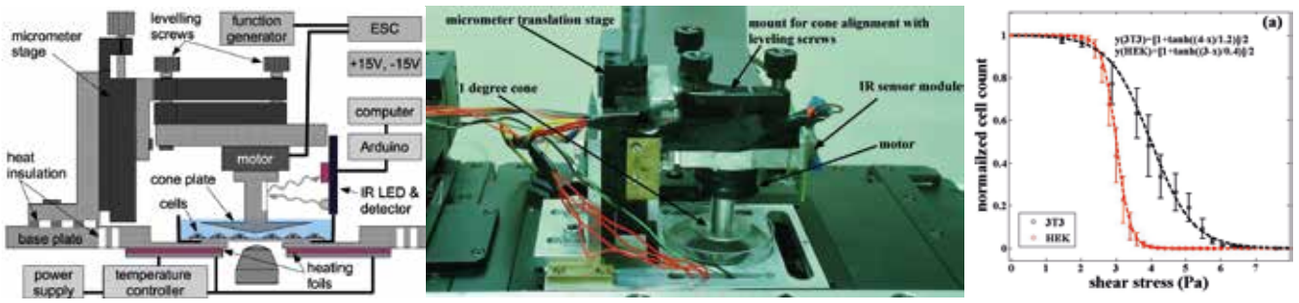


Figure 23. (Left, Middle) A schematic and a photograph of the compact fluid shear deice developed at RRI to quantify cell adhesion properties (Phys. Biol., 2018; joined patent with IISc). The device is built using a high precision computer hard disc motor. The motor and encoder are controlled using a computer interface to apply different shear stress protocols to adherent cells. (Right) A plot of the cell detachment dynamics (normalised count of adherent cells) as a function of applied shear stress. The dashed lines are from a theoretical model. Apart from understanding cell adhesion, this device can be used to study changes in cell adhesion during metastasis.

Renu Vishavkarma and Pramod Pullarkat has developed a shear device for studying the effect of shear stress on cells along with fluorescence microscopy. The device itself is new—it was made using a computer hard-disk motor which provides superb wobble-free performance and is very compact and hence mountable on any standard microscope including confocal systems. Renu has shown that this device can differentiate changes in adhesion and it can also be used along with micropatterning to create well defined cell geometries. She has shown that cell adhesion can be quantitatively studied by measuring the cell detachment under either a constant shear as a function of time or as a function of shear stress. A theoretical model describing the stochastic bond detachment kinetics under shear stress was developed by Gautam Menon and his student from IMSc Chennai. This device will now be used to study mechno-transduction in cells and to quantify changes in cell adhesion occurring in cells undergoing metastasis. [published in Physical Biology, 2018]
[Renu Vishavkarma, Gautam Menon (IMSc, Chennai) and Pramod Pullarkat]

Active contractile response of axons

This work is aimed at understanding how active tension is generated in axons and the role played by this in axonal length regulation. This work was done in collaboration with Aurnab Ghose, Sampada Mutalik and Joby Joseph. For this Sampada developed an axon-straightening-assay using micropatterning (see Figure 24) and successfully showed that myosin-II molecular motor proteins are essential for axonal tension development. The contractile responses are measured by tracking fluorescently labelled docked mitochondria in the axon. The tension thus developed enables axons to undergo length minimization. [published in Biophysical Journal, 2018]
[Aurnab Ghose (IISER, Pune), Sampada Mutalik (IISER, Pune), Joby Joseph (University of Hyderabad) and Pramod Pullarkat]

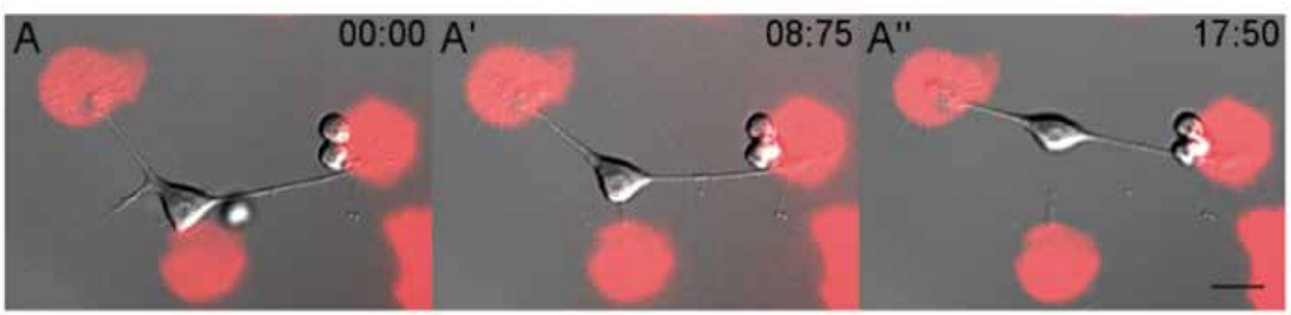
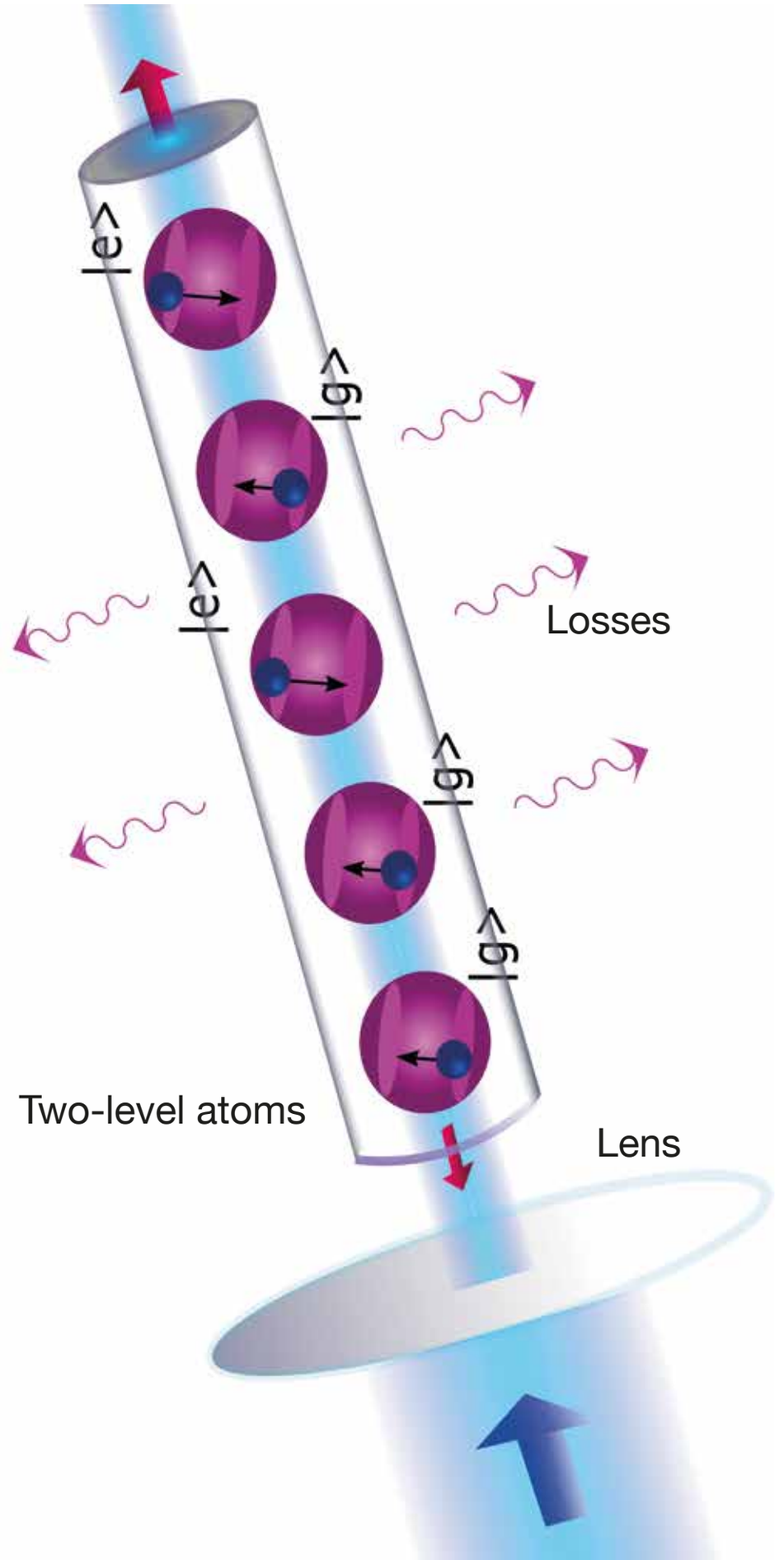


Figure 24. Images showing length minimization happening in a neuronal cell which has extended axons and made connections with micro-patterned protein islands (red). They have shown that this process is driven by the generation of "active" contractile stresses using myosin-II molecular motor proteins (Biophys. Journal, 2018).



Research: Knowledge Creation

Theoretical Physics

Theoretical Physics

Overview

Theoretical physics is an endeavor that attempts to make sense of the inner workings of nature, using the language of mathematics. The goal is to model and predict the behavior of all systems from the very small (sub-atomic and smaller) to the very large (galaxies and beyond) that constitute this beautiful and complex universe that we live in. The Theoretical Physics (TP) group at RRI is actively pursuing research in the following areas: Statistical Physics, Classical and Quantum Gravity, Foundations of Quantum Mechanics and General Relativity. TP group has also forged a robust collaboration with experimental groups within RRI. The connection with Light and Matter Physics group is specifically in the areas of foundational questions in quantum mechanics, quantum information and nonlinear quantum optics. The overlap with the Soft condensed matter group is in areas such as biophysics, polymer physics and modelling stochastic search process. Additionally, RRI theorists have fruitful ongoing collaborations in the above research areas with both national and international peers.

Focus 2017-18

Statistical Physics

Statistical physics comprises a set of mathematical techniques that can be applied to a physical system to estimate its properties. Simply put, statistical techniques derive high-level (macroscopic) descriptions starting from low level (microscopic) ones after averaging out a lot of details. Finding the correct method of averaging out the details is key to the statistical method for investigation of physical systems. As an example, consider a box filled with gas. A correct statistical average of the momentum and position of individual atoms is mandatory for accurate descriptions of macroscopic quantities such as temperature and pressure. Researchers at RRI routinely employ statistical methods to understand physical systems.

Statistical physics gives a probabilistic description of systems that evolve in a stochastic manner. Examples of such systems include the motion of colloidal particles in water, motion of bacteria, externally shaken granular particles, as well as gas in equilibrium. For equilibrium systems, there is a well-defined formalism to study the static properties. However, for systems away from equilibrium, there is no standard method. During the past year, Sanjib Sabhapandit and his students at RRI along with collaborators, investigated such nonequilibrium systems using various mathematical methods.

Stochastic efficiency of an isothermal work-to-work converter engine

Deepak Gupta and Sanjib Sabhapandit have investigated the efficiency of an isothermal Brownian work-to-work converter engine, composed of a Brownian particle coupled to a heat bath at a constant temperature. The system was maintained out of equilibrium by using two external time-dependent stochastic Gaussian forces, where one is called load force and the other is called drive force. Work done by these two forces are stochastic quantities. The efficiency of this small engine was defined as the ratio of stochastic work done against load force to stochastic work done by the drive force. They studied the probability density function as well as large deviation function of the stochastic efficiency analytically and verified the results using numerical simulations.
[Deepak Gupta and Sanjib Sabhapandit]

Unusual equilibration of a particle in a potential with a thermal wall

Sanjib Sabhapandit and collaborators Deepak Bhat, Anupam Kundu and Abhishek Dhar considered a particle in a one-dimensional box of length L with a Maxwell bath at one end and a reflecting wall at the other end. Using a renewal approach, as well as directly solving the master equation, they have shown that the system exhibits a slow power law relaxation with a logarithmic correction towards the final equilibrium state. Further, they extended the renewal approach to a class of confining potentials of the form $U(\chi) \propto \chi^{\alpha}$, $\chi > 0$, where they found that the relaxation is $\sim t^{(\alpha+2)/(\alpha-2)}$ for $\alpha > 2$, with a logarithmic correction when $(\alpha + 2)/(\alpha - 2)$ is an integer. For $\alpha < 2$ the relaxation is exponential. Interestingly for $\alpha = 2$ (harmonic potential) it was observed that the localised bath cannot equilibrate the particle.
[Deepak Bhat (ICTS, TIFR), Anupam Kundu (ICTS, TIFR), Abhishek Dhar (ICTS, TIFR) and Sanjib Sabhapandit]

Gaps between avalanches in 1D Random Field Ising Models

Sanjib Sabhapandit and collaborators Jishnu Nampoothiri, Kabir Ramola and Bulbul Chakraborty have analysed the statistics of gaps (ΔH) between successive avalanches in one dimensional random field Ising models (RFIMs) in an external field H at zero temperature. In the first part of the work they have studied the nearest-neighbor ferromagnetic RFIM. They have mapped the sequence of avalanches in this system to a non-homogeneous Poisson process with an H-dependent rate $\varrho(H)$ and have used this to analytically compute the distribution of gaps $P(\Delta H)$ between avalanches as the field is increased monotonically from $-\infty$ to $+\infty$. They have shown that $P(\Delta H)$ tends to a constant C (R) as $\Delta H \to 0^{+}$, which displays a non-trivial behavior with the strength of disorder R. They verified their predictions with numerical simulations. In the second part of the work, motivated by avalanche gap distributions in driven disordered amorphous solids, they studied a long-range antiferromagnetic RFIM. This model displayed a gapped behavior $P(\Delta H) = 0$ up to a system size dependent offset value ΔH_{off}, and $P(\Delta H) \sim (\Delta H - \Delta H_{off})^{\theta}$ as $\Delta H \to \Delta H_{off}^{+}$. They performed numerical simulations on this model and determined $\theta \approx 0.95(5)$. They have also discussed mechanisms which would lead to a non-zero exponent θ for general spin models with quenched random fields.
[Jishnu N. Nampoothiri (Brandeis University, USA), Kabir Ramola

(Brandeis University, USA), and Bulbul Chakraborty (Brandeis University, USA) and Sanjib Sabhapandit]

Exact extremal statistics in the classical 1d Coulomb gas

Sanjib Sabhapandit and collaborators Abhishek Dhar, Anupam Kundu, Satya Majumdar and Gregory Schehr have considered a one-dimensional classical Coulomb gas of N like-charges in a harmonic potential – also known as the one-dimensional one-component plasma (1dOCP). They have analytically computed the probability distribution of the position χ_{max} of the rightmost charge in the limit of large N and have shown that the typical fluctuations of χ_{max} around its mean are described by a non-trivial scaling function, with asymmetric tails, which is different from the Tracy-Widom distribution of xmax for the Dyson's log-gas. They have also computed the large deviation functions of χ_{max} explicitly and have shown that the system exhibits a third-order phase transition, as in the log-gas. They numerically verified their theoretical predictions.
[Abhishek Dhar (ICTS, TIFR), Anupam Kundu (ICTS, TIFR), Satya N. Majumdar (LPTMS, CNRS, France and Adjunct Professor, RRI) and Gregory Schehr (LPTMS, CNRS, France)

Steady state, relaxation and first-passage properties of a run-and-tumble particle in one-dimension

Sanjib Sabhapandit and collaborators Kanaya Malakar, V Jemseena, Anupam Kundu, K Vijay Kumar, Satya Majumdar, S Redner and Abhishek Dhar have investigated the motion of a run-and-tumble particle (RTP) in one dimension. They found the exact probability distribution of the particle with and without diffusion on the infinite line, as well as in a finite interval. In the infinite domain, they found that this probability distribution approaches a Gaussian form in the long-time limit, as in the case of a regular Brownian particle whereas at intermediate times, this distribution exhibited unexpected multi-modal forms. In a finite domain, the probability distribution reached a steady-state form with peaks at the boundaries, in contrast to a Brownian particle. They also studied the relaxation to the steady-state analytically. Finally, they computed the survival probability of the RTP in a semi-infinite domain with an absorbing boundary condition at the origin. In the finite interval, they computed the exit probability and the associated exit times. They have provided numerical verification of their analytical results.
[Kanaya Malakar (Presidency University, Kolkata), V. Jemseena (ICTS, TIFR), Anupam Kundu (ICTS, TIFR), K. Vijay Kumar (ICTS, TIFR), Satya N. Majumdar (LPTMS, CNRS, France), S. Redner (Santa Fe Institute, USA), and Abhishek Dhar (ICTS, TIFR)]

Extreme statistics and index distribution in the classical 1d Coulomb gas

Sanjib Sabhapandit and collaborators Abhishek Dhar, Anupam Kundu, Satya Majumdar and Gregory Schehr considered a one-dimensional gas of N charged particles confined by an external harmonic potential and interacting via the one-dimensional Coulomb potential. For this system they have shown that in equilibrium the charges settle, on an average, uniformly and symmetrically on a finite region centred around the origin. They studied the statistics of the position of the rightmost particle χ_{max} and have shown that the limiting distribution describing its typical fluctuations is different from the Tracy-Widom distribution found in the one-dimensional log-gas. They also computed the large deviation functions which characterise the atypical fluctuations of χ_{max} far away from its mean value. In addition, they studied the gap between the two rightmost particles as well as the index N+, i.e., the number of particles on the positive semi-axis. They computed the limiting distributions associated to the typical fluctuations of these observables as well as the corresponding large deviation functions and have provided numerical supports to their analytical predictions.
[Abhishek Dhar (ICTS, TIFR), Anupam Kundu (ICTS, TIFR), Satya N. Majumdar, (LPTMS, CNRS, France), Gregory Schehr, (LPTMS, CNRS, France) and Sanjib Sabhapandit]

*Partial entropy production in heat transpor*t

Deepak Gupta and Sanjib Sabhapandit considered a system of two Brownian particles (say A and B), coupled to each other via harmonic potential of stiffness constant k. Particle-A is connected to two heat baths of constant temperatures T_1 and T_2, and particle-B is connected to a single heat bath of a constant temperature T_3. In the steady state, the total entropy production for both particles obeys the fluctuation theorem. They computed the total entropy production due to one of the particles called as partial or apparent entropy production, in the steady state for a time segment t. They studied the fluctuation theorem for partial and apparent entropy production when both particles are weakly interacting with each other and found a significant deviation from the fluctuation theorem. They verified their analytical results using numerical simulations.
[Deepak Gupta and Sanjib Sabhapandit]

Entropy production for partially observed system in a harmonic trap

Deepak Gupta and Sanjib Sabhapandit have considered a harmonically coupled system of two Brownian particles (say A and B) in a harmonic confinement with the whole system immersed in a heat bath at a temperature T. Both particles were driven by external stochastic Gaussian white noises and it was found that the system generates entropy and that total entropy production satisfies fluctuation theorem in steady state. In the weak coupling limit, they showed that the partial system also satisfied steady state fluctuation theorem for total entropy production. Numerical simulation was done to verify the analytical results and they had very good agreements.
[Deepak Gupta and Sanjib Sabhapandit]

Classical and Quantum Gravity

The construction of fully quantum mechanical description of the

gravitational interaction remains the outstanding open problem in fundamental theoretical physics. Quantum gravitational effects are expected to be dominant in extreme situations such as at the Big Bang and deep inside Black Holes. Einstein's General Relativity identifies gravitation as arising with the geometry of space and time. Hence, a theory of Quantum Gravity is expected to revolutionise our very notions of spacetime and would herald a paradigm shift exceeding that following the discovery of Quantum Mechanics.

Loop Quantum Gravity

One very successful approach to building such a theory goes by the name of Loop Quantum Gravity (LQG). It attempts to generalise the familiar techniques of quantum mechanics and quantum field theory and apply them to the context of gravitation. This generalization is technically and conceptually very intricate because, unlike the case of quantum field theory where the quantum fields evolve on a fixed spacetime, here it is the very geometry of spacetime which is dynamical. Hence, one needs a generalization which does not rely on notions of a background fixed spacetime. While one has a fine understanding of how to describe quantum spatial geometry in LQG (`LQG kinematics'), a key open problem is how to describe quantum spacetime geometry (`LQG dynamics').

Technical description of Specific Work undertaken during 2017-18:

The constraint algebra in Smolin's G⟶0 limit of 4d Euclidean Gravity

The conservative techniques of LQG are those of canonical quantization wherein one splits spacetime into space and time, reformulates the Einstein equations as Hamiltonian equations on phase space and seeks to replace Poisson brackets between functions by commutators between their operator correspondents. One key issue then is, how to achieve this in a manner in which spacetime emerges from space and time in this Hamiltonian description. Since there is no preferred choice of background time, for each choice of time there is a different Hamiltonian (called a 'Hamiltonian constraint') and the emergence of classical spacetime is tied to the consistency of the dynamical evolutions generated by each of these constraints. This consistency is captured by the particular structure of the Poisson Brackets between these different constraints. Similarly, quantum spacetime is expected to emerge only if this algebraic structure is captured by the corresponding commutators. The commutator structure is very different than that encountered in known theories. Since full blown gravity has a variety of complications, Madhavan Varadarajan has focussed on an extremely non-trivial system which is obtained as a novel weak coupling limit of Euclidean General Relativity and which exhibits a constraint algebra which is isomorphic to that of Euclidean gravity. Through the introduction of a host of new techniques, he has constructed a quantum representation for this system in which the intricate commutator structure is exactly of the type required. The complexity of the work represents a significant breakthrough and is reflected in the 123 pages long preprint (which has been recently accepted for publication).

In the paper, Madhavan Varadarajan considers Smolin's generally covariant $G_{Newton} \longrightarrow 0$ limit of 4d Euclidean gravity, a useful toy model for the study of the constraint algebra in Loop Quantum Gravity. In particular, the commutator between its Hamiltonian constraints has a metric dependent structure function. While a prior LQG like construction of non-trivial anomaly free constraint commutators for the model exists, that work suffers from two defects. First, Smolin's remarks on the inability of the quantum dynamics to generate propagation effects apply. Second, the construction only yields the action of a single Hamiltonian constraint together with the action of its commutator through a continuum limit of corresponding discrete approximants; the continuum limit of a product of 2 or more constraints does not exist. He incorporated changes in the quantum dynamics through structural modifications in the choice of discrete approximants to the quantum Hamiltonian constraint. The new structure is motivated by that responsible for propagation in an LQG like quantization of Paramaterized Field Theory and significantly alters the space of physical states. He studied the off shell constraint algebra of the model in the context of these structural changes and has shown that the continuum limit action of multiple products of Hamiltonian constraints is (a) supported on an appropriate domain of states (b) yields anomaly free commutators between pairs of Hamiltonian constraints and (c) is diffeomorphism covariant. He further says that many of his considerations seem robust enough to be applied to the setting of 4d Euclidean gravity.

Technical description of Specific Work currently in progress:

One failing of the proposals for LQG dynamics hitherto relate to the fact that they are unlikely to propagate quantum gravitational perturbations from one region of space to another. In earlier work, Madhavan Varadarajan had isolated the structural properties responsible for such propagation in the simpler model system of Parameterised Field Theory.
In the work undertaken during 2017-18, he has incorporated these structural lessons to the context of the immensely more complicated model of weakly coupled Euclidean Gravity. In ongoing research, he seeks to demonstrate that the new structures indeed facilitate propagation of quantum perturbations in the model. This is essential as he aims to use these structure in Euclidian Gravity and then in the physically relevant domain of Lorentzian Gravity. This is also cutting edge work for which there is no precedent in the field.
[Madhavan Varadarajan]

Causal Set Theory

A radically different, but manifestly covariant approach to quantum gravity is Causal Set Theory (CST). CST is motivated by deep theorems in Lorentzian geometry that demonstrate the primacy of the causal structure of spacetime. The causal structure of any reasonable spacetime forms what is known as a partially ordered set.

Rather than quantise the geometry, in CST one quantises this causal structure. The spacetime continuum is thus replaced by a discrete substructure, which is a locally finite partially ordered set or causal set.

Studies on the Sorkin Johnston Vacuum

An important feature of quantum field theory on a generic curved spacetime is the lack of a preferred vacuum. As was pointed out by Hawking and subsequently, Unruh, the choice of vacuum and thence particles depends on the observer and is not in this sense fundamental. This reinforced the algebraic approaches to quantum field theory in curved spacetime, which are defined without reference to a vacuum. In the last decade or so, a new prescription has emerged for an observer-independent vacuum, the so-called Sorkin-Johnston or SJ vacuum. This has potentially very interesting phenomenological consequences, especially for the early universe. Unlike the construction of observer dependent vacua, finding the exact SJ vacuum for different spacetimes has proved challenging analytically, and only the 2d massless scalar field vacuum in Minkowski spacetime has been found explicitly.

1)Nomaan X and Sumati Surya in collaboration with Yasaman Yazdi, have obtained the SJ vacuum for causal sets approximated by deSitter spacetime using a combination of analytic and numerical techniques.
[Nomaan X, Yasaman Yazdi (University of Alberta, Canada) and Sumati Surya]

2) Abhishek Mathur and Sumati Surya constructed the SJ vacuum analytically for the massive scalar field theory in 2d Minkowski spacetime in the small mass limit and shown it to coincide with the Minkowski vacuum.
[Abhishek Mathur and Sumati Surya]

Entanglement Entropy for deSitter Horizons

One of the most interesting open questions in quantum gravity is the origin of blackhole entropy. Sorkin and his collaborators made seminal contributions to this question by examining the role of entanglement entropy for a quantum scalar field in the late ’80s. Recently, interest in entanglement entropy has been regenerated both in quantum gravity, especially string theory, as well as in condensed matter systems. A covariant definition of this entropy based on the SJ vacuum was studied by Nomaan X and Sumati Surya along with collaborator Yasaman Yazdi in 2d Minkowski spacetime for nested causal diamonds. In this project, they obtained the entanglement entropy numerically for nested causal diamonds in 4d Minkowski spacetime and global deSitter horizons. Using a generalisation of a cut-off prescription suggested by Sorkin and Yazdi the area law was shown to emerge in both cases.
[Nomaan X, Yasaman Yazdi (University of Alberta, Canada), Sumati Surya]

Spatial Geometry from Causal Set Theory

In the causal set approach to quantum gravity, a fundamental discreteness is assumed, with the continuum thought to arise as an approximation. In order to obtain all the relevant Lorentzian geometric information, causal set discretisation must occur as a random lattice. This makes it very challenging to obtain continuum geometric information. In this project, Sumati Surya in collaboration with Astrid Eichhorn and Fleur Versteegen has constructed a spatial distance function from the causal relations and has shown that it limits to the continuum distance. Numerical simulations were then performed by them to show that for causal sets approximated by a flat spacetime in two and three dimensions, the discrete distance is a good approximation of the continuum distance.
[Astrid Eichhorn (University of Heidelberg, Germany), Fleur Versteegen (University of Heidelberg, Germany) and Sumati Surya]

Quantum Foundations, Information and Optics

Periodically driven lattices

During the past year, Vivek Vyas and Dibyendu Roy have been working on quantum mechanical lattices, which are periodically driven externally using electromagnetic field. Such driven systems have been extensively studied, for it is found that a driven D dimensional lattice actually mimics the behaviour of an undriven D+1 - dimensional lattice. However, it is not clear, as to whether the driven low dimensional lattice system will display all the properties of a higher dimensional lattice or not. In particular, the questions regarding the nature of the correlations and global aspects like topology of the state space remains a subject of investigation. In the absence of an exact solution to the driven lattice system, in the literature such a correspondence is usually studied by looking at a particular class of states of the system, using approximation methods, and employing topological invariants. Currently, they are working in the direction of constructing an exact solution to such a driven system, using a transformation that maps the states of the driven lattice to that of the undriven one. They hope that this approach will provide a clearer understanding of the effect of forcing in such systems.
[Vivek M. Vyas and Dibyendu Roy]

Charge confinement

In quantum field theory, the concept of charge confinement is not well understood. It plays a crucial role in comprehending the dynamics of non-Abelian gauge theories like QCD. Motivated by some earlier work of Srinivasan and Rajasekaran, Vivek Vyas and collaborator Prasanta Pranigrahi have studied the connection between origin of gauge particle mass and charge confinement. Generally, it is believed that gauge boson becomes massive via either Anderson-Higgs mechanism or dynamical - Schwinger mechanism. In their work, they were able to construct a field theory model, wherein confinement of a certain current led to gauge invariant

mass for the photons. This example motivated them to consider a distinct possibility, that the gauge boson mass in a class of theories can have an origin in confinement of some current, rather than quantum corrections and spontaneous symmetry breaking.
[Vivek M. Vyas and Prasanta K. Panigrahi (IISER, Kolkata)]

Accelerating coherent states

It is well known that a Gaussian wavepacket disperses while evolving with the free particle Schrodinger equation, and a suitable confining potential is needed for a wavepacket to propagate coherently without dispersing and distorting. Berry in 1979 discovered that there exists wavepackets, with probability distribution having an Airy function profile, which uniformly accelerate and propagate without spreading in free particle Schrodinger equation. These wavepackets have been realised in many optical experiments. While these wavepackets have been extensively studied, the origin of uniform acceleration and non-spreading was not clear. Vivek Vyas has recently shown that these peculiar properties have their origin in the fact that these wavepackets are (Perelomov) coherent states. He found that the Galilean invariance of the free particle Schrodinger equation plays a pivotal role in giving these coherent states their unique dynamical property.
[Vivek M. Vyas]

Lorentzian Geometry of Qubit entanglement

Quantum systems can be entangled, that is they show correlations that cannot be classically understood. Entanglement is a resource that one uses in performing quantum information theoretical tasks and it is very important to learn how to detect entanglement. This work uses ideas borrowed from the physics of special relativity to study the entanglement of two qubit quantum systems.

Kumar Shivam, Supurna Sinha and Joseph Samuel have described a new approach based on Lorentzian geometry to detect qubit entanglement. The treatment is based physically, on the causal structure of Minkowski spacetime, and mathematically, on a Lorentzian Singular Value Decomposition. A surprising feature is the natural emergence of ''Energy conditions'' used in Relativity. They found that all states satisfied a ''Dominant Energy Condition'' (DEC) and separable states satisfied the Strong Energy Condition(SEC), while entangled states violated the SEC. They thus propose a test for two qubit entanglement which is an alternative to the positive partial transpose (PPT) test. This test is based on the partial Lorentz transformation (PLTs) on individual qubits. Apart from testing for entanglement, their approach also enables the construction of a separable form for the density matrix in those cases where it exists. Their approach leads to a simple graphical three dimensional representation of the state space which shows the entangled states within the set of all states.
[Kumar Shivam, Supurna Sinha and Joseph Samuel]

Gravitation and Decoherence: the double slit experiment revisited

This work concerns the large distance behaviour of quantum theory. It is motivated by the desire to understand the relation between gravitation and quantum mechanics. An analysis of the double slit experiment shows that gravitational fields can destroy the interference pattern seen in double slit experiment.

The double slit experiment is iconic and widely used in classrooms to demonstrate the fundamental mystery of quantum physics. The puzzling feature is that the probability of an electron arriving at the detector when both slits are open is not the sum of the probabilities when the slits are open separately. The superposition principle of quantum mechanics tells us to add amplitudes rather than probabilities and this results in interference. This experiment defies our classical intuition that the probabilities of exclusive events add. In understanding the emergence of the classical world from the quantum one, there have been suggestions by Feynman, Diosi and Penrose that gravity is responsible for suppressing interference. This idea has been pursued in many different forms ever since, predominantly within Newtonian approaches to gravity. In this work, Joseph Samuel has proposed and theoretically analysed two 'gedanken' or thought experiments, which lend strong support to the idea that gravity is responsible for decoherence. The first makes the point that thermal radiation can suppress interference. The second shows that in an accelerating frame, Unruh radiation plays the same role. Invoking the Einstein equivalence principle to relate acceleration to gravity, the work supports the view that gravity is responsible for decoherence.
[Joseph Samuel]

Boundaries without boundaries

Motivated by the different choice of boundary condition that are possible, Supurna Sinha and Joseph Samuel along with collaborators Paolo Facchi, Giancarlo Garnero, Giuseppe Marmoe have explored the generation of boundaries, starting from a manifold without boundaries and have investigated various boundary conditions. They considered a free nonrelativistic quantum particle on the circle as an illustrative example. One possible application of this work is in the area of helioseismology.

Starting with a quantum particle on a closed manifold without boundary, they considered the process of generating boundaries by modding out by a group action with fixed points and have studied the emergent quantum dynamics on the quotient manifold. As an illustrative example, they considered a free nonrelativistic quantum particle on the circle and generated the interval via parity reduction. A free particle with Neumann and Dirichlet boundary conditions on the interval was obtained and by changing the metric near the boundary, Robin boundary conditions can also be accommodated.

They also indicate a possible method of generating non-local boundary conditions. Then they explored an alternative generation mechanism, which makes use of a folding procedure and is applicable to a generic Hamiltonian through the emergence of an ancillary spin degree of freedom.
[Paolo Facchi and Giancarlo Garnero (INFN, Bari, Italy), Giuseppe Marmo (INFN, Napoli, Italy), Supurna Sinha and Joseph Samuel]

Quantum Diffusion

One area of research in TP group has been on studying diffusion in the presence of quantum fluctuations. Brownian motion is one of the cornerstones of nonequilibrium statistical mechanics. The relevant equation for studying Brownian motion is the Langevin equation; it contains frictional forces and random forces. The fluctuation dissipation theorem (FDT) relates these forces to each other. A Brownian particle suspended in a liquid subjected to thermal fluctuations undergoes diffusion. In classical theory, the diffusion constant is related to the frictional coefficient by Smoluchowski-Einstein relation. In quantum statistical mechanics, starting from the linear response theory, it is possible to obtain the FDT. The FDT forms a bridge connecting equilibrium and nonequilibrium statistical mechanics. The goal of the linear response theory is to figure out how a system reacts to outside influences. These outside influences are things like applied electric and magnetic fields, or for instance applied pressure. The FDT states a general relationship between the response of a given system to an external disturbance and the internal fluctuations of the system in the absence of the disturbance. Such a response is characterized by a response-function R(t). The internal fluctuation is characterized by a correlation function of physical quantities of the system fluctuating in thermal equilibrium. It is possible to obtain the known classical results in the high temperature regime. But the question worth addressing is: what happens as we lower the temperature and scale down the size of the particle?

Quantum Brownian motion in a magnetic field: Transition from monotonic to oscillatory behaviour

Urbashi Satpathi and Supurna Sinha have studied the Brownian motion of a charged particle in a magnetic field and they notice a qualitatively interesting transition from a monotonic to an oscillatory behaviour of the mean square displacement growth with time, which can be tested against cold ion experiments.

They investigated the Brownian motion of a charged particle in a magnetic field by using the quantum Langevin equation for a charged particle in a magnetic field as a starting point to investigate the growth of the mean square displacement as a function of time. They studied this in the high temperature classical and low temperature quantum domains. In both domains, they observed a transition of the mean square displacement from a monotonic behaviour to a damped oscillatory behaviour as one increases the strength of the magnetic field. When the strength of the magnetic field is negligible, the mean square displacement increased linearly with time in the classical domain and logarithmically with time in the quantum domain. They noticed that these features of the mean square displacement are robust and remain essentially the same for an Ohmic dissipation model and a single relaxation time model for the memory kernel. The predictions stemming from their analysis can be tested against experiments in trapped cold ions. In fact, Sanjukta Roy and collaborators from LAMP group are currently finalising experiments to test these predictions.

Nonlinear Quantum Optics

The optical response of a material scales linearly to the electric field of incident radiation. However, when the intensity of the incoming radiation (in other words the amplitude of the electric field) is sufficiently high, the material can respond nonlinearly. The study of the interaction of intense light with matter is the subject of nonlinear optics. Nonlinear quantum optics is a relatively new field to specifically investigate nonlinear light-matter interaction in the quantum regime with few photons.

Light propagation through one-dimensional interacting open quantum systems

Pooja Manasi and Dibyendu Roy have generalized the quantum Langevin equations approach to study nonlinear light propagation through one-dimensional interacting open quantum lattice models. They have developed a matrix product operator description to efficiently write and solve a large set of quantum Langevin equations of lattice operators obtained after integrating out the light fields. They first apply their method to a Heisenberg like interacting spin-1/2 chain with nearest-neighbour coupling. They calculated the transient and steady- state transport properties of an incoming monochromatic laser light for this model and understood how the local features of the spin chain and the chain length dependence of light transport coefficient evolve with an increasing power of the incident light. They found that the steady-state light transmission coefficient at a higher power depends non-monotonically on the interaction in a finite chain, while the nonlinear light transmission in their studied model seems to be ballistic in the absence of interaction and for a high interaction, it shows an apparent system-size dependence at intermediate interactions. Later, they extend the method to the long-range interaction between spins of the driven- dissipative lattice model and incorporate various losses typical in many atomic and solid-state systems.

Earlier, Dibyendu Roy and collaborators have developed a theoretical method based on quantum Langevin equations and Green's function (LEGF) to study nonequilibrium quantum transport across a system connected to baths at the boundaries. Their method is a generalization of the Heisenberg-Langevin equation approach to non-equilibrium when the baths at the boundaries of the system are kept at different temperatures or chemical potentials or magnetizations. Quantum LEGF method leads to the

non-equilibrium Green's function (NEGF) like expressions for transport coefficients. It also reproduces the results of the Landauer-Buttiker formalism in particular limits. Previously they had applied quantum LEGF method for investigating non-equilibrium transport in various non-interacting and mean-field interacting open quantum systems of electrons and phonons.

During the past year, they have extended the application of quantum LEGF method to study nonlinear light propagation through a one-dimensional lattice model of atomic medium (see Figure. 1) modelled as a Heisenberg type spin-1/2 chain with nearest-neighbour coupling. In this sense, it is an extension of the above research theme. However, it requires a sophisticated numerical calculation using matrix product operators. The numerical calculation was carried out by Pooja Manasi. They have been able to calculate transmission and reflection of a laser light in the coherent state from different nonlinear optical media. They have also derived local properties of the atoms driven by the laser field. The article has been submitted for publication and is also available on arXiv:1712.04474.

[Pooja Manasi and Dibyendu Roy]

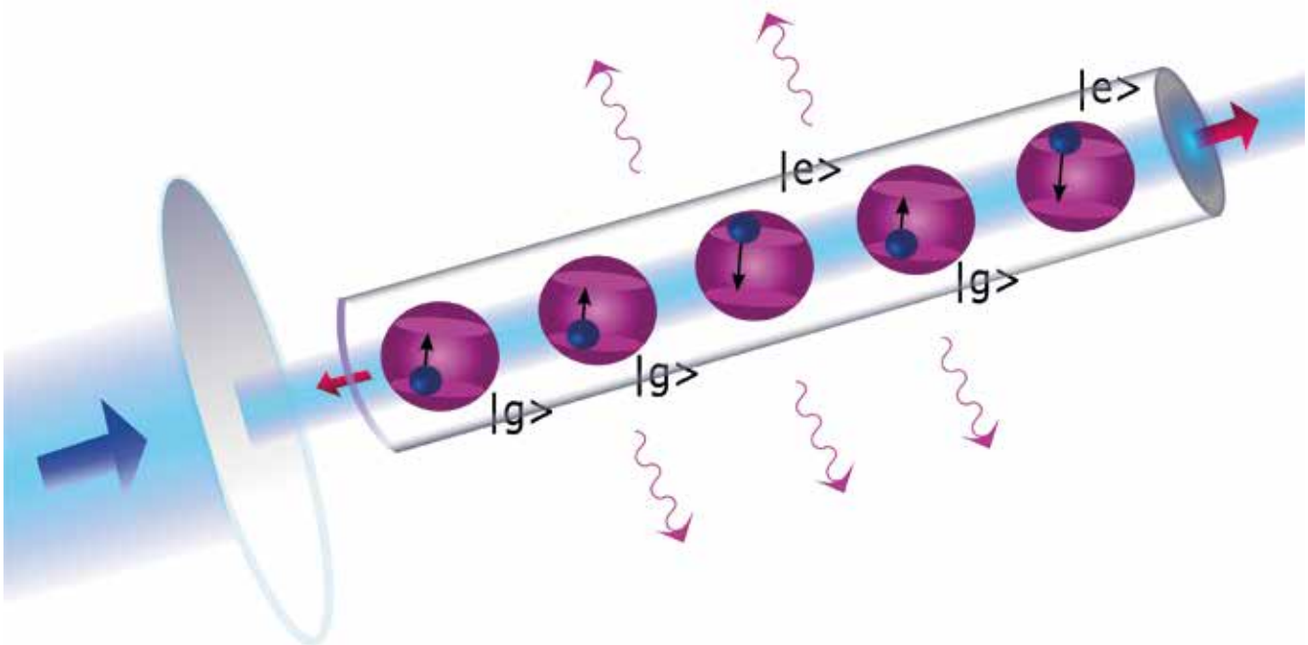


Figure 1. A cartoon of a one-dimensional nonlinear quantum optical medium consisting of two- level atoms with levels |g> and |e>. The atomic medium is driven out of equilibrium by a tightly focused, coherent light (blue arrow) shined from the left of the medium. The red arrows show transmitted and reflected lights.

Publications

Scientific staff and students of the Raman Research Institute publish their research activities carried out over the year in reputed national and international peer-reviewed journals. Each of the four research groups at RRI publishes their work in renowned journals that focus on their specific research area.

For the Astronomy and Astrophysics group, these include the Monthly Notices of the Royal Astronomical Society, Nature Astronomy, Astrophysics, Astrophysical Journal, Astrophysical Journal Letters, Astrophysical Journal Supplement Series, New Astronomy, Astronomy and Astrophysics, Physical Review D, Physics Uspekhi, Current Science, Scientific Reports, Open Astronomy, Experimental Astronomy, European Physical Journal Plus, Journal of Cosmology and Astroparticle Physics, Journal of Astrophysics and Astronomy and Publications of the Astronomical Society of Australia.

The Soft Condensed Matter group has its work published in Advanced Materials Interfaces, Asian Journal of Organic Chemistry, Chemical Communications, Colloids and Surfaces A: Physicochemical and Engineering Aspects, Langmuir, Liquid Crystals, Soft Matter, Materials, ChemPhysChem, Physical Review E, Journal of Analytical Chemistry, Journal of Applied Physics, Journal of Physics D: Applied Physics, Journal of Applied Polymer Science, Journal of Electroanalytical Chemistry, Journal of Luminescence, Journal of Materials Chemistry, Journal of Thermal Analysis and Calorimetry, Nature Communications, New Journal of Chemistry, Material Science and Engineering, Journal of Molecular Liquids, Journal of Molecular Structure, Journal of Cell Biology, Particle and Particle Systems Characterization, Physical Review Materials, Physical Biology, General Chemistry, Opto-Electronics Review and Scientific Reports.

Publications of the Light and Matter Physics group can be found in Scientific Reports, Physical Review A, Applied Physics A, Applied Physics Letters, European Physical Journal Plus, Journal of Analytical Atomic Spectrometry, Journal of Physical Chemistry A, Journal of Physics B: Atomic, Molecular and Optical Physics, Materials Research Express, Annals of Physics, Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy and Small.

Theoretical physicists at RRI use journals like Nature Communications, Physical Review Letters, Physics Letters B, Physical Review A, Physical Review E, Review of Modern Physics, Annals of Physics, Classical and Quantum Gravity, Journal of Statistical Mechanics: Theory and Experiment, Physica A, International Journal of Quantum Information, Journal of Statistical Mechanics and others as a medium to share their knowledge with the national and international scientific community.

117 papers with RRI members as authors and/or co-authors were published during 2017-2018. There were 8 publications in conference proceedings and 25 publications (23 in journals and 2 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. During the past year, RRI members wrote 1 book and 1 Editorial. 3 popular science articles were published in Desh and Kolpobigyan (both are Bengali literary magazines) and CGQ+.

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

Extramural Grants, Awards and Fellowships

Extramural Grants

1	Sadiq Rangwala	*CEFIPRA proposal 5404*
		Project title: LORIC - Long Range Interaction in ultracold gases. Co-PI - Olivier Dulieu (Laboratoire Aime Cotton, France). Total grant amount: EUR 279,400 RRI share: INR 90,89,135. Project duration: March 2016 - February 2019.
2	Biswajit Paul	*ISRO grant for POLIX*
		Project title: Development of "X-ray Polarimeter experiment (POLIX) Payload" Total grant amount: INR 9,50,00,000 Received so far: INR 4,25,00,000 Project start date: September 2017
3	Sanjib Sabhapandit	*CEFIPRA Proposal 5604-2*
		Project title: Extreme events and large deviations in strongly correlated many body systems. Co-PI's - Abhishek Dhar (ICTS, TIFR), Gregory Schehr (LPTMS, Orsay). Total grant amount: INR 33,99,336 RRI share: INR 65,000 Grant duration: December 2016 – November 2019
4	Urbasi Sinha	*Templeton grant 57758 awarded by John Templeton Foundation*
		Project title - Unveiling the nature of quantum reality: a theoretical and experimental approach employing non-destructive weak measurements. Co-PI - Alexandre Matzkin(CNRS, France) Total grant amount - EUR 77, 880 Received so far: EUR 70,902 Grant period: November 2015 - July 2018
		ISRO – QKD grant
		Project title: Development of a prototype for satellite based secure quantum communication PI: Urbasi Sinha Total grant amount: INR 27,00,00,000 Received so far: INR 2,43,00,000 Project started in December 2017
5	Biman Nath	*Indo-Israel grant No. 504/14*
		Project title: Galactic outflows and the sky's biggest shock. PI - Prateek Sharma, IISc. Total grant amount (Indian side): INR 86,00,000. Project duration: 4 years, started in 2014
		Indo-Russian grant No P270
		Project title: The 500 parsecs around the galactic center Total grant amount: INR 5,00,000 Received so far: INR 2,50,000 PI's: Biman Nath , Yuri Shchekinov, Lebedev Physical Research Institute, Moscow, Russia Project duration: Sep 2017 – August 2019
6	Sumati Surya	*Foundational Questions Institute (FQXI) Fund*
		Proposal Title: Quantum Dynamics of Causal Sets Duration: September 2014 – August 2018 Sanctioned: $58,000 Spent so far: $51,317

7	Shiv Sethi	*1) Indo – US Science and Technology Forum IUSSTF/JC-009/2016*
		Project title: "Probing Fundamental Nature of Dark Matter through upcoming 21 cm Signals from Reionization Epoch" from the Indo-U.S. Science and Technology Forum (IUSSTF) under 2016 the call of Joint R&D Networked Joint Center program. Indian PI: Shiv Sethi, CoPI: Subinoy Das, IIA US PI : Marc Kamionkowski, John Hopkins, Adrienne Erickcek, University of North Carolina Total grant money: INR 27, 24,350 Received so far: INR 6,00,000 Project duration: May 2017-April 2019
		Indo – Russian grant through DST – RFBR INT/RUS/RFBR/P-276
		Project title: Probing the reionization epoch and the high redshift IGM Indian PI : Shiv Sethi, Russian PI: Dr. Evgenii O. Vasiliev, Southern Federal University, Rostov Total grant money: INR 4,65,200 Received So far: INR 2,32,600 Project duration: September 2017 – August 2019
8	Gautam Soni	*Grand challenges India*
		Project title: High throughput electrical detection of Malaria infection in single RBC's under low parasite density Total grant amount: INR 50,00,000 Received so far: INR 18,00,000 Project duration: January 2018 – July 2019
9	K S Dwarakanath	*IUSSTF / JC-014 / 2017*
		Project title: Investigating dark matter and star formation in the outer disks of galaxies using UV, optical and 21 cm radio observations Indian PI: Mousumi Das (IIA), Co-PI K S Dwarakanath, USA PI: Stacy McGaugh (Case Western Reserve University), Co-PI James Schombert (University Oregon) Total grant money: INR 30,29,600 Project duration: March 2018 to February 2020

Fellowships

1	Dibyendu Roy	*SERB-Ramanujan Fellowship*
		Received the Ramanujan Fellowship in November, 2015. The funding for the first year is INR 1780000/- sanctioned by SERB of DST, India on 18-01-2016. Received so far: INR 38,60,000 Fellowship duration: 5 years
2	Sumati Surya	*Emmy Noether Fellowship by Perimeter Institute, Waterloo, Canada*
		Full financial support towards visits to Perimeter Institute, Waterloo, Canada. Fellowship duration: April 2017-September 2017 and April 2018-September 2018.
3	Gautam Soni	*DBT- Ramalingaswami Fellowship*
		Project title - Epigenetic gene sequencing by chromatin condensation using nanodevices. Fellowship started in January 2014. Total grant amount - 88,00,000 Received so far: INR 37,00,000 Fellowship duration: January 2014-December 2019
4	Urbasi Sinha	*Homi Bhabha Fellowship*
		INR 25,000 per month plus contingencies for travel/books connected with research Duration: July 2017 to July 2019.
5	Sourav Dutta	*DST Inspire Faculty Fellowship*
		Grant - 7,00,000 per annum. Fellowship - INR 80,000 per month Fellowship duration: 5 years, started April 2015

6	Kartick Chandra Sarkar	*KITP Fellowship*
		Graduate fellowship program at the Kavli Institute for Theoretical Physics, Santa Barbara, USA. Fellowship duration: January 2017 to July 2017
7	Nayantara Gupta	*DAAD Fellowship*
		Awarded DAAD fellowship in February, 2017 for professional collaborative visit to Germany for two months.
8	Sayantan Majumdar	*SERB Ramanujan Fellowship*
		Total grant amount: INR 35,00,000 Fellowship duration: 5 years Current status: The fellowship has been awarded on March 22, 2018. The details of the sanctioned amount by SERB is still awaited.

Awards

ICO-ICTP Gallieno Denardo Award in Optics to Urbasi Sinha

Urbasi Sinha has been selected as the 2018 recipient of the ICO-ICTP Gallieno Denardo Award in Optics. This award is recognition of her research in optics and photonics.

Best Poster Award for Subhajit Bhar

PhD student Subhajit Bhar (LAMP) has been awarded the Best Poster Award at the International Symposium on New Frontiers in Quantum Correlations (ISNFQC18) held in Kolkata from 29th Jan to 2nd Feb 2018. His poster was titled "Experimental certification and quantification of entanglement in a novel spatially correlated bipartite qutrit system".

Block Award for Saurabh Singh

At the Aspen conference on Cosmological Signals from Cosmic Dawn to the Present, held during 4th to 10th Feb 2018 in Colorado in the US, RRI PhD student Saurabh Singh (AA) was selected by the organisers for the Block Award, which is presented to the one person they judge to be the "Promising Young Physicist" at the conference.

Best poster award for SWAN

A poster describing the SWAN developmental activities and current status was presented in Astronomical society of India 2018 meeting, held at Osmania university, Hyderabad and obtained 'The best poster award' in Instrumentation and Techniques category. Title of the poster : SWAN (Sky watch array network) demonstrator: development and status. The personnel involved in the SWAN project are Vinutha Chandrashekar, K B Raghavendra Rao, Rahul Kinger, H A.Aswathappa, P S Sasikumar, T S Mamatha, Bhawana Bansal, Harsh Grover, H N Nagaraja, Sandhya, Indrajit Barve and Avinash A Deshpande.

First prize in Oral Presentation for Maheshwar Swar

PhD student Maheshwar Swar (LAMP) was awarded first prize for his oral presentation at the International Conference on Molecular Spectroscopy held during December 2017 at MGU, Kottayam.

Best Librarian award to B M Meera

B M Meera was honoured with "Granthalaya Seva Puraskaara' by the Department of Public Libraries, Government of Karnataka. This award is given in recognition of contributions in the field of Library and Information Sciences on the occasion of National Librarian's Day.

Patents

Indian Patents

Name	Title	Details
Ruckmongathan T N	Method of reduction in hardware or/ and power consumption for displays	Patent number: 289105 Filing date: 28-01-2010 Granted on: 01/11/2017

International patents

Name	Title	Details
Hema Ramachandran	Optical reciever for full-field optical quadrature demodulation	Patent Number: WO/2017/194988 Filing Date: 10-5-2016 Granted on: 16-11-2017

Electronics Engineering Group

Electronics Engineering Group (EEG) is one of the facilities of the Raman Research Institute providing engineering support to the experimental groups of the Institute. It is a dedicated team of electronics engineers and technical personnel capable of designing and developing state of the art electronics systems for conducting research in experimental projects across various disciplines of basic science. Traditionally, the strength of EEG was in the development of state of the art radio receivers for radio astronomy. But in the recent past, we have gained expertise in diverse fields; for example: (i) design and development of payloads for space missions, and (ii) building systems for interfacing computers with the brain. EEG is equipped with the state of the art software that includes CAD packages like Genesys for RF and Microwave circuit design, WIPL-D/CST Microwave for antenna design, Allegro for PCB design, Xilinx ISE for firmware development and test and measurement instruments like Precision Vector Network Analyser, Noise Figure Meter and Spectrum Analyser, for characterizing the in-house developed instruments.

The contribution of EEG to various groups is highlighted in the paragraphs below emphasizing more on its expertise and capability to work with challenges.

Expertise in the design of Antennas

Antenna forms a primary element in any radio telescope which is used for detecting sky radiation. It plays a key role in any observation aiming at studying a specific event in the background sky. EEG has over decades built antennas of different categories for diversified applications at multi wavelengths. In the recent past it has been developing antennas specific to detecting faint features imprinted in the spectrum of cosmic microwave radiation. The group has developed expertise in tuning and optimizing the structural parameters of the radiation structure to meet the stringent requirement of experimental cosmology. Its recent contribution to the on-going cosmological experiment which is aiming to detect the Epoch of Reionization (EoR) signal is the design and development of spherical and discone antennas capable of observing the sky in the frequency range of 50-200 MHz. These antennas are unique in the sense that their impedance characteristics are smooth to a level of few parts in 100,000 and radiation patterns are frequency independent.

Figure 1. Spherical Monopole antenna

Figure 2. Discone antenna

Fig. 1 and 2 show two prototype antennas built to detect EoR signal in the frequency range 50-100 MHz. They are being tested in the field for their performance characteristics.

Expertise in the hardware and software development of high speed signal processing platforms

Over the past several decades the Raman Research Institute has developed expertise in the field of digital signal processing in diversified research areas such as Radio astronomy, Liquid crystals, X-ray astronomy, Optics and many others. It has kept itself abreast of the latest technology for use in its development of digital systems.

The most recent addition to this thrust area at RRI is from EEG. We have developed a new signal processing platform called SPARC (Spectrometer for Precision meAsurement of signals from the ReCombination epoch) tailored specifically for the detection of spectral lines from the epoch of

recombination in the frequency range of 2-4 GHz. The precision spectrometer has been built on latest technology using modern off-the-shelf available devices such as ADC- ASNT7120A- Single-core 4-bit Flash Analog to Digital converter and XC6VSX315T-2 FPGA having 1156 pins. The analog to digital converter is capable of bandpass sampling an RF input band of 7.5 GHz anywhere between DC and 20 GHz. The FPGA has highly advanced high performance logic, improved routing efficiency, powerful mixed-mode clock manager, 14 modules each supporting 14 Gbps and many other salient features. It offers the best solution for the needs of high performance engineering with unprecedented logic. Using these devices, a correlation spectrometer (Refer Figure 3) capable of producing 1024 spectral channels across 2 GHz band has been realized on SPARC using pipelined FFT IP-cores and a custom-designed parallel FFT engine.

During the design and implementation phase of the high speed board, several challenges like (i) matching of flight-times of signals routed between ADCs and FPGA and inside FPGA to within timing-budget limits (ii) maintaining signal integrity in the board design (iii) handling high data rates (iv) grabbing of 32-bit data from the ADCs on to the FPGA at 4 GHz and (v) adjusting the path delays of the data traces inside the FPGAs were encountered. However they were overcome by appropriately using features like high performance fabric, auto clock-data alignment circuits, connectivity of FPGA and transmission line techniques.

Figure 3. Top and bottom views of the signal processing platform built by the Electronics Engineering Group

Development of Brain Computer Interface system for disabled individuals

RRI is developing a Brain computer Interface system to enable a physically impaired but mentally alert person to communicate and operate devices based on brain signals, without physical movement. The system looks for steady state visually evoked potentials (SSVEP) in electroencephalogram of a patient and uses them to drive mechanical devices like robotic arm.
As a result of development effort followed by exhaustive tests on subjects, RRI has produced a novel stand-alone, portable, battery operated BCI system called BRAIN-1 (BCI system of the RAman INstitute). It is a two channel system which can constantly monitor the electroencephalogram of a subject and look for SSVEP signals. EEG has played a major role in the development of the system followed by its exhaustive verification. It has gained expertise over years in understanding the brain signals and have built appropriate electronics to process them. Since the strength of electroencephalogram signals varies from subject-to-subject, EEG has developed an automated "wizard" that determines the optimal operation parameters of the BCI system for each subject. The BCI system is robust enough to perform outdoors with greater than 90% accuracy. All work on the BCI project has been carried out in EEG.

(A) (B)

(C)

Figure 4. a. Subject looking at the visual stimulus while EEG is monitored
b.Home-built bioamp that acquires, processes and analyses EEG
c.Robotic arm that has been controlled based on the subject's EEG signal. The tube held by the robotic arm was originally on the wooden block in the foreground and has been picked by the robotic arm to be placed at a different location.

Expertise in the development of payload for a space mission

The X-ray polarimeter (POLIX) is a scientific payload (Refer Figure 5) currently being built at RRI to detect polarized X-rays from celestial sources. A dedicated satellite mission of ISRO named X-ray Polarimeter Satellite (XPoSat) has been approved for POLIX. It is the only Thomson X-ray polarimeter currently being built worldwide and has an energy range of 5-30 keV. The instrument is designed, developed and tested at the Raman Research Institute. Recently, it has successfully cleared a Preliminary Design Review (PDR) paving the way for fabrication of the space qualification model of the same instrument. PDR is a technical assessment of the design to ensure its operational effectiveness in space.

Electronics Engineering Group of RRI has carried out the design and development of both the analog and digital electronics systems for this instrument, meeting stringent requirements of a typical space mission. EEG has developed in-house a complete electronics system for (i) detector operation, (ii) pulse processing and digitisation, (iii) on-board data handling, (iv) house keeping, and (v) control. POLIX consists of four independent detectors, each with its own front end and processing

electronics. Localisation of the X-ray photon in the detectors is carried out by the method of charge division in a set of resistive anode wires connected in series. The analog electronics of POLIX include high voltage generation and control for operation of the detectors, amplification of the charge pulses, threshold comparisons and digitization of the housekeeping parameters. The digital electronics consists of anti-coincidence logic, digitation of the pulse amplitudes, data generation in multiple modes and combining of data from the four detectors. EEG has successfully developed a digital signal processing system for POLIX which is more complex than schemes used in other space experiments based on proportional counters. The telecommand and telemetry interface of the POLIX payload with the satellite bus is developed jointly with the Space Astronomy Group of ISRO.

The POLIX detectors are designed (Refer Figure 6) and fabricated in collaboration with the MES and are wired and assembled in EEG. Each detector has about 400 wires of 25 and 50 micron diameters precisely wired and soldered onto a frame. EEG has developed expertise over several years, of making it reliable so that the large number of wires sustain satellite launch vibration and thermal cycling in space for several years. Handling about 400 thin wires and making a durable detector out of them calls for high quality workmanship and EEG has that at present.

Being involved in this project has enabled EEG to gain vast experience in designing instruments for space experiments. It has acquired good expertise in (i) understanding the stringent requirements of a space mission and (ii) interfacing the instrument with the other electronics of the satellite. In particular, end to end development of an X-ray Polarimeter for a space mission including both detectors and electronics is unique to EEG. Overall, the X-ray polarimeter project has made RRI, and in particular EEG, acquire adequate capability to venture into building payloads for other future space missions.

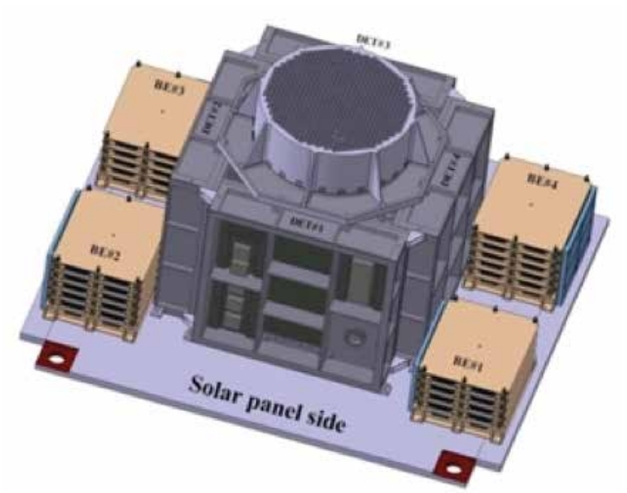


Figure 5. X-Ray Polarimeter – Mechanical configuration with electronics

Figure. 6. Proportional counter detector wiring

EEG's participation in SWAN

The Indian Sky Watch Array Network (SWAN) is an initiative from the Raman Research Institute, to enhance Indian astronomical observing capabilities at radio wavelengths. In addition, it is also to nurture future generations of talented radio astronomers in India to take up the challenges in exciting research in astronomy. SWAN aims to develop an interferometer array of antennas across India (Refer Figure 7) to facilitate and conduct deep searches of fast and slow radio transients and provide opportunities to get hands-on experience to a large number of students through direct participation in various design aspects of the array network. The array network is capable of operating over a decade bandwidth spanning from 50 MHz to 500 MHz.

EEG's contribution to this endeavour has been multifold. It is actively participating in (i) the development of proof-of-concept/demonstrator system (ii) educating students about the engineering aspects of the receiver system and training them to build simple modules and (iii) give talks on various specialized areas relevant to experimental radio astronomy.

EEG has built a receiver system for SWAN (Refer Figure 8) to operate in the frequency range of 80-320 MHz providing an instantaneous bandwidth (BW) of 14 MHz. However the range would get extended to 50-500 MHz 140 MHz using a GPS disciplined local oscillator before getting digitized using a 8 bit analog to digital converter. The power spectrum is produced off line from the raw data saved in the computer. The receivers are miniaturized using the expertise and experience gained in the field of RF, microwave and digital electronics to make them compact and portable. Figure 9 shows the rack-housed receiver system built for each antenna tile.

EEG has been training students spending time with them both in the laboratory and field station teaching them about experimental radio astronomy. It actively participated in the CHERA Summer School programme organized by RRI during July 2017. During morning sessions of the programme, students were taught about the receiver system and introduced to the basic concepts relevant to the receiver design. However,

during afternoons, they were guided to design and characterize various modules of the receiver chain like antenna, amplifier, filter etc. At the end of the session, using the modules that they had built, a simple receiver system was configured and mock sky observation was conducted.

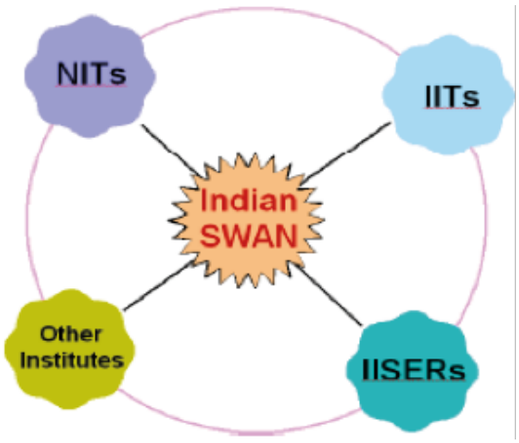


Figure 7. Network of Technology and science institutes across India forming SWAN

FIgure 8. An array of 16 bow-tie antennas (MWA antenna tile) forming one of the elements of SWANproviding an enhanced BW of 250 MHz. The RF signal is down converted to

Figure 9. Racks housing the receiver systems.

Mechanical Engineering Services

The Mechanical Engineering Services (MES) provides facilities to various departments of the Institute ranging from preliminary design concepts to final stage fabrication of various components, equipment and experimental setups. MES also provides mechanical assistance for various labs as well as overall infrastructure development of the campus and its facilities. MES mainly consists of a basement workshop with multiple machines including a CNC machine, a sheet metal workshop, a painting section and a carpentry section. MES also has licensed software such as CATIA-V5, Autodesk product design Suite, Creo 2.0, CamWorks etc. in order to help with design and simulation work for numerous projects and experimental setups.

The CNC machine was extensively used for fabricating components of high precision and accuracy. Some examples include (i) HV mounting plate for detector housing of POLIX project (ii) Brain computer interface lab motor gripper and (iii) Optical pedestal and clamp for LAMP group members.

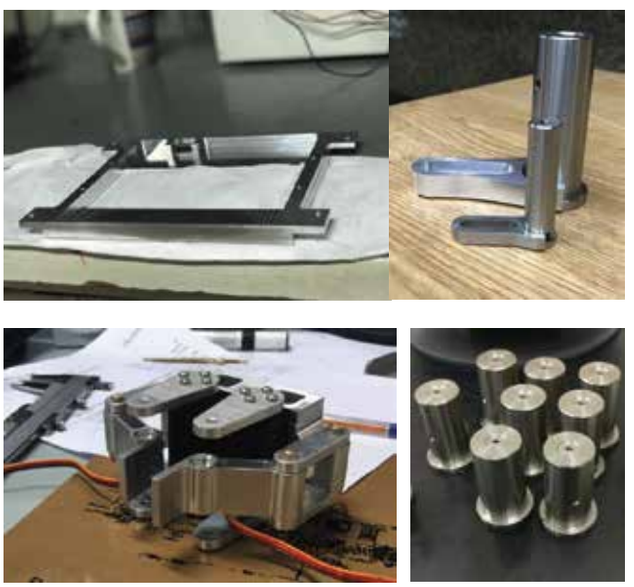


Figure 1. (Clockwise from top) CNC milled HV mounting plate for detector housing of POLIX, Optical pedestal posts and clamps and Brain computer interface lab motor gripper.

A description of the major projects the MES section was involved in during 2017-18 follows:

Setting up the 12 meter X-ray beamline

The X-ray lab at RRI together with MES has setup an X-ray beamline to calibrate the collimator of the X-ray polarimeter, POLIX. A twelve-meter long vacuum beamline with one-cm aperture has been constructed. The beamline, along with the end components, was designed at RRI and manufactured partly in-house and partly with help of Bangalore Vacuum Technology, a local company. The entire beamline is placed on pipe holders (each entity is an assembly of few parts) that were machined in-house at MES with provisions for finer adjustments in height as well as the lateral axis.

Figure 2. 12 m X-ray beamline with provisions for fine adjustments along both the vertical and horizontal directions.

Optical enclosures for labs in LAMP group

MES was also involved in building optical table enclosures for two labs associated with the LAMP group. The 3D design, procurement of materials and fabrication were performed in-house. The frame was constructed using aluminium T-slot profile extrusions that are easy to machine and assemble. The top sheet as well as the sliding doors on all the sides are fixed and mounted onto these T-slot channels. The frame is rigid and was assembled after taking into account design considerations of the experimental setup. The in-house built enclosure enabled drastic reduction in cost. The enclosure doubles up as a faraday cage providing electromagnetic isolation.

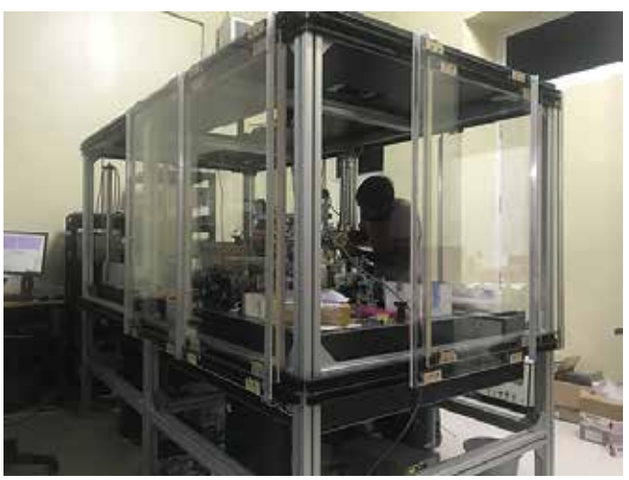


Figure 3. Customized optical enclosure for LAMP group labs

Fabrication of SARAS antenna and support structure

For the SARAS (Shaped antenna measurement of the background radio spectrum) project MES was tasked with fabricating a hollow spherical antenna and a conical antenna. This was achieved by using two spun hemispheres welded along the center line. The conical antenna was made using laser-cut sheets (1.5 mm thickness) fragmented into four pieces for ease of transportation, assembling and disassembling. The inside structure gives it rigidity as well as stability to support the conical sheet with minimal weight. The antenna rests on a SMA pin which is 1.4 mm in diameter, necessitating a support structure that will both hold the antenna in place and not interfere with the experiment. This was accomplished by designing and implementing a Styrofoam support structure.

Figure 4. The SARAS antenna being carefully mounted on the SMA pin using a pulley. The pink Styrofoam support structure is clearly visible.

Receiver Chassis for SWAN

For the SWAN project, a chassis was developed in-house by MES. The frame was made of MS tubes along with attached wheels. The sides were mounted with aluminium sheets and the top lid was made of MS mesh. The front part was painted whereas the insides are chrome plated. The electronics were subsequently integrated into the chassis.

Figure 5. Chassis custom built with slots to house SWAN receivers

Library

Library Collection

The RRI Library founded by Sir C V Raman in 1948, started functioning with his personal collection of books and journals. This is a hybrid library comprising of both print and electronic information resources. The library is central to all the research and science communication activities of the Institute. Library caters to both general and specialized information needs of its users. Currently, the library has a total collection of 70285 comprising of books and bound volumes of journals. Out of this 28937are books and 41348 are bound volumes of journals. Library subscribed to 50 e-journals and 70 Print journals during this year. Additionally, the library has 669 non-book materials that include CD-ROMS, DVD's and Audio/video tapes. RRI users can avail of Grammarly, an English language writing platform to hone their writing skills. This service is provided through the National Knowledge Resource Consortium (NKRC).

Library activities

The library's renewed partnership with NKRC for next three years has brought in online access to 4600 journals published by 15 publishers. RRI library is a content partner to the National Digital Library of India project of IIT Kharagpur. Research output of RRI is hosted on https://ndl.iitkgp.ac.in/, which acts as a single window to the nation's scholarship. Library web page is continuously monitored to keep it current and provide access to both subscribed and open source contents of research interest.

Plagiarism check of 3 doctoral theses was done at the library during the year. ResearcherID of the entire faculty is regularly updated. The library is also in the process of creating ORCID ID for scientists and students upon request. Article processing charges (APC) of 12 papers were handled by RRI library during the year. An MOU with Gubbi Labs, a social media centre, has resulted in one news item based on RRI research appearing during the year in a popular daily. RRI library plays a major role in outreach activity by donating Hindi books to school libraries in rural areas of North India.

Library automation and Digital Library

The Raman Research Institute Digital Repository (RRIDR) also known as e-Sangrah is an active repository for variety of information related to the Institute. The digital repository is currently hosted on version 6.0 of DSpace. Scholarly publications and doctoral theses submitted to RRI are uploaded regularly. During the past year, continued efforts were towards digitization and upload of archival materials, photographs, and audio/video. Number of uploads during this year are 1564, and the total records on RRIDR are 9480. "Imprints-collection", an off shoot of RRI digital repository continues to thrive with regular updated information. This bio-bibliographic database currently has 28 profiles of superannuated scientists and 5 profiles of those scientists who have left RRI to pursue assignments elsewhere and have left behind some imprint in the form of publications with RRI affiliation.

Another major development is implementing KOHA – an open source integrated library management software. RRI library will very soon replace the existing library software, Libsys with KOHA. KOHA-Online Public Access Catalogue (OPAC) is already put into use.

Training activities

RRI library has kept up the tradition of supporting manpower development programs by giving internship training to students from Bangalore University, Bengaluru; Kuvempu University, Shimoga; Shri Jayachamarajendra Government Polytechnic for Women, Bengaluru; and Rani Chennamma University, Belagavi. During the past year, fourteen students from Library Science departments were trained.

Other Events

1. Theme display of books on the occasion of 'International Museum day was arranged from 18th to 31st May, 2017.
2. RRI library was invited to be a part of the International Literacy Day celebration on 8th October, by Pratham books. The program was held at Parikrma Centre for Learning, Kodugehalli, Sahakara Nagara, Bengaluru and our Library staffs experienced the joy of story reading to underprivileged children.
2. RRI Library and Informatics India Pvt. Ltd. jointly organized a special evening lecture by Mr. Marshal Breeding on the topic – "Technology in Context: How economic and cultural realities shape the use of technology in libraries", on 21st January 2018.

Computer Group

The Computer group handles various computing needs of the Institute and provides support for the computing facilities. During 2017-18, the computer group undertook setting up Eduroam wireless network in our wireless LAN. We are now part of the global Eduroam network. Eduroam is a global service that enables students, researchers and staff from participating institutions to obtain Internet connectivity across campus and when visiting other participating institutions. RRI staff may now use their RRI ID and password for internet access in participating institutions worldwide.

The computer group installed Kaspersky Antivirus software in all the computers in the campus, which replaced the earlier Sophos Antivirus. Printing and Print Accounting System using the software PaperCut was implemented. This allows users to check their print usage and also print from anywhere using web printing by uploading files using a browser. An online work request form was created for the Mechanical Engineering Services (MES) group which facilitates online submission of work requests to the MES in place of using paper forms. This application allows the MES In-charge to keep a record of the jobs, assign the job, change the status of the job and generate a report based on various parameters.

The computer group undertook and completed the upgradation of the Digital Repository software DSpace of the Library to the latest version v6.0. The data from the existing server running an old version of DSpace was migrated succesfully. The layout and the colour schemes of the repository pages were also customised for better appearance. The Computer Group installed the Open Source Library Management Software KOHA and helped in migrating the data from LibSys LMS to KOHA last year. The library started using the Open source Koha Library Management System software and is

operating it in parallel with the LibSys LMS. Some additional records were imported and problems with KOHA were fixed. RRI now has its own IPv4 /24 and IPv6 /48 address space which was obtained from Asia-Pacific Network Information Center (APNIC). APNIC is the Regional Internet Registry administering IP address for the Asia Pacific region. This will be useful and help in seamlessly changing ISPs without changing the IP address assignments of our servers.

A new rackmount server, the latest version of Linux operating system and the latest version of Zimbra collaboration server software was installed. All the users' mailboxes were migrated to the new server and the new rackmount servers replaced the existing old servers running various services like web, email and digital repository. The web server was also upgraded completely with a new rackmount server, the latest version of Linux operating system and web server software. All the web pages were migrated to the new server.
The computer group routinely alerts and educates everyone about Phishing and Spam emails by sending screenshots of such emails to everyone. A new projector with high resolution (WUXGA) and intensity (5200 lumens) was procured and installed in the Main Building auditorium.

A new data center is now ready with the server racks, high-density cooling systems and cold-aisle containment in place. This facility, which is a modular system, is housed in the mantap area of EEG building. The present system has six server racks, each with 20 kW load capacity, adding up to a total capacity of 120 kW as well as five 35 kW high-density cooling systems for cooling the server racks. The modular server racks are upgradable up to ten racks, providing additional load capacity up to 200 kW. Electrical work is on-going and a 120 kW UPS is being procured to power the computing systems in the facility.

New PoE switches were procured and installed for the IP security cameras. The cameras were connected to the LAN and access provided to security. The network cabling was carried out earlier. A tender document for a 1024 cores High Performance Cluster (HPC) with the latest Intel scalable xeon processor was drafted and published. We also procured gigabit network switches and replaced all the 10/100 fast ethernet switches in the Gauribidanur Field Station to increase the bandwidth of the network.
To facilitate advance and confusion-free booking of meeting rooms, halls and auditorium in the campus that are used for discussions, meetings, talks and conferences, an online booking system has been installed. This uses the Open Source software MRBS (Meeting Room Booking System). Additionally, essential and commonly used software upgrades and purchases were also carried out as a matter of routine.

Figure 1. The data centre, a modular system, with the server racks, high density cooling systems and cold aisle containment.

Knowledge Communication

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 aimed at challenging graduate students to rise to their full creative potential and develop the ability to conduct research. RRI offers an exceedingly high degree of intellectual freedom to students allowing them to pursue their individual interests within the four broader 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 scientific staff and other students encourages the students 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 a 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, Bengaluru and the Physics and Biology programme with the National Centre for Biological Sciences, Bengaluru. Further details on the PhD programme, admission requirements and procedure can be found on the Institute website.

During 2017-18, 87 students from all over India were enrolled in the PhD programme and conducted research with scientific staff members from the four broad research groups at the Institute.

Last year 5 PhD theses were completed and submitted for review:

1. Madhukar S: Influence of some sterols and nucleotides on the structure of self-assembled amphiphilic systems

2. Gayathri Raman: Multi-wavelength study of X-ray reprocessing in low mass X-ray binaries

3. Rahul Sawant: Interactions between ultracold gas of atoms, ions and cavity

4. Priyanka Singh: A study of multiple probes of the circumgalactic medium

5. Kartick Chandra Sarkar: Fermi Bubbles and galactic outflows in circumgalactic medium

Last year 5 PhD theses were awarded:

1. Priyanka Singh: A study of multiple probes of the circumgalactic medium

2.Kartick Chandra Sarkar: Fermi Bubbles and galactic outflows in circumgalactic medium

3.Saurabh Paul: Study of Redshifted HI from the Epoch of Reionization Era

4.Karthik H S: Quantum information theoretic approach to explore non-classical correlations and uncertainty

5.Lijo Thomas George: A study of radio relic and radio halo emission in galaxy clusters

Postdoctoral Fellowship Programme

RRI offers a postdoctoral fellowship programme, which is open for applications through 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 either or is attached to a specific scientific staff at the Institute. However, it is desirable that their professional research interests and previous experience in research has a significant overlap with the ongoing and envisaged research plans of the Institute. A healthy amount of mutually beneficial interaction with the scientific staff is desired so that collaborations can be struck up. 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 post doctoral 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 RRI website.

During the past year there were 20 postdoctoral and Pancharatnam fellows and one DST INSPIRE Faculty fellow at RRI.

Research Assistants Programme

This Programme provides opportunities for graduates (BSc/BE/BTech) and post-graduates (MSc/MTech) to participate in the research of the Institute and assist in the research by joining our research staff in one of the professional research works. These opportunities arise when research activity requires specialized help that is technical, computational or analysis and cannot be done by the scientific and technical members of the Research Facilities of the Institute. Research Assistants are for when research activity requires specialized assistance in the research work, which may be for durations up to 2 years. The specialized assistance may include engineering and computational skills that are either not currently available in the Electronics, Computing and Mechanical engineering groups of the Institute, or where the quantum of work required at that instance overwhelms the resources of the Institute. The participation is intended to motivate the Research Assistant to pursue careers in research, research support, develop technical skills particularly in hands-on experimental methods and move on to higher learning empowered by the in-house experience. During the past year 27 personnel were involved in research activities via the Research Assistant programme.

Visiting Student Programme (VSP)

The Programme is aimed at offering research experience to highly motivated students who are presently pursuing their Undergraduate or Masters Studies or who are in a gap year that is within a year of their completion of these degrees. Exceptional high school students may also be accepted as interns under this scheme. The purpose of the programme is to expose these students to the research of the Institute and motivate them to take up research as a career. Research Staff at RRI accept VSP students so that significant numbers of Undergraduate and Masters students are given an experience of experimental, phenomenological and theoretical physics/astronomy and thereby gain motivation to enter into research careers. In particular, experimental laboratories at RRI provide students the opportunity to participate in activities that invent, design, develop, build, and commission complex systems that explore frontier areas in the physical sciences, together with learning theoretical tools necessary to understand the complex systems and their purposeful design for the science goals. Enrollment to the Visiting Student Programme is open throughout the year.

Undergraduate and postgraduate students currently enrolled in Universities may undertake their research credits at RRI by working with a research staff member in a research project of the Institute as a separate part of the VSP scheme. During the past year 84 students availed of this programme. A complete list of VSP students who interned at the Institute during the year is given in Appendix VI.

Academic Activities

Conferences

Institute members visit various other institutions in India as well as overseas 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. Last year, scientific staffs and students of the Institute attended numerous conferences in India, USA, South Africa, Germany, France, Singapore, Jordan, Russia, Israel, Canada, Sweden, Czech Republic, Italy, Luxembourg, Hungary, Spain and Poland.

In addition, scientific staff members 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.

Seminars and Colloquia

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

The Thursday Colloquium is an 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. The colloquium aims to cover emerging science topics and bring an interdisciplinary flavour 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 India and the world to deliver the seminars and colloquia. A complete list of speakers and the diverse topics presented is given in Appendix III.

Visiting scholars

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 99 scholars who visited RRI from both Indian and international institutions. RRI is happy to have hosted so many academic visitors 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.

Science Forum

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 RRI Science Forum was conceptualized and first came into being in 2014. The goal was to provide an attractive forum to all scientific members on campus for discussions on current research in a variety of topics. Gautam Soni, Andal Narayanan and Nayantara Gupta are the organizers of this regular event. The RRI Science Forum is held on alternate Thursdays between 3:30-4:30pm.

Talks at this forum comprise of 2 parts, the first introductory talk of about 20 minutes (where the field is introduced to non-experts at a very basic level by a scientific staff member or postdoctoral fellow) followed by the "Science Talk" (where the chosen paper is presented by a PhD student).

Typically, as part of the RRI Science Forum, papers with exciting new results that are often considered landmarks in that particular field are presented to a wider and more general audience. Based on the presentation, informal discussions, questions and demonstrations are strongly encouraged leading to a better understanding of the underlying concepts of the work presented. This in turn often results in new ideas and new research problems for the members of the RRI scientific community to work on. Through the year 2017-2018, the forum has become a useful platform to learn about and appreciate the breadth of research done in RRI.

A list of publications reviewed during the RRI Science Forum meetings last year is attached to the Annual Report as Appendix V.

Extramural Activities

Public Outreach

RRI engages with the wider society for communications on science and related topics. RRI staff and students routinely organize and participate in popular seminars, talks and workshops. RRI also invites and welcomes school and college students to visit the campus and interact with scientific staff of the Institute. Apart from these general interactions, over the years many college students have gained hands-on experience working with sophisticated Radio Telescopes at the Gauribidanur field station. Additionally, RRI shares its latest research, events, activities and general news through Facebook, Twitter, blogsposts, YouTube and Newsletters. Once every two years, RRI coordinates the selection and participation of Indian high school students in the International Science School held in Sydney, Australia. All of these continued in 2017-18 with participation in a variety of outreach activities. A comprehensive list of RRI member outreach activities in the form of popular talks, seminars and workshops is given in Appendix II. Other major outreach activities are discussed below.

Talented Indian high school students at the 2017 Sydney International Science School

In July this year five of India's talented high school students once again had the opportunity to participate in the prestigious International Science School in Sydney. Raman Research Institute coordinates the selection and facilitates the students' participation in the 2-week program. The ISS as it is referred to is an abbreviation for the Professor Harry Messel International Science School, one of the longest running science events, and this is held once in two years in Sydney organized by the School of Physics at the University of Sydney.

India's participation in this event began in 2007 when the Raman Research Institute was approached for coordinating the selection of Indian students for award of the ISS scholarships. Thirty Indian high school students have been to the ISS since 2007. This year a total of eight countries participated in the event. There is a varying allocation of number of scholarships for each country with five scholarships for students from India, UK and USA, seven for students from Thailand and New Zealand, ten for students from China and Japan and eighty scholarships for students from Australia. Participation in past ISS events included students from Singapore, Malaysia as well as Canada.

The buildup to the travel to Sydney involves a mandatory meeting at RRI where the whole team meets each other for the first time and details of travel and the visit itself are discussed. This is an important orientation step for the students for several of whom this would be the first visit out of the country. Over the days at RRI in May this year the students got to visit some research laboratories and listen to a few lectures related to research happening on campus.

The theme for the ISS this year was on "Future Power: Challenges, Opportunities & Solutions". Pitched at university level the lectures are given by scientists working in the area from around the world. Over the two weeks there were two lectures each day that covered various forms of energy and their generation from science basics to practical applications. They covered between them fusion, fission, solar, wave, wind, biomass and battery giving the students a ringside view into the world of energy innovations, energy considerations, transmission, storage, the inevitable impact on climate and the coming trends in energy usage. The 2-week event also included several "Science & Engineering Challenge" events each day, visits to several research laboratories within the University of Sydney, a set of highly engrossing lectures on ethics in science, a set of lectures introducing the world of high-potential, high-impact energy technology research being carried out at the Advanced Research Projects Agency-Energy (ARPA-E) and an enjoyable and quite hands-on afternoon lecture on Australian aboriginal culture. After a packed day of lectures and activities the evenings included a varied fare of social activities over the two weeks including a talent night event and a dinner cruise of the Sydney Harbour.

(Left) One of the teams working at a science and engineering challenge activity. (Right) Indian students that were selected for ISS 2017.

At this ISS (as in the very first ISS that Indian students attended in 2007) one of the Indian students - Poorvi Hebbar - won the coveted award for science leadership, the Len Basser prize. With full involvement in all activities over the two weeks, be they at the daily lectures where they participated actively by asking questions and interacting with the speakers or in social events or in exhibiting individual talent in music, classical dance and song all five students (as do all others invariably) came away with the view of the ISS experience as one of the most stimulating and enjoyable experiences.

RRI at the India International Science Festival

The third edition of the India International Science Festival (IISF 2017), jointly organized by the Ministry of Science and Technology, Ministry of Earth Sciences and Vijnana Bharati was held between 13-16 October at Anna University, IIT and CSIR-CLRI campus in Chennai. IISF is one of the largest outreach events of its kind and showcases achievements in Indian science to the general public. One of the many events at IISF 2017 was a "Mega Science and Technology Expo: theme-based pavilions in Engineering, Water, Healthcare, Agriculture, Environment, Strategic Sectors, etc".

Raman Research Institute participated in this expo with an eye-catching pavilion that had the shape of the antenna element that forms the International MWA Radio Telescope array in Western Australia, in which RRI has been a partner for the last decade and for which RRI built the digital receivers. For the benefit of visitors we had an explanatory "Why does the RRI stall have this weird shape?" at the entrance to the pavilion.

The pavilion included posters highlighting the research achievements at the Institute this past year as well as models of a radio telescope, antenna and detectors. A TV screen constantly replayed images of the Milky Way galaxy and distant universe at a range of frequencies from Gamma rays down to radio frequencies. Incidentally the image of the radio sky that was part of the slide show resulted from the sky survey using the MWA telescope.

The posters discussed (i) Cold Atoms – A chill cocktail of atoms and ions at near absolute zero temperatures (ii) Theoretical Physics – "Understanding the Universe – One equation at a time" (iii) Two posters on Theoretical Astrophysics – "Understanding the Dynamic Universe" (iv) Two posters on Radio Astronomy – "Seeing the Unseen" (v) Quantum Key Distribution – "A new security paradigm" (vi) POLIX: X-ray vision – "India's own eye in the sky" (vii) Liquid crystals – "The fourth state of matter". Apart from the above there were posters that gave an overview of RRI along with posters on PhD, postdoc, visiting students and research assistants programmes.

Over the course of the four days more than five thousand people from all walks of life – high-school students, undergraduates, graduates, PhD students, academics from the scientific fraternity, Ministry

Photo of RRI pavilion at IISF 2018

officials and also the general public visited the pavilion. Visitors were very interested in the shape of the pavilion as well as the science and enthusiasiatically put forth questions; some gently asked us if they could be answered in the local vernacular. The same was the reaction from many school students who had made the trip to Chennai from remote locations across India.

The pavilion was ably managed by RRI PhD students Rishab Chatterjee (LAMP), Sagar Suthradhar (LAMP) and visiting student Urvashi Nakul (AA). The interactions were not limited to questions and answers but to in-depth scientific discussions with PhD students from other institutes. Needless to say, there was never a dull moment and everyone involved came back richer from the experience. RRI hopes to continue such public engagements in the years to come.

A collection of photos with visitors to RRI pavilion at IISF 2018

Nature appreciation and sketching workshop for children on RRI campus

RRI played host to a small group of city children in the age group of seven to eleven years. This event, held over the summer school holidays, saw RRI share with children its beautiful campus and the opportunities it offers for observing and sketching nature, to awaken in them a sensitivity for the environment. A group of children, along with arts teachers, visited RRI campus for several hours every morning during the week of 18th to 21st April, 2017. During these times the city children saw the variety in shapes and colours and patterns in leaves, flowers, seeds and barks, saw and heard the birds, mingled with butterflies, and sketched their experiences. RRI sincerely hopes that the time spent in these sylvan settings, away from the hustle and bustle of city life, will stay in the memory of the children for a long time to come, perhaps sowing in their minds the seeds of passion for explorations into the unknowns in nature. After all, to quote RRI's founder Professor C V Raman, ''In the history of science, we often find that the study of some natural phenomena has been the starting point in the development of a new branch of knowledge.'' The Institute looks forward to many more opportunities to share its campus in ways beyond scientific empowerment and towards encouraging a holistic development in the next generation.

RRI in the media

The professional pursuit of science may be a relatively personal enterprise, or a joint activity of a few scientists collaborating with each other towards a common goal, or an enterprise involving hundreds and even thousands of scientists who may be distributed worldwide. Any insight gained or phenomena discovered are then communicated in the form of publications that are intended mainly for fellow scientists. On the other end of the spectrum is the general public whose money more often than not enables these scientific pursuits, but are none the wiser for it. Human beings have this innate curiosity to know and understand the natural world they live in and it would ultimately serve science well to kindle this curiosity, particularly in impressionable young minds. Whatever be the reason, communication of ''hi-fi'' scientific research couched in language that is easily understandable to one and all is highly desired. Additionally, these popular science articles, snippets and news may be disseminated in such a way as to have maximum outreach. The Raman Research Institute is attempting to bridge this gap by posting general write-ups based on research publications by RRI research staffs and students on Facebook, Twitter and blogposts. During 2017-18, RRI continued its commitment to research communication by launching the official RRI YouTube channel. The channel playlists contain lectures, talks, workshops, student and postdoc videos, and archival videos. Along with adding new playlists, existing playlists will be periodically updated with new videos.

The biannual RRI Newsletter is another such endeavor that highlights recent research at the Institute through its science articles. The articles are written in a language that enables sharing the Institute's exciting research with the wider community. The Newsletter also serves the purpose of updating RRI members, collaborators and the general public on recent news and diverse activities that are part of daily functioning of the Institute. To enable easy access to all these posts, tweets, blogs, videos and newsletter a link ''RRI in the media'' has been created on the RRI homepage.

Student visitors to RRI campus

4 May 2017 -
8 meritorious students from Aryabhat Foundation for Promoting Basic Science, visited RRI and interacted with scientists.

12 July 2017
A batch of 30 M.Sc. (Physics) students from Sathyabama University, Chennai visited RRI as part of their science activities.

13 September 2017
A batch of 50 Pre-University (Physics / Chemistry) students from Reva University, Bangalore visited the Institute as part of their science activities.

15 September 2017
A batch of 45 B.Sc. (Physics) students from Sacred Heart College, Chalakudy, kerala visited RRI as part of their science activities.

October 25th 2017
A batch of 45 M.Sc. students of Mahatma Gandhi University, Kottayam, Kerala visited RRI. Professor Reji Philip gave a talk and interacted with the students.

November 7th 2018
A batch of 45 tenth standard Students of Kautilya Vidyalaya, Kanakadasanagar, Mysore visited the Institute. Professor Andal Narayanan gave a talk and interacted with the students.

December 14, 2018
A batch of 45 M.Sc. students of St. Thomas College, Palai, Kerala visited the Institute. Professor Ravi Subrahmanyan gave a talk and interacted with the students.

January 22, 2018
40 high school students of Army Public School, JC Nagar, Bangalore visited RRI.
Dr B M Meera gave a talk and interacted with the students.

February 2, 2018
A batch of 48 B.Sc. students of PSMO College, Tirurangadi, Kerala visited the Institute. Professor Reji Philip gave a talk and interacted with the students.

February 28, 2018
A batch of 50 high school students from Parikrma Humanity Foundation, Bangalore took part in the National Science Day celebration.

March 2, 2018
A batch of 60 Pre-University science students of Indian Academy Degree College, Bangalore visited RRI. Professor Reji Philip gave a talk and interacted with the students.

HANDS-ON Radio Astronomy camp conducted by RRI

Despite the several student internship programs offered by the various Indian research institutes providing useful research experience to typically a few hundred students each year, an overwhelming majority of the bright and motivated students still remain unexposed to the exciting developments and research opportunities in Radio Astronomy. Due to the lack of exposure at an early stage, much of the talent is missed to be attracted to graduate studies and research in astronomy. The initiatives such as the "Radio Astronomy Winter School for College students" (RAWSC, since 2008) and the "Pulsar Observing for Students" (POS, since 2012) aim to bridge this gap. These programs have provided such opportunity to more than 200 students so far. New programs, particularly aimed at mentoring radio measurement techniques and instrumentation skills, would complement and enhance capacity for future development in these areas.

This decade has seen an unprecedented increase in radio astronomy initiatives and related developmental activities, as well as research in general with existing and new facilities, across the world. India has a long history in radio astronomy, including instrumentation development. RRI ensures the continuity of this tradition, by training the next generation of radio astronomers and instrumentation developers in hands-on camps conducted at our Gauribidanur field station (since 2017 jointly with IIA) and at RAC, Ooty (in 2015 and 2016 jointly with NCRA). The focus in these camps is on hands-on experience with instrumentation/observation/measurement/analysis, thus distinct from the other initiatives that are already in place. In addition to the hands-on component, the 2+ week camp will introduce undergraduate and masters students to radio astronomy, basic concepts and advanced topics/techniques.

In Gauribidanur field station students also get to know the SWAN (Sky Watch Array Network) Phase-0 (8-station) system closely, work with it in an uninhabited manner and conduct tests/observations in single station and interferometer modes. With such exposure, hands-on experience and involvement, the students are encouraged to follow-up their participation in the development and use of SWAN through remote access, as well as locally at a later time when their institutes host one of the SWAN stations. It is encouraging to see the students come forward on their own to participate in the SWAN programs. At present, telecons with a dozen students across India happen every evening (of course, except during their exams) in order to help them pursue their interest in SWAN and carry out real data analysis leading to imaging. To know more about the SWAN program visit http://www.rri.res.in/SWAN/SWANRRI.html

CHERA (Camp for Hands-on Experience in Radio Astronomy)

23rd June to 8th July 2017: 7 students from CUSAT-Kochi, BMS-Bangalore, SVNIT-Surat, St. Stephen's College -Delhi, IISER-Tirupati, St. Xaviers College -Kolkota and IIT-BHU attended the CHERA Summer 2017 camp at our Gauribidanur field station.

SWAN-CHERA (multiple student visits of 5-10 days duration, each)

May - July 2017: 21 students from Maulana Azad National Urdu University-Hyderabad, IIT Madras, BITS-Pilani, IIT Kharagpur, Kirori Mal College-University of Delhi, IIT Indore, Shivaji College-Delhi University, Miranda House-Delhi University, Nehru Planetarium-New Delhi and IISER-Mohali attended the Indian SWAN (Sky Watch Array Network) HANDS-ON Summer 2017 Camp at our Gauribidanur field station.

Dec 2017 - Jan 2018: 8 students from BITS-Pilani, Federal Institute of Science and Technology (FISAT)-Kerala, Siddaganga Institute of Technology-Tumkur, IIT-Kharagpur, Thapar Institute of Engineering and Technology-Patiala and IIT-Madras attended the Indian SWAN (Sky Watch Array Network) HANDS-ON Winter 2017 camp at our Gauribidanur field station.

Participants at the hands-on radio astronomy camp at Gauribidanur field station

Student visitors to Gauribidanur field station

Between April 2017 and March 2018, students from High Tech Diploma College Gauribidanur, BIT institute of Technology, Hindupur, Gitam University, Bangalore, SJCIT, Chikkaballapur, MSR Institute of Technology, Bangalore, Vishweshwaraiah Institute of Technology, Bangalore and BMS Institute of Technology, Bangalore visited the Institute field station at Gauribidanur. More than twenty Government and private, primary & high school students from Tumkur, Kolar, Bangalore and Chikkaballapur districts visited the field station. Additionally, staff from LIC, BESCOM and Revenue department also visited the site.

Official Language activities

During the year 2017-18, the Institute has conducted Hindi week, workshops, letters for external communication including RTI replies apart from translating internal communications.

Hindi week was conducted during 20-26, September 2017 in association with the Indian Academy of Sciences. During the Hindi week celebrations Hindi dictation, story writing, newspaper reading, poem recital competitions were conducted. During the valedictory function an invited talk by Smt. Sharadamani Rao, Sr. Hindi Officer, Central Power Research Institute, on ‘‘Official Language Implementation – Why and How?’’ was organized along with prize distribution for the winners in the competitions.

Others

During 2017-18, RRI organized conferences, meetings and workshops described in detail under the section titled ‘‘Events’’. Other events include high teas on superannuation of regular staff, sports tournaments, concerts and a variety of cultural programs, both with invited performers and RRI members themselves.

EMBO cell mechanics lectures

EMBO cell mechanics lectures on experimental and theoretical approaches to cell mechanics was conducted at RRI and NCBS between 23rd April – 6th May 2017. The first week consisted of lecture sessions in the RRI auditorium by eminent researchers from India and abroad. Topics covered in the lectures include fundamentals of polymer physics, stochastic dynamics, active particles and gels, pattern formation in development, tissue dynamics and membrane biophysics. Dr Pramod Pullarkat and Dr Gautam Soni from RRI gave lectures on optical tweezers and AFM techniques. The second week was reserved for hands on training at the excellent experimental facilities of NCBS.

Mechanical forces play a fundamental role in a multitude of cellular phenomena. Typically, such forces arise from two molecular-scale processes: (i) the action of molecular motor proteins and (ii) polymerization dynamics, both of which involve an interplay between Brownian effects and non-equilibrium molecular processes. These mechanisms not only operate at the scale of a single molecule, but they also exhibit collective dynamics, generating active stresses and flows that can change cell shapes, drive cell locomotion, or result in tissue remodelling.

The importance of a lecture series on this topic followed by hands on training is because in recent years tremendous progress has been made in understanding the main principles behind such ''active dynamical processes'' due to the development of fundamentally new theoretical ideas, novel experimental techniques to perform high precision mechanical measurements on live cells, and the development of simplified in-vitro systems. Key to these advancements is a strong interdisciplinary culture between physicists and biologists, combining the tools and expertise of the respective fields.

Thus this programme was conducted with two goals in mind. First, to introduce the above mentioned physical concepts-via a series of pedagogical lectures starting from very basic concepts-to students new to the field and post-doctoral fellows wishing to venture into this area of research. Second, to provide PhD students and post-doctoral fellows with hands-on experience in advanced experimental and computational techniques. Students developed these techniques from scratch under the guidance of experts. Additionally, physics and biology students working together on the hands-on module enabled them to gain valuable experience working in an interdisciplinary environment.

70 participants from both India and abroad availed of this unique opportunity to further their conceptual knowledge along with experimental and computational skills in this exciting field of research. Looking forward, RRI hopes to successfully host such schools as well as similar lecture series that serve as excellent platforms for knowledge transfer from experts in the field to students and young researchers, in India as well as the rest of the world.

Group photo of all the participants.

Attentive audience during one of the lectures.

Discussions over refreshments

Welcoming RRI's 2017 batch of PhD students

The new students joining the RRI doctoral program this year were given a warm welcome on 4th October, 2017 in an event held at the Library block terrace. The Institute's Director gave a welcome speech followed by the students introducing themselves. This was followed by High Tea. A total of 21 new students joined RRI this past year. A hearty welcome and best wishes to the students for a successful tenure at RRI.

The 2017 batch of PhD students

Remembering Professor Narendra Kumar

The Institute organized an event in RRI main building auditorium reminiscing the life and work of Professor N Kumar – director from 1994 to 2005 – who sadly passed away recently. The event included a set of talks from people who had the opportunity to interact with Professor Kumar. Given the varied and multifaceted interactions that Professor Kumar had, there were speakers from RRI colleagues, administration, scientific collaborators from elsewhere, friends and students. The event started on time with an introduction by Professor Reji Philip followed by reminiscences by the Director Professor Ravi Subrahmanyan and Dr K Kasturirangan. Professor R Srinivasan next remembered his interactions and the guidance he received from Professor Kumar while they were setting up the experiments to produce ultra-cold atoms at RRI. Then it was the turn of Professor Rajaram Nityananda who reminisced about the physics lectures Professor Kumar delivered at IISc. He was followed by Professor K A Suresh who remembered the mentoring role played by Professor Kumar when he took up the responsibility as Director of the Center for Nano and Soft Matter Sciences. The reminiscences between individuals continued over a cup of coffee, tea and biscuits during a break. In the post break session the audience was treated to anecdotes by Mr K Krishnamaraju, which was followed by talks from Professor Anders Kastberg and Professor Anantharamakrishna, a former student of Professor Kumar. The event closed with personal reminiscences and thoughts from Professor Andal Narayanan and Professor Hema Ramachandran who also delivered the vote of thanks. A slide show of pictures of Professor Kumar provided by the library played in the background, taking people down memory lane.

Copper-moon viewing at RRI

The year 2018 ushered itself in by putting up one of the most spectacular celestial events in its very first month. The dusky skies of 31st January, 2018, saw the rising of the copper-moon, a solemnly red and eclipsed full moon that greeted astronomy enthusiasts around the globe and in RRI.

Even though full moons and new moons occur every month, they do not present an alignment of the earth-sun-moon system, conducive for eclipses, that often. However, 31st January, 2018, marked a rare amalgam of several interesting astronomical phenomena. It was the second full moon of the month (a blue-moon), with the earth's natural satellite rising from below the eastern horizon, around sunset. The moon, on this day, was aligned perfectly in a straight line with the sun and the earth; since the sun's light falling on the earth, cast a shadow on the moon, this manifested as a lunar eclipse. This eclipse happened to coincide with moon-rise time (around half past five in the evening) for viewers in Bangalore, due to which, scattering effects by the earth's atmosphere near the horizon rendered a tint to the rising eclipsed moon, making it appear copper-red. Coincidentally, on this very day, the moon also happened to be at its closest proximity to Earth, making it a super-moon. Drawn in by the anticipation of viewing such a rare phenomenon, an astronomy picnic was organized at RRI.

The RRI copper-moon viewing picnic was held on the terrace of the Library building. Nearly two hundred astronomy enthusiasts including students, children, faculty members and their families, gathered around five in the evening to witness the eclipse event. After a refreshing round of tea and biscuits, there was an introductory demonstration of the science behind the event that was about to unfold. A model of the solar system, consisting of the sun, moon and the earth was setup. This was to enable the audience to visualize the relative positioning of these three objects during an eclipse. Ideas about the phases of the moon, the lunar spin and orbital motions as well as the lunar rise and set times were discussed.

The discussion was brought to an end right about the time when people started spotting a hazy copper-moon, rising above the tall trees, in the eastern direction. People clambered about to get a good long look at the rising eclipsed moon, which was very faint in the beginning. As the moon slowly rose well above the horizon, the visibility improved and a much sharper image was seen. The viewing experience was aided by a few binoculars and two portable telescopes that were setup at the event location. Several skilled students tried their hands at amateur astro-photography of the different phases of the eclipse. A collage is shown below.

As the moon slowly meandered its way out from the Earth's circular shadow, after almost an hour, the eastern sky was lit up by the sheer brilliance of the full moon. All in all, that night's spectacle left people in awe of the cosmos and it's elegant workings.

Demonstration of the science behind the lunar eclipse using a sun-moon-earth system.

A collage of different phases of the eclipse.

"On Science and Nationalism", a special lecture by Shiv Visvanathan

The Institute hosted its first "Special Lecture" on 22nd February 2018, inviting RRI Adjunct Professor Shiv Visvanathan, who obliged us with a stirring lecture on "Science and Nationalism". Professor Visvanathan spoke of the days of our freedom struggle during which science and nationalism were spoken of in the same breath. He wove a narrative around the contributions of prominent scientists to the idea of nation building. He spoke about how scientists and poets were not just two mutually exclusive departments in a university, but exchanged ideas that captured the imagination of many.

Though the lecture officially ended after an hour, the discussion continued with a discussion meeting that was organized with the speaker with the intent of an informal tete-a-tete. The discussion flowed and touched many issues. It was a delight to see Professor Shiv Visvanathan engaging with the students over a cup of tea. And it was a greater delight to witness enthusiastic conversations about the talk over lunch tables, in lounges and in the lobbies, days after the talk.

Professor Shiv Visvanathan delivering the lecture

Engaging with students and visitors in an informal discussion that followed the lecture.

National Science Day celebration

The discovery of the Raman effect is celebrated all over our country as National Science Day. As has been the tradition at the Institute, students were invited to visit the campus and interact with RRI staff and PhD students. The day started with fifty high-school students from Parikrma Humanity Foundation assembling in the RRI

auditorium to be acquainted with the history of the Institute, its founder and the significance of the day. The students then had the unique experience of visiting the RRI museum that houses the collection of Professor C V Raman. Needless to say, the students were fascinated by the artifacts and really enjoyed their time in the museum. After the museum tour it was time for lunch, which was arranged on the library block terrace. Post lunch, the students assembled back in the auditorium for an interactive session with RRI PhD students Kumar Shivam (TP), Anirudh Reddy (TP) and RRI alumnus, Jayakumar. The aim of this session was to engage and share the wonders of science with young minds through simple table-top demonstrations. This new venture at RRI was very well received as evidenced by the enthusiastic participation of the students in the demonstrations as well as volunteering their explanation of the science behind some of the demonstrations.

Students from Parikrma Humanity Foundation participating in the Science Day celebrations

French delegation visits RRI

Representatives from ENS Paris-Saclay and Université Paris-Saclay visited RRI on 8th March. The delegation was composed of Professor Keitaro Nakatani (vice-president, research - ENS Paris-Saclay), Professor Claire Lartigue (vice president, education - ENS Paris-Saclay), Professor Fabien Bretenaker, (physicist, ENS Paris-Saclay and adjunct professor, RRI), Professor Guillaume Garreta (director of international development -Université Paris-Saclay), Professor Sandrine Lacombe (vice president, international relations -Université ParisSud), Mr Sergei Shikalov (international projects officer-Université Paris-Saclay) and Dr Jérôme Bove (scientific and academic attaché, French embassy in India). The RRI representatives included Professor Ravi Subrahmanyan (director), LAMP group members Professor Andal Narayanan, Professor Hema Ramachandran, Professor Reji Philip, Professor Sadiq Rangwala, Dr Saptarishi Chaudhuri, Professor Sanjib Sabhapandit (TP) and Dr V G Subramanian (director's office).

RRI already has a robust collaboration with our French peers; a few of the RRI staff have ongoing Indo-French collaborative projects, while others have successfully completed theirs. RRI also has regular visits by French scientists in various capacities- Professor Anders Kastberg was a visiting professor until very recently and Professor Fabien Bretneker is currently an Adjunct Professor. The aim of this particular visit was to discuss ongoing projects as well as explore possibilities for future collaboration. The visit began with a meeting in the Council Room. A presentation by Professor Guillaume Garreta on the opportunities and the funding sources available for scientists and students for collaborations and student exchange programs was followed by over-the-table interactions and discussions between the representatives. Following a short photo session, the discussions concluded over lunch at the RRI canteen.

Group photo with the iconic RRI lawn as a background

An evening of "Mitti – back to roots" film screening

RRI welcomed the public to its auditorium for a free and open screening of the movie "Mitti – back to roots"- a film based on real life stories. The film highlights the ongoing agrarian crisis in our country and provides sustainable solutions. The crisis, as you may be aware, is perpetuated by unregulated use of pesticides and chemical cocktails that result in soil and groundwater contamination, surreptitious sale and spread of genetically modified seeds to unsuspecting farmers as well as a host of other factors. The screening commenced at five in the evening after a refreshing round of tea and snacks. The event was well attended, with not a seat left empty. The screening was followed by a lively discussion session. It is worth noting that a few farmers from in and around Bengaluru participated in the discussion and offered their point of view, which served as an eye opener to all the problems they face on a day-to-day basis.

Australian National University delegation visits RRI

A delegation from Australian National University (ANU) visited RRI on 10th April 2018. The delegation was represented by Professor Peter Bouwknegt (director, ANU Mathematical sciences institute), Professor John Carver (director, ANU Research school of chemistry), Professor Tim Senden (director, ANU Research school of physics and engineering), Professor Chennupati Jagadish (distinguished professor, ANU Research school of physics and engineering), Mr David Akers (general manager, ANU College of science and ANU

College of health and medicine) and Mr Jay Poria (manager, International development and partnerships). The RRI representatives included Professor Ravi Subrahmanyan (director), group coordinators Professor Andal Narayanan (LAMP), Professor Nayantara Gupta (AA), Professor Pratibha R (SCM), Professor Sanjib Sabhapandit (TP), Student academic affairs committee chairman Professor V A Raghunathan (SCM) and Dr V G Subramanian (director's office). The aim of their visit was to explore opportunities for research collaborations and student exchange programs including the option of dual PhD programs. The delegates were pleasantly surprised to know that there have been PhD students who registered at ANU for their PhD and carried out research work at RRI and in collaboration with and co-supervised by RRI staffs.

The visit started with an overview meeting in the Council Room. The delegates from both sides gave brief introductions about their respective groups/research schools. Areas with common research interests between ANU and RRI were identified. The council room meeting was followed by two guest lectures later in the day - "Semiconductor nanowires for optoelectronics applications" by Professor Chennupati Jagadish in the RRI auditorium and "From nano-mechanical work on molecular assemblies, to micro-X-ray computed tomography for improved oil recovery" by Professor Tim Senden in the library block lecture hall. The visit concluded with a tour of laboratories in SCM and LAMP groups.

Over-the-table interaction with the delegates in the RRI council room.

In-house Meeting 2018

The RRI In-house meeting, an annual event organized by PhD students, was held between 11th – 13th April. The aim of this annual meeting is to serve as a forum for students and staff from the four groups of the Institute and the facilities to get together and present their research work. The meeting provides a platform for exchange of ideas as well as an opportunity to learn about the research activities in groups other than their own.

Students and staff delivered a total of twenty-six talks, each of twenty minutes duration and spread over nine sessions. Additionally, students communicated their research via posters.

As on earlier occasions an open-house discussion was held in the final session of the meeting. Over the years, the final session of the In-house meeting has come to be used by the students as an opportunity to discuss matters pertaining to their life on campus. This year the discussion was towards improving quick access to first aid and medical care in emergencies, which do happen in and out of hours in an academic institute like ours with a sizable student population. And on how late working hours may be helped with access to refreshments late in the night. And how improvement in sports facilities on campus would be really appreciated by the growing student community.

The In-house meeting was brought to a close with a cultural event followed by dinner.

Question and answer session during one of the talks.

An evening of music and dance

Campus

The Institute campus is located in the northern part of Bengaluru. It covers an area of 20 acres replete with trees and shrubs. The hustle and bustle of the developing metropolis outside is left behind as one enters the Institute gates. The environment inside is a world apart: a campus that has landscaped greenery including a variety of species from near and far, patches of wilderness tended only by nature, together with the laboratories, workspaces and facilities. Distinctly a shade cooler, this sylvan setting is an attempt to create generative surroundings for the creative research and academic learning that goes on within the campus.

The campus hosts the buildings containing workspaces, laboratories, workshops, canteen, clinic and the guesthouse. And these are surrounded by aesthetically planned and well-kept vegetation that is very appropriate for a campus of a renowned research institute. Indeed it was Professor Raman who had himself landscaped much of the campus. At the center of the campus lies the iconic main building, which faces a manicured lawn flanked on both sides by majestic eucalyptus trees that seem to reach for the sky. The lawn is where Professor Raman was cremated, respecting his wishes, and a *Tabebuia donnell-smithii* grows here as a memorial. The Institute is proud and obliged to respect and protect this special environment.

The campus abounds in flowering trees and shrubs like the common Hibiscus, Ixora, Frangipani, Gulmohar, Golden shower tree, Bougainvillea and many more, indeed a welcome sight for the discerning. Members of the Institute and a lucky few elderly neighbors who visit the campus for an early morning constitutional are audience to nature's symphony. The sensitive ear might differentiate the cooing of the koel, chirping of the mynah and bulbuls and many more sounds whose origin is lost within the protective embrace of the branches and leaves. Looking up at the source of the screeching sound heard in the early afternoon, one might find a parrot dangling from a branch with one foot, the other foot holding what passes off for a delicacy in the parrot world, which it then proceeds to peck into and relish with gusto. Along with birds that are indigenous to this part of the country, migratory birds from North India and beyond wintering on RRI campus are a familiar sight. However, do not walk along the well laid out pathways trying to catch a glimpse of bird life, lest you step on - a snail lumbering along or the myriad armies of ants and other insect life that we share our campus with.

The Guesthouse on campus is equipped with rooms blending modernity with ethnic elegance 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 members of the Institute and also those who work at the Indian Academy of Sciences, which is also located in a corner of the campus. Informal meetings, 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, or on the terrace of the Library building that is in the canopy.

Minimal sports facilities exist in the limited open spaces on campus: there are spaces for Badminton, Volleyball, Table Tennis plus a small Football ground. The buildings adjacent to the Canteen houses a small Clinic where consultant medical practitioners pay visits at fixed hours on working days of the week, providing for the health and well being of the members of the Institute and their families.

People at RRI

Academic Staff

Astronomy and Astrophysics

Ravi Subrahmanyan (Director)
Research Interests: Observational cosmology, extragalactic astronomy, antennas and signal processing
E-mail: rsubrahm@rri.res.in

Nayantara Gupta (Coordinator – from 26.8.2017)
Research Interests: Neutrino and gamma ray astronomy, origin and propagation of cosmic rays, astroparticle physics
E-mail: nayan@rri.res.in

Shiv Kumar Sethi (Coordinator - till 25.8.2017)
Research Interests: Cosmology
E-mail: sethi@rri.res.in

N Udaya Shankar (Consultant)
Research Interests: Detection of Epoch Of Reionisation (EoR), an array for the detection of epoch of recombination, instrumentation and signal processing for radio astronomy
E-mail: uday@rri.res.in

Biman Nath
Research Interests: Interaction of diffuse gas with galaxies; galactic outflows; cosmic rays; intracluster medium
E-mail: biman@rri.res.in

Avinash A Deshpande
Research Interests: Radio astronomy, signal & image processing, radio transients, pulsars, polarization, instrumentation
E-mail: desh@rri.res.in

B Ramesh
Research Interests: Diffuse matter in our and other galaxies, analog & digital signal processing, instrumentation and techniques for astronomy; brain computer interfaces and patient assistant systems
E-mail: ramesh@rri.res.in

S Sridhar
Research Interests: Exoplanetary dynamics, stellar dynamics in galactic nuclei
E-mail: ssridhar@rri.res.in

Biswajit Paul
Research Interests: Developmental work for an X-ray polarimeter, ASTROSAT and an X-ray pulsar based interplanetary navigation system and investigation of various aspects of compact X-ray sources
E-mail: bpaul@rri.res.in

KS Dwarakanath
Research Interests: Groups and clusters of galaxies, HI at high z
E-mail: dwaraka@rri.res.in

Lakshmi Saripalli (RRI Trust funded position)
Research Interests: Radio galaxy morphologies; giant radio galaxies; galaxy environments
E-mail: lsaripal@rri.res.in

Vikram Rana – from 12.10.2017
Research Interests: X-ray instrumentation and observational X-ray astronomy. Experimental research involves development of X-ray detectors (CZT and CdTe) and focusing X-ray optics for measuring X-rays from various astronomical sources with high sensitivity and high resolution. Observational research mainly focuses on understanding the accretion processes, geometry and physical conditions in X-ray Binaries, Cataclysmic Variables (CVs) and Ultra-luminous X-ray sources (ULXs) utilizing their X-ray observations
E-mail: vrana@rri.res.in

Yuri Shchekinov (Visiting Professor)
Research Interests: Interstellar and intergalactic medium, starbursts, galactic winds, physics and dynamics of cosmic dust, epoch of reionization, chemical evolution of galaxies and the universe
E-mail: yuri.and.s@gmail.com

Mayuri S (Research Associate)
Research Interests: Simulation and feasibility studies to experimentally detect spectral signatures from the Epoch of Recombination, application of maximally smooth fitting algorithm for foreground modeling towards the recovery of the 21-cm global Epoch of Reionization signal from synthetic sky spectrum
E-mail: mayuris@rri.res.in

Lekshmi M Nair (Research Associate)
Research Interests: One-element interferometry and its deployment as a Supernova Search Engine. Instrumentation for high frequency radio astronomy - amplifiers, low-noise mixers, oscillators etc. and high frequency radio astronomy in itself
E-mail: lekshmi@rri.res.in

Magendran Sambasivam (Research Associate)
Research Interests: Astrometric and astrodynamics applications of radio interferometry, radio recombination lines from ISM, interferometric intensity mapping of cosmological neutral hydrogen
E-mail: magendran@rri.res.in

Jishnu Nambissan T (Research Associate)
Research Interests: Experimental detection and foreground modelling of Epoch of Recombination
E-mail: jishnu@rri.res.in

Viral Parekh (Post Doctoral Fellow – till 30.9.2017)
Research Interests: Galaxy cluster, diffuse radio sources, GLEAM continuum survey, and GMRT observations
E-mail: viral@rri.res.in

Sayan Biswas (Post Doctoral Fellow)
Research Interests: Origin of galactic cosmic rays: Study of acceleration and propagation of galactic cosmic rays, dark matter search using Fermi-LAT data, Strange Quark Matter (SQM) : Study of strange stars, properties of SQM and both origin and properties of small lumps of SQM i.e. 'strangelets'
E-mail: sayan@rri.res.in

Asif Iqbal Ahangar (Post Doctoral Fellow - from 15.6.2017)
Research Interests: (a) Late Universe Cosmology: X-ray studies of galaxy clusters, Sunyaev-Zel'dovich effect in galaxy clusters, Non-gravitational feedback in intra-cluster medium, Dater matter profile, gravitational lensing (b) Early Universe Cosmology: Physics of early universe and Inflation, Low CMB power anomaly and infrared cut-off in the primordial power spectrum, Cosmological parameter estimation using Markov chain Monte Carlo algorithm and CMB data
E-mail: asif@rri.res.in

Kshitija Kelkar (Post Doctoral Fellow - from 1.8.2017)
Research Interests: (a) Optical (imaging +spectroscopy) and radio studies of galaxies, and their environments (b) environmental signatures on structure and star formation in galaxies
E-mail: kshitija@rri.res.in

Light and Matter Physics

Andal Narayanan (Coordinator- from 26.8.2017)
Research Interests: Quantum optics with atoms and light, quantum measurements in atom-quantum-optical systems
E-mail: andal@rri.res.in

Reji Philip (Coordinator – till 25.8.2017)
Research Interests: Nonlinear optics, laser produced plasmas and ultrafast phenomena
E-mail: reji@rri.res.in

Sadiq Rangwala
Research Interests: Quantum interactions in cold, dilute gas ensembles, atom-cavity interactions, cavity QED
E-mail: sarangwala@rri.res.in

Hema Ramachandran
Research Interests: Light in random media; few-atom and few-photon systems; brain-computer interfaces
E-mail: hema@rri.res.in

Urbasi Sinha
Research Interests: Quantum information, quantum computation and quantum communication using single photons, experiments on quantum foundations
E-mail: usinha@rri.res.in

Saptarishi Chaudhuri
Research Interests: Ultra-cold atoms and molecules in optical and magnetic traps; quantum simulation of condensed matter physics using degenerate gases; precision measurements
E-mail: srishic@rri.res.in

E. Krishna Kumar (Emeritus Professor – from 1.1.2018)
Research Interests: Atomic collision physics, electron-controlled chemistry, negative ions, cold collisions, electron and ion spectroscopy, momentum imaging, high harmonic generation and attosecond physics
E-mail: krishnakumar@rri.res.in

Sourav Dutta (DST-INSPIRE Faculty – till 12.1.2018)
Research Interests: Cooling and trapping of ultracold atoms, ions and molecules, photoassociation of ultracold homonuclear and heteronuclear molecules, optical manipulation of atoms, ions and molecules, cavity based detection of interactions
E-mail: sourav@rri.res.in

Sanjukta Roy (Pancharatnam Fellow)
Research Interests: Quantum entanglement with ultracold Rydberg atoms, Anderson localisation of quantum gases in disordered potentials
E-mail: sanjukta@rri.res.in

KK Anoop (Post Doctoral Fellow – till 28.6.2017)
Research Interests: Ultrashort laser ablation, laser produced plasma diagnostics, laser induced plasma spectroscopy, pulsed laser deposition, optical-vortex laser ablation, and femtosecond laser surface micro/nanostructuring and its applications
E-mail: anoop@rri.res.in

Amrendra Kumar Pandey (Post Doctoral Fellow)
Research Interests: Study of cold atoms, molecular ions, and molecules; theoretical study of collision processes at low temperatures
E-mail: amrendra@rri.res.in

Soft Condensed Matter

Yashodhan Hatwalne (Coordinator – till 31.5.2017)
Research Interests: Phenomenological theory of liquid crystals, polycrystallites and membranes
E-mail: yhat@rri.res.in

Pratibha R (Coordinator – from 1.6.2017)
Research Interests: Chirality in liquid crystals, electric field induced phase transitions in liquid crystals, dielectric properties of polyelectrolytes, liquid crystal-nano particle composites
E-mail: pratibha@rri.res.in

Sandeep Kumar
Research Interests: Liquid crystal nanoscience, synthesis and physical studies of liquid crystals
E-mail: skumar@rri.res.in

Raghunathan VA
Research Interests: Lipid bilayers, amphiphiles in the presence of strongly bound polyelectrolytes, mechanical properties and phase behaviour of lipid-sterol membranes
E-mail: varaghu@rri.res.in

Arun Roy
Research Interests: Soft condensed matter physics, phase transitions, electro-optics of liquid crystals, liquid crystals nano-particle composites, Micro Raman spectroscopy, phenomenological theories of liquid crystals
E-mail: aroy@rri.res.in

Vijayaraghavan D
Research Interests: Electrical, optical and diamagnetic properties of lyotropic liquid crystals and liquid crystal-nanoparticles composites; self-assembly of nanostructures in liquid crystals
E-mail: vijay@rri.res.in

Ranjini Bandyopadhyay
Research Interests: 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 and sedimentation of colloidal suspensions; physics of granular media
E-mail: ranjini@rri.res.in

Pramod Pullarkat
Research Interests: Soft condensed matter, in particular, mechanical properties and instabilities of axons and pattern formation in differentiating stem cells
E-mail: pramod@rri.res.in

Gautam Soni
Research Interests: Nano-bio-physics of chromatin
E-mail: gvsoni@rri.res.in

Sayantan Majumdar – from 3.10.2017
Research Interests: Soft condensed matter physics, non-equilibrium statistical physics
E-mail: smajumdar@rri.res.in

Nupur Biswas (Post Doctoral Fellow)
Research Interests: Resistive pulse technique, thus far largely used to detect biological macromolecules at the single molecule level, and its possible application in distinguishing two emulsified immiscible liquids - in particular - oil in water or oil-like pollutants in water and vesicle (spheroidal structures bounded by a lipid bilayer) translocation through a micro/nanopore
E-mail: nupur@rri.res.in

Paramesh Gadige (Post Doctoral Fellow)
Research Interests: Dynamics in glass-forming liquids, glasses and complex fluids
E-mail: paramesh@rri.res.in

Yuvaraj AR (Post Doctoral Fellow)
Research Interests: Liquid crystals
E-mail: yuvaraj@rri.res.in

Amit Kumar Majhi (Post Doctoral Fellow)
E-mail: majhi@rri.res.in

Neha Bhagwani (Post Doctoral Fellow)
Research Interests: Liquid crystals
E-mail: nehab@rri.res.in

Ayush Agrawal (Post Doctoral Fellow - from 29.5.2017)
Research Interests: Influence of nanoparticles and proteins on mechanical property of various lipid membranes
E-mail: ayush@rri.res.in

Durai Murugan Kandhasamy (Post Doctoral Fellow - from 11.9.2017)
Research Interests: Molecular aspects DNA-protein complexes, biophysics and biomechanics of cells, physics and chemistry of synthetic and bio-polymers & ultrafast photochemistry
E-mail: murugan@rri.res.in

Sarika CK (Post Doctoral Fellow - from 19.3.2018)
Research Interests: Stability of fluid interfaces and pattern formation, dynamics of binary mixture films and collective behavior of active particles near soft interfaces
E-mail: sarika@rri.res.in

Theoretical Physics

Sanjib Sabhapandit (Coordinator)
Research Interests: Statistical physics
E-mail: sanjib@rri.res.in

Joseph Samuel - till 30.11.2017; Emeritus Scientist from 2.12.2017
Research Interests: Geometric phases, general relativity quantum measurements quantum entanglement
E-mail: sam@rri.res.in

Madan Rao (on lien)
Research Interests: Nonequilibrium statistical mechanics, soft matter, biology, information theory, control theory
E-mail: madan@rri.res.in

Sumati Surya
Research Interests: Classical and quantum gravity
E-mail: ssurya@rri.res.in

Madhavan Varadarajan
Research Interests: Classical and quantum gravity
E-mail: madhavan@rri.res.in

N Kumar (Emeritus Professor - till 28.8.2017)
Research Interests: Quantum first-passage time (Q-FPT) models, classical harmonic dynamics especially elastic energy transport in a spider dragline silk fibre, Bohr-Van Leeuwen theorem
E-mail: nkumar@rri.res.in

Supurna Sinha
Research interests: Theoretical physics
E-mail: supurna@rri.res.in

Dibyendu Roy
Research Interests: Theoretical condensed matter physics, statistical mechanics and atomic, molecular & optical physics
E-mail: droy@rri.res.in

Anupam Kundu (Visiting Scientist)
Research Interests: Various aspects of out of equilibrium systems, interacting many particle systems which are taken out of equilibrium by applying external forces (locally or globally) in the bulk or through boundaries where the transport properties of the system are usually anomalous in low dimensions. His other research interests include stochastic thermodynamics of small non-equilibrium systems, current fluctuations, large deviations and extreme value statistics
E-mail: anupam.kundu@icts.res.in

Urbashi Satpathi (Post Doctoral Fellow)
Research Interests: Quantum information, non-equilibrium statistical mechanics, quantum transport
E-mail: urbashi@rri.res.in

Sujit Kumar Nath (Post Doctoral Fellow)
Research Interests: Stochastic processes, complex systems, non-equilibrium statistical physics, fluid mechanics
E-mail: sujitkumar@rri.res.in

Vivek M Vyas (Post Doctoral Fellow)
Research Interests: Formal and applied aspects of quantum field theory
E-mail: vivekv@rri.res.in

Adjunct Professors

Barry Sanders
Institute for Quantum Science and Technology, University of Calgary, Canada

Shiv Visvanathan
Professor and Vice Dean (Institution Building), Executive Director, Centre for the Study of Science, Society and Sustainability, Jindal School of Government and Public Policy
O. P. Jindal Global University, Sonipat, Haryana

Kandaswamy Subramanian
Distinguished Professor and Dean, Visitor Academic Programmes
The Inter-University Centre for Astronomy & Astrophysics, Pune

Satya Majumdar
Laboratoire de Physique Théorique et Modèles Statistiques (LPTMS)
Université de Paris-Sud, France.

Rafael Sorkin
Perimeter Institute for Theoretical Physics, Canada

Fabien Bretenaker
Laboratoire Aimé Cotton, France

Igor Musevic
Department of Physics, Faculty of Mathematics and Physics University of Ljubljana
Jadranska 19, 1000 Ljubljana, Slovenia

Scientific/Technical Staff

Electronics Engineering Group

A Raghunathan (In-charge)
raghu@rri.res.in

KS Srivani
vani_4s@rri.res.in

Arasi Sathyamurthy
arasi@rri.res.in

BS Girish
bsgiri@rri.res.in

MR Gopala Krishna
gkrishna@rri.res.in

PA Kamini
kamini@rri.res.in

S Kasturi
skasturi@rri.res.in

S Madhavi
madhavi@rri.res.in

C Vinutha
vinutha@rri.res.in

HN Nagaraja
nraj@rri.res.in

T Prabu
prabu@rri.res.in

KB Raghavendra Rao
kbrrao@rri.res.in

Sandhya
sandhya@rri.res.in

G Sarabagopalan
gopal@rri.res.in

R Somashekar
som@rri.res.in

S Sujatha
sujathas@rri.res.in

TS Mamatha
mamatha@rri.res.in

KR Vinod
vinod@rri.res.in

PV Rishin
rishinpv@rri.res.in

Mugundhan Vijayaraghavan (from 13.2.2018)
mugundhan@rri.res.in

Light and Matter Physics

MS Meena
meena@rri.res.in

Soft Condensed Matter

A Dhason - till 31.5.2017; Consultant from 1.6.2017
dhas@rri.res.in

Mohammed Ishaq
ishaq@rri.res.in

HT Srinivasa
seena@rri.res.in

KN Vasudha
vasudha@rri.res.in

D Vijayaraghavan
vijay@rri.res.in

Serene Rose David
serene@rri.res.in

Yatheendran
yadhu@rri.res.in

Mechanical Engineering Services

Mohd. Ibrahim (In-charge)
M Achankunju (Consultant)
KO Francis
M Mani
N Narayanaswamy
T Puttaswamy
M Suresh Kumar
P Srinivasa
Sivasakthi

Computers

Jacob Rajan (In-charge)
jacobr@rri.res.in

B Sridhar
sridhar@rri.res.in

S Krishna Murthy
skmurthy@rri.res.in

Gauribidanur

HA Aswathappa (Consultant)
aswath@rri.res.in

Library

BM Meera, Librarian
meera@rri.res.in

M Manjunath
manu@rri.res.in

MN Nagaraj
nagaraj@rri.res.in

Manjunath Kaddipujar
kaddipujar@rri.res.in

Vani Hiremath
vanih@rri.res.in

Medical

R Shanthamma

PhD Students

Astronomy and Astrophysics

Abir Sarkar (JAP student) till 14.7.2017
Research interests: Cosmology, in particular dark matter and its origin
E-mail: abir@rri.res.in
Advisor: Shiv Sethi

Kartick Sarkar (JAP student) till 14.9.2017
Research interests: Galaxy and cosmology - topic - mass and metal outflow from galaxies
E-mail: kcsarkar@rri.res.in
Advisor: Biman Nath

Karamveer Kaur
Research Interests: Secular dynamics of nuclear star clusters
E-mail: karamveer@rri.res.in
Advisor: S Sridhar

Priyanka Singh - till 14.9.2017
Research Interests: Cosmology and galaxy physics
E-mail: priyankas@rri.res.in
Advisor: Biman Nath

Nafisa Aftab
Research Interests: Accretion powered binary X-ray pulsars
E-mail id: nafisa@rri.res.in
Advisor: Biswajit Paul

Gayathri Raman - till 31.7.2017
Research Interests: X-ray astronomy
E-mail: graman@rri.res.in
Advisor: Biswajit Paul

Kumar Raviranjan
Research Interests: Scintillation of radio signals from pulsars
E-mail: raviranjan@rri.res.in
Advisor: Avinash Deshpande

Janakee Raste (JAP student)
Research Interests: Cosmology
E-mail: janakee@rri.res.in
Advisor: Shiv Sethi

Varun
Research Interests: X-ray instrumentation
E-mail: varun@rri.res.in
Advisor: Biswajit Paul

Saurabh Singh (JAP student)
Research Interests: Radio astronomy, in particular epoch of reionization and the SARAS experiment
E-mail: saurabhs@rri.res.in
Advisors: Ravi Subrahmanyan, Shiv Sethi, N Udaya Shankar

Raj Prince
Research Interests: Describing the high energy(PeV) neutrino events detected by the ice cube detector by using AGN (Blazars) as the possible source of the high energy neutrino
E-mail: rajprince@rri.res.in
Advisors: Nayantara Gupta

Akash Kr. Patwa
Research Interests: Theoretical and observational studies of Epoch of Reionization (EoR), detection of HI signal from EoR, using the MWA
E-mail: akpatwa@rri.res.in
Advisors: Shiv Sethi, KS Dwarakanath

Siddhartha Gupta
Research Interests: Different aspects of superbubbles triggered by multiple supernovae in dense parts of the interstellar medium and effects of different instabilities on these superbubbles triggering largescale outflows from galaxies. The dynamics, especially the effect of radiation pressure on it, will be studied, with the help of hydrodynamical simulations and analytical calculations
E-mail: siddhartha@rri.res.in
Advisor: Biman Nath

Saikat Das
Research Interests: Astroparticle physics, particle cosmology, origin and propagation of ultra high energy cosmic ray particles
E-mail: saikat@rri.res.in
Advisor: Nayantara Gupta

Lalatendu Pradhan – till 31.7.2017
E-mail: lalatendu@rri.res.in
Advisor: Nayantara Gupta

Avik Kumar Das
Research Interests: Theoretical modeling of astrophysical source
E-mail: avikdas@rri.res.in
Advisor: Nayantara Gupta

Sreetama Goswami – till 12.5.2017
E-mail: sreetama@rri.res.in

Ranita Jana
Research Interests: Radioactive processes in ISM and IGM, heating of IGM by cosmic ray particles, morphology and dynamics of galaxies
E-mail: ranita@rri.res.in
Advisor: Biman Nath

Sanhita Kabiraj (JAP student)
Research Interests: X-ray observation of compact binary stars; Timing and spectral analyses of X-ray sources to discover their physical properties and behaviour
E-mail: sanhita@rri.res.in
Advisor: Biswajit Paul

Aditi Vijayan
Research Interests: Study of galaxy outflows using simulations
E-mail: aditiv@rri.res.in
Advisor: Biman Nath

Chaitanya Priyadarshi (JAP student)
Research Interests: Modelling of high energy processes in galactic cosmic ray sources. Correlating X-ray binaries with possible neutrino detection
E-mail: chaitanya@rri.res.in
Advisor: Nayantara Gupta

Jyotirmoy Dey – till 4.8.2017
E-mail: jyotirmoy@rri.res.in
Advisor: Ravi Subrahmanyan

Divya Bharati – till 30.6.2017

Rishab Mallik – 26.7.2017 – 10.4.2018
Email: rishabh@rri.res.in

Hemanth – from 26.7.2017
Email: hemanthm@rri.res.in

Tanuman Ghosh – from 31.7.2017
Email: tanuman@rri.res.in

Agnibha de Sarkar – from 26.7.2017
Email: agnibha@rri.res.in

Prerana Biswas – from 1.1.2018
Email: prerana@rri.res.in

Sahel Dey – from 1.1.2018
Email: sahel@rri.res.in

Light and Matter Physics

Rahul Sawant Vaijanath
Research Interests: Interactions in ultra-cold dilute gases
E-mail: rahuls@rri.res.in
Advisor: Sadiq Rangwala

Muhamed Shafi Ollakkan – till 3.7.2017
Research Interests: Intense light – matter interactions
E-mail: ollakkans@rri.res.in
Advisor: Reji Philip

Niranjan Myneni
Research Interests: Quantum interactions (ion-atom interactions and atom-cavity coupling)
E-mail: niranjan@rri.res.in
Advisor: Sadiq Rangwala

Ashutosh Singh
Research Interests: Quantum information
E-mail: ashutoshs@rri.res.in
Advisor: Urbasi Sinha

Simanraj Sadana
Research Interests: Quantum information and computation
E-mail: simanraj@rri.res.in
Advisor: Urbasi Sinha

Atul Vinu
Research Interests: Theory of open quantum systems in particular three level systems under particular environments like vacuum fields, thermal baths, or coherent and incoherent radiation fields. To study the evolution of the system population density of states and coherences under the influence of environment in both markovian as well as non markovian regimes
E-mail: atulv@rri.res.in
Advisor: Andal Narayanan

Sagar Sutradhar
Research Interests: Atomic, molecular and optical physics
E-mail: sagar@rri.res.in
Advisor: Sadiq Rangwala

Subodh
Research Interests: Atomic, molecular and optical physics
E-mail: subodh@rri.res.in
Advisor: Sadiq Rangwala

Surya Narayan Sahoo
Research Interests : Weak measurements using single photons
E-mail: suryans@rri.res.in
Advisor: Urbasi Sinha

Ajay Kumar – on leave
Research Interests: Synthesis and NLO properties of 2D materials
E-mail: ajayk@rri.res.in
Advisor: Reji Philip

Ayyappan J – till 19.5.2017
Research Interests: A study of non-linearity induced gain and absorption phenomena using Phase sensitive excitation in cyclic atomic systems, which show ground-state coherence. Using this effect to construct a very sensitive microwave magnetometer
E-mail: ayyappan@rri.res.in
Advisor: Andal Narayanan

Sreyas P Dinesh
Research Interests: Atomic, molecular and optical physics
E-mail: sreyaspd@rri.res.in
Advisor: Sadiq Rangwala

Gaurav Tiwari – till 1.12.2017
Research Interests: Plasma physics
E-mail: gaurav@rri.res.in
Advisor: Reji Philip

Bhagyalakshmi
Research Interests: Experimental investigation of the role of short and long range interactions and disorder in quantum degenerate gases
E-mail: bhagyadds@rri.res.in
Advisors: Saptarishi Chaudhuri

Kaushik Joarder
Research Interests: Leggett Garg inequalities, quantum key distribution
E-mail: kaushik@rri.res.in
Advisor: Urbasi Sinha

KV Adwaith
Research Interests: Experiments and theoretical studies on coherence based non-linear quantum optics with a view to generating squeezed light. The ultimate goal is to develop sensors and meters which will utilise these properties to work below the standard quantum limit
E-mail: adwaith@rri.res.in
Advisor: Andal Narayanan

Maheswar Swar
Research Interests: Investigating the physics of quantum degenerate, ultra-cold atoms and molecules experimentally so as to simulate the complex phenomena in condensed matter physics using ultra-cold atoms and molecules as model systems
E-mail: mswar@rri.res.in
Advisor: Saptarishi Chaudhuri

Nishant Joshi
Research Interests: Atomic, molecular and optical physics
E-mail: njoshi@rri.res.in
Advisor: Sadiq Rangwala

Subhajit Bhar
Research Interests: Quantum correlation
E-mail: subhajit@rri.res.in
Advisor: Urbasi Sinha

Nancy Verma
Research Interests: Non-linear optics and laser plasma studies
E-mail: nancy@rri.res.in
Advisor: Reji Philip

BS Silpa
Research Interests: Interaction of single atoms and single photons
E-mail: silpa@rri.res.in
Advisor: Hema Ramachandran

Sanchari Chakrabarti
Research Interests: (i) Weak Measurements (ii) Quantum mechanics as quantum measure theory
E-mail: sanchari@rri.res.in
Advisor: Urbasi Sinha

Anand Prakash
E-mail: prakash@rri.res.in
Advisor: Sadiq Rangwala

Rishab Chatterjee
Research Interests: Quantum information and quantum cryptography
E-mail: rishab17@rri.res.in
Advisor: Urbasi Sinha

Raja Vikram Bhat – till 17.7.2017
E-mail: vikrambhat@rri.res.in

Pradosh Kumar Nayak
E-mail: pradosh@rri.res.in

Bapan Debnath
E-mail: bapan@rri.res.in
Advisor: Urbasi Sinha

Shovan Kanti Barik – from 24.7.2017
E-mail: shovanb@rri.res.in

Snehal Dalvi – from 25.7.2017
E-mail: snehald@rri.res.in

Vardhan Thakar – from 26.7.2017
E-mail: vardhanr@rri.res.in

Arun Bahaleyan – from 24.7.2017
E-mail: arunb@rri.res.in

Soft Condensed Matter

V Marichandran – till 31.7.2017
Research Interests: Chemistry of liquid crystals
E-mail: vmchandru@rri.res.in
Advisor: Sandeep Kumar

RV Jagadeesh – till 31.7.2017
Research Interests: Electrochemistry
E-mail: jagadeeshrv@rri.res.in
Advisors: V Lakshminarayanan, Arun Roy

Sushil Dubey
Research Interests: Biophysics
E-mail: dubeys@rri.res.in
Advisor: Pramod Pullarkat

Meera Thomas
Research interests: X-ray studies on ionic amphiphile systems
E-mail: meerathomas@rri.res.in
Advisor: VA Raghunathan

Buti Suryabrahmam – till 31.7.2017
Research Interests: Phase transitions of amphiphilic systems
E-mail: suryabrahmam@rri.res.in
Advisor: VA Raghunathan

Madhukar S – till 31.7.2017
Research Interests: Small-angle X-ray diffraction studies
E-mail: madhukar@rri.res.in
Advisor: VA Raghunathan

Sanjay Kumar Behera
Research Interests: Glass transition and rheology of aging colloidal suspension
E-mail: sanjay@rri.res.in
Advisor: Ranjini Bandopadhyay

Deepshika Malkar
Research Interests: Experimental soft condensed matter – bent core hockey stick liquid crystals
E-mail: deepshika@rri.res.in
Advisor: Arun Roy

Ashwathanarayana Gowda
Research Interests: Synthesis and characterization of TCQ and other discotic liquid crystals
E-mail: ashwathgowda@rri.res.in
Advisor: Sandeep Kumar

Sreeja Sasidharan
Research Interests: Lipid bilayer
E-mail: sreeja@rri.res.in
Advisor: VA Raghunathan

Anindya Chowdhury
Research Interests: Liquid crystals
E-mail: anindya@rri.res.in
Advisor: VA Raghunathan

Sumanth Kumar
Research Interests: Characterizing living cells based on their size and elasticity using glass micropores which would be helpful in disease diagnosis
E-mail: sumanth@rri.res.in
Advisors: Gautam Soni

Irla Siva Kumar
Research Interests: Synthesis and characterization of liquid crystals (discotic) for technological applications and supramolecular chemistry
E-mail: irlasiva@rri.res.in
Advisor: Sandeep Kumar

C Saichand
Research Interests: Soft matter (theory)
E-mail: saichand@rri.res.in
Advisor: Arun Roy, Yashodhan Hatwalne

Mohd. Arsalan Ashraf
Research Interests: Force generation mechanism in living cells
E-mail: arsalan@rri.res.in
Advisor: Pramod Pullarkat

Subhadip Ghosh
Research Interests: The complex molecular systems are renowned for showing the different types of mesophases as well as polymorphic crystalline phases. We have used Raman Spectroscopy technique to probe the changes in molecular vibrational energy levels of different modes and their unique signatures in different phases of a highly polar complex molecular system. The other experimental techniques also have been used to probe the molecular system.
E-mail: subhadip@rri.res.in
Advisors: Arun Roy, Pratibha R, Reji Philip

Dipak Patra
E-mail: dipak@rri.res.in

Ashish Kumar Mishra
Research Interests: Biophysics on neurons - response of neurons after different perturbations
E-mail: ashishkm@rri.res.in
Advisor: Pramod Pullarkat

Rajkumar Biswas
E-mail: rajkumar@rri.res.in

Sayooj Kiran IK
Research Interests: Biophysics
E-mail: sayoojkiran@rri.res.in

Vishnu Deo Mishra
Research Interests: Biophysics - bent-core liquid crystals
E-mail: vishnudmishra@rri.res.in
Advisors: Arun Roy, Yashodhan Hatwalne, Sayantan Majumdar

Swarnak Ray
Research Interests: Solubilization of liquid crystalline droplets in micellar solution and self-propelled motion of the droplets due to this solubilization. Study of collective behavior of such droplets and the effect of phase transition of liquid crystalline phase on such droplets
E-mail: swarnak25@rri.res.in
Advisor: Arun Roy

Palak
E-mail: palak@rri.res.in

Chandeshwar Mishra
E-mail: chandeshwar@rri.res.in

Saurabh Kaushik
E-mail: saurabh@rri.res.in

Sukh Veer – from 24.7.2017
E-mail: sukh@rri.res.in

Intezar Husain – from 25.7.2017
E-mail: intezar@rri.res.in

Saikat Shyamal – from 25.9.2017
E-mail: saikat@rri.res.in

Prince Sharma – 25.7.2017 to 31.1.2018
E-mail: prince@rri.res.in

Sebanti C – from 25.7.2017
Research Interests: Jamming transition in non-Brownian dense suspensions
E-mail: sebantic@rri.res.in
Advisor: Sayantan Majumdar

Theoretical Physics

Kumar Shivam
Research Interests: Quantum entanglement
E-mail: kshivam@rri.res.in
Advisors: Supurna Sinha, Joseph Samuel

Anirudh Reddy
Research Interests: Aspects of classical and quantum cloning
E-mail: anirudhr@rri.res.in
Advisor: Supurna Sinha

Deb Sankar Banerjee
Research Interest: Bio-physics
E-mail: debsankar@rri.res.in
Advisor: Madan Rao

Raj Hossein
Research Interests: Biophysics
E-mail: rajhossein@rri.res.in
Advisor: Madan Rao

Deepak Gupta
Research Interests: Non-equilibrium statistical mechanics
E-mail: deepakg@rri.res.in
Advisor: Sanjib Sabhapandit

Amit Kumar
Research Interests: Biophysics
E-mail: amit@rri.res.in
Advisor: Madan Rao

Santanu Das
Research Interests: Statistical mechanics
E-mail: santanu@rri.res.in
Advisor: Sanjib Sabhapandit

Adit Raj Sharma – till 6.4.2017
Research Interests: Gravity, statistical physics
E-mail: aditraj@rri.res.in

Alkesh Yadav
Research Interests: Biophysics. In particular - Eukaryoyic cells have a organelle called Golgi complex. Golgi complex is a membraneous structure composed of several flattened sacs called cisternae. It is situated near the endoplasmic reticulum. The question being addressed is what sets the number of compartments in a golgi complex based on the functions of golgi
E-mail: alkesh@rri.res.in
Advisor: Madan Rao

Abhishek Mathur
Research Interests: Quantum field theory, quantum gravity
E-mail: abhishekmathur@rri.res.in
Advisor: Sumati Surya

Siddharth Mahesh – till 6.4.2018
E-mail: siddharthm@rri.res.in

Administration

CSR Murthy
Administrative & Vigilance Officer
csrmurthy@rri.res.in

Naresh VS
Asst. Administrative Officer
vsnaresh@rri.res.in

Subramanian V Ganapathy
Scientific Officer
subramanian@rri.res.in

Marisa D'Silva – till 31.10.2017
marisa@rri.res.in

VS Shailaja
svs@rri.res.in

K Radha
kradha@rri.res.in

Vidyamani V
vidya@rri.res.in

V Raveendran
ravee@rri.res.in

R Ganesh
ganeshr@rri.res.in

Ranjeet Kr. Koshta -till 10.7.2017
ranjeet@rri.res.in

GV Indira

Group Secretaries

Radhakrishna K
Soft Condensed Matter
krk@rri.res.in

S Harini Kumari
Astronomy and Astrophysics
harini@rri.res.in

G Manjunatha (Public Relations Officer)
Theoretical Physics
manju@rri.res.in

Mamatha Bai R
Electronics Engineering Group
mamta@rri.res.in

Savitha Deshpande
Light & Matter Physics
savithamd@rri.res.in

Accounts

Suresh Varadarajan, Accounts Officer
R Ramesh, Internal Auditor
V Raghunath
R Pradeep

Purchase

CN Ramamurthy, Purchase Officer
M Prema
G Gayathri

Stores

B Srinivasa Murthy, Stores Officer

Estates and Buildings

GB Suresh, Civil Engineer
Muneeswaran
S Anantha Raman – till 31.10.2017
K Bhoopalan
Gunashekar
C Haridas
KN Srinivas
K Palani
M Rajagopal
K G Narasimhalu
M Ramesh
M Gopinath
Hanumantha – till 31.3.2018
Jayamma
C Lakshmamma
T Murali
Narayana
Sidde Gowda – till 12.4.2017
V Venkatesh
Ramanna
Varalakshmi
C Elumalai
A Ramanna
Lingegowda

D Mahalinga
Mailarappa
Marappa
D Muniraja – till 31.5.2017
S Muniraju
Rangalakshmi
D Krishna
T Mahadeva

Security

Matadeen, Security In-charge – from 1.7.2017
BM Basavarajaiah
UA Earappa
H Gangaiah
Keshavamurthy
Suresha
K Krishnappa
K Pushparaj
OM Ramachandra
G Ramakrishna
M Sannaiah
H Vaderappa

Transport

M Balarama
CK Mohanan
G Prakash
Rahamath Pasha
G Raja
M Venkateshappa

Canteen & Guest House

N Narayanappa (Consultant)
Shivamallu
Mangala Singh
Muniratna
T Naganna
DB Padmavathy
PC Prabhakar
N Puttaswamy
Uma
Sharadamma

Gauribidanur

Gangaram – till 28.2.2018
Papanna
RP Ramji Naik
NR Srinath

Medical Consultants

Paediatrician: Dr. MR Baliga – till 31.12.2017
Physician: Dr. BV Sanjay Rao
Dr. PH Prasad
Dr. N Sundari – from 1.2.2018

Publications

Papers in Journals

1. Rapid formation and macroscopic self-assembly of liquid-crystalline, high-mobility, semiconducting thienothiophene
   Pandey, Manish* ; Gowda, Ashwathanarayana ; Nagamatsu, Shuichi* ; Kumar, Sandeep ; + 3 Co-authors
   Advanced Materials Interfaces **5**, 1700875, 2018

2. Data-intensive research in physics: challenges and perspectives
   Meera B M ; Hiremath, Vani
   Annals of Library and Information Studies **65**, 43, 2018

3. Ion dynamics of a laser produced aluminium plasma at different ambient pressures
   Sankar, Pranitha ; Shashikala H D* ; Philip, Reji
   Applied Physics A **124**, 26, 2018

4. Direct femtosecond laser surface structuring of crystalline silicon at 400 nm
   Nivas, Jijil JJ* ; Anoop K K ; Bruzzese, Riccardo* ; Philip, Reji ; Amoruso, Salvatore*
   Applied Physics Letters **112**, 121601, 2018

5. Zirconia-supported Cu(I)-stabilized copper oxide mesoporous catalyst for the synthesis of quinazolinones under ambient conditions
   Parashuram L* ; Sreenivasa, Swamy* ; Akshatha S* ; Udaya Kumar V* ; Kumar, Sandeep
   Asian Journal of Organic Chemistry **6**, 1755, 2017

6. Supergiant fast X-ray transients versus classical supergiant high mass X-ray binaries: Does the difference lie in the companion wind?
   Pradhan P* ; Bozzo E* ; Paul, Biswajit
   Astronomy & Astrophysics **610**, A50, 2018

7. Spectral energy distribution and radio halo of NGC 253 at low radio frequencies
   Kapinska A D ; Dwarakanath K S ; Paul, Biswajit ; Sethi S K ; Udaya Shankar N ; Subrahmanyan, Ravi ; Deshpande A A ; Prabu T ; Srivani K S ; + 62 Co-authors
   Astrophysical Journal **838**, 68, 2017

8. AstroSat/LAXPC detection of milli-second phenomena in 4U 1728-34
   Chauhan, Jai Verdhan* ; Yadav, J S* ; Paul, Biswajit ; +10 Co-authors
   Astrophysical Journal **841**, 41, 2017

9. Wavelet-based characterization of small-scale solar emission features at low radio frequencies
   Suresh A* ; Deshpande A A ; Prabu T ; Udaya Shankar N ; Srivani K S ; Subrahmanyan, Ravi ; +32 Co-authors
   Astrophysical Journal **843**, 19, 2017

10. Constraints on a proton synchrotron origin of VHE gamma rays from the extended jet of AP librae
    Basumallick, Partha Pratim* ; Gupta, Nayantara
    Astrophysical Journal **844**, 58, 2017

11. Long-term study of the light curve of PKS 1510-089 in GeV energies
    Prince, Raj ; Majumdar, Pratik* ; Gupta, Nayantara
    Astrophysical Journal **844**, 62, 2017

12. X-Ray timing analysis of Cyg X-3 using AstroSat/LAXPC: detection of milli-hertz quasi-periodic oscillations during the flaring hard X-ray state
    Pahari, Mayukh* ; Anita H M* ; Yadav J S* ; Paul, Biswajit ; +9 Co-authors
    Astrophysical Journal **849**, 16, 2017

13. What are "X-shaped" radio sources telling us? I. very large array imaging of a large sample of candidate XRGs
    Roberts, David H* ; Saripalli, Lakshmi ; Wang, Kevin X* ; Sathyanarayana Rao, Mayuri ; Subrahmanyan, Ravi ; +3 Co-authors
    Astrophysical Journal **852**, 47, 2018

14. What are "X-Shaped" radio sources telling Us? II. properties of a sample of 87
    Saripalli, Lakshmi ; Roberts, David H*
    Astrophysical Journal **852**, 48, 2018

15. First results on the Epoch of reionization from first light with SARAS 2
    Singh, Saurabh ; Subrahmanyan, Ravi ; Udaya Shankar N ; Sathyanarayana Rao, Mayuri ; Fialkov, Anastasia* ; Cohen, Aviad* ; Girish B S ; Raghunathan A ; Somashekar R ; Srivani K S
    Astrophysical Journal Letters **845**, L12, 2017

16. The mysterious 6565 Å absorption feature of the galactic halo
    Sethi S K ; Shchekinov, Yuri+ ; Nath, Biman B
    Astrophysical Journal Letters **850**, L20, 2017

17. Calibration of the large area x-ray proportional counter (LAXPC) instrument on board AstroSat.
Antia, H M* ; Paul, Biswajit ; +22 Co-authors
Astrophysical Journal Supplement Series **231**, 10, 2017

18. Hot dust in ultraluminous infrared galaxies
Shchekinov Yu A+ ; Vasiliev E O*
Astrophysics **60**, 449, 2017

19. Tri-s-triazine (s-heptazine), a novel electron-deficient core for soft self-assembled supramolecular structures
Shiva Kumar, Irla ; Kumar, Sandeep
Chemical Communications **53**, 11445-48, 2017

20. Scalar field green functions on causal sets
Ahmed, Nomaan S ; Dowker, Fay* ; Surya, Sumati
Classical and Quantum Gravity **34**, 124002, 2017

21. Echoes of asymptotic silence in causal set quantum gravity
Eichhorn, Astrid* ; Mizera, Sebastian* ; Surya, Sumati
Classical and Quantum Gravity **34**, 16LT01, 2017

22. Gravity and decoherence: the double slit experiment revisited
Samuel, Joseph
Classical and Quantum Gravity **35**, 045004, 2018

23. Finite size scaling in 2d causal set quantum gravity
Glaser, Lisa* ; O'Connor, Denjoe* ; Surya, Sumati
Classical and Quantum Gravity **35**, 045006, 2018

24. Effects of aging on the yielding behaviour of acid and salt induced Laponite gels
Ranganathan V T ; Bandyopadhyay, Ranjini
Colloids and Surfaces A: Physicochemical and Engineering Aspects **522**, 304, 2017

25. Large area x-ray proportional counter instrument on Astrosat
Yadav J S* ; Agrawal P C* ; Antia H M* ; Manchanda R K* ; Paul, Biswajit ; Misra, Ranjeev*
Current Science **113**, 591, 2017

26. A high-speed, reconfigurable, channel- and time-tagged photon arrival recording system for intensity-interferometry and quantum optics experiments
Girish B S ; Pandey, Deepak ; Ramachandran, Hema
European Physical Journal Plus **132**, 348, 2017

27. Plane shearing waves of arbitrary form: Exact solutions of the Navier-Stokes equations
Singh, Nishant K* ; Sridhar S
European Physical Journals Plus **132**, 403, 2017

28. Bandpass calibration of a wideband spectrometer using coherent pulse injection
Patra, Nipanjana ; Bray, Justin D* ; Roberts, Paul* ; Ekers, Ron D*
Experimental Astronomy **43**, 119, 2017

29. Writing with light: Recent advances in optical storage property of azobenzene derivatives†
Yuvaraj A R ; Kumar, Sandeep
General Chemistry **4**, 170020, 2018

30. Optical emission and dynamics of aluminum plasmas produced by ultrashort and short laser pulses
Sankar, Pranitha ; Nivas, Jijit J J ; Smijesh N ; Tiwari, Gaurav K ; Philip, Reji
Journal of Analytical Atomic Spectrometry **32**, 1177, 2017

31. Synergistic hybrid catalyst for ethanol detection: enhanced performance of platinum palladium bimetallic nanoparticles decorated graphene on glassy carbon electrode
Anupam Kumar, Manne* ; Patnaik, Sai Gourang* ; Lakshminarayanan V ; Ramamurthy, Sathish*
Journal of Analytical Chemistry **73**, 266, 2018

32. Effect of metallic silver nanoparticles on the alignment and relaxation behaviour of liquid crystalline material in smectic C* phase
Vimal, Tripti* ; Gupta, Swadesh Kumar* ; Katiyar, Rohit* ; Srivastava, Atul* ; Czerwinski, Michal* ; Krup, Katarzyna* ; Kumar, Sandeep ; Manohar, Rajiv*
Journal of Applied Physics **122**, 114102, 2017

33. Plasmon-enhanced two-photon absorption in photoluminescent semiconductor nanocrystals
George, Nisha* ; Thomas, Anitta Rose ; Subha, Radhu* ; Mary N L*
Journal of Applied Polymer Science **134**, 45377, 2017

34. Large area X-Ray proportional counter (LAXPC) instrument on Astrosat and some preliminary results from its performance in the orbit
Agrawal P C* ; Yadav J S* ; Paul, Biswajit ; + 30 Co-authors
Journal of Astrophysics and Astronomy **38**, 30, 2017

35. Neutron stars in x-ray binaries and their environments
Paul, Biswajit
Journal of Astrophysics and Astronomy **38**, 39, 2017

36. Classical orbital paramagnetism in non-equilibrium steady state
Deshpande A A ; Kumar N
Journal of Astrophysics and Astronomy **38**, 57, 2017

37. Active galactic nucleus feedback with the square kilometre array and implications for cluster physics and cosmology
Iqbal, Asif* ; Kale, Ruta* ; Nath, Biman B ; +5 Co-authors
Journal of Astrophysics and Astronomy **38**, 68, 2017

38. Suzaku observation of the eclipsing high mass X-ray binary pulsar XTE J1855-026
Devasia, Jincy+ ; Paul, Biswajit
Journal of Astrophysics and Astronomy **3**9, 7, 2018

39. Thermonuclear X-ray burst of MXB 1658-298 with NuSTAR
Sharma, Rahul* ; Jaleel, Abdul* ; Jain, Chetana* ; Paul, Biswajit ; Dutta, Anjan*
Journal of Astrophysics and Astronomy **39**, 16, 2018

40. Human centromeric CENP-A chromatin is a homotypic, octameric nucleosome at all cell cycle points
Nechemia-Arbel, Yael* ; Fachinetti, Daniele* ; Miga, Karen H* ; Sekulic, Nikolina * ; Soni, Gautam V ; +9 co-authors
Journal of Cell Biology **216**, 607, 2017

41. The effects of the small-scale behaviour of dark matter power spectrum on CMB spectral distortion
Sarkar, Abir ; Sethi S K ; Das, Subinoy*
Journal of Cosmology and Astroparticle Physics **07**, 012, 2017

42. Constraints on dark matter models from the observation of Triangulum-II with the Fermi large area telescope
Biswas, Sayan ; Bhattacharjee, Pooja* ; Majumdar, Prathik* ; Das, Subiony* ; Das, Mousumi* ; Joarder, Partha S*
Journal of Cosmology and Astroparticle Physics **11**, 003, 2017

43. Sensitive detection of Ferulic acid using multi-walled carbon nanotube decorated with silver nano-particles modified carbon paste electrode
Erady, Veera* ; Mascarenhas, Ronald J* ; Satpati, Ashis K* ; Dhason A ; +3 Co-authors
Journal of Electroanalytical Chemistry **806**, 22, 2017

44. Time-resolved fluorescence and absence of Förster resonance energy transfer in ferroelectric liquid crystal-quantum dots composites
Singh D P* ; Pandey S* ; Manohar R* ; Kumar, Sandeep ; Pujar G H* ; Inamdar S R*
Journal of Luminescence **190**, 161, 2017

45. Novel achiral four-ring bent-shaped nematic liquid crystals with trifluoromethyl and methyl substituents in the central molecular core: an unusually large Kerr constant in blue phase III of nematic-chiral dopant mixture
Khan R K* ; Turlapati S* ; Rao N V S ; Pratibha R ; +3 Co-authors
Journal of Materials Chemistry **C 5**, 6729, 2017

46. CdTe quantum dot dispersed ferroelectric liquid crystal: Transient memory with faster optical response and quenching of photoluminescen
Pandey, Shivani* ; Singh, Dharmendra Pratap* ; Kumar, Sandeep ; +4 Co-authors
Journal of Molecular Liquids **237**, 71, 2017

47. Soft discotic matrix with 0-D silver nanoparticles: Impact on molecular ordering and conductivity
Varshney, Shalaka ; Kumar, Manish ; Gowda, Ashwathanarayana ; Kumar, Sandeep
Journal of Molecular Liquids **238**, 290, 2017

48. Silver nanodisks in soft discotic forest: Impact on self-assembly, conductivity and molecular packing
Kumar, Manish ; Varshney, Shalaka ; Gowda, Ashwathanarayana ; Kumar, Sandeep
Journal of Molecular Liquids **241**, 666, 2017

49. The optical properties of quantum dots in anisotropic media
Singh U B* ; Singh Deepa* ; Kumar, Sandeep ; Dhar, R* ; Pandey, M B*
Journal of Molecular Liquids **241**, 1009, 2017

50. Trapping of inorganic nanowires in supramolecular organic nanoribbons
Avinash B S ; Kumar, Manish ; Gowda, Ashwathanarayana ; Kumar, Sandeep
Journal of Molecular Liquids **244**, 1, 2017

51. Synthesis, structural and mesophase characterization of isoindoline-1,3-dione based mesogenic Schi bases
Dubey, Ragini* ; Yerrasani, Rajasekhar* ; Karunakar M* ; Singh, Angad Kumar* ; Kumar, Sandeep ; Rao T R*
Journal of Molecular Liquids **251**, 142, 2018

52. Ethyl 7-hydroxycoumarin-3-carboxylate derivatives: Synthesis, characterization and effect of liquid crystal properties
Srinivasa H T ; Palakshamurthy B S* ; Mohammad, Abdulkarim-Talaq*
Journal of Molecular Structure **1155**, 513, 2018

53. Electronic and nonlinear optical properties of l-Histidine on Silver: a theoretical and experimental approach
Felscia, U Retta* ; Rajkumar, Beulah J M* ; Nidya, Monickaraj* ; Sankar, Pranitha
Journal of Physical Chemistry A **122**, 1045, 2018

54. Demonstration of a high-contrast optical switching in an atomic Delta system
Ghosh, Megha ; Karigowda, Asha ; Jayaraman, Ayyappan ; Bretenaker, Fabien ; Sanders, Barry C* ; Narayanan, Andal
Journal of Physics B: Atomic, Molecular and Optical Physics **50**, 165502, 2017

55. Pico-ampere current sensitivity and CdSe quantum dots assembly assisted charge transport in ferroelectric liquid crystal
Pratap Singh, Dharmendra* ; Boussoualem, Yahia* ; Duponchel, Benoit* ; Sahraoul, Abdelhak Hadj* ; Kumar, Sandeep ; Manohar, Rajiv* ; Daoudi, Abdelylah*
Journal of Physics D: Applied Physics **50**, 325301, 2017

56. Unusual equilibration of a particle in a potential with a thermal wall
Bhat, Deepak* ; Sabhapandit, Sanjib ; Kundu, Anupam* ; Dhar, Abhishek*
Journal of Statistical Mechanics: Theory and Experiment **2017**, 113210, 2017

57. A quantum diffusion law
Satpathi, Urbashi ; Sinha, Supurna ; Sorkin, Rafael D+
Journal of Statistical Mechanics: Theory and Experiment **2017**, 123105, 2017

58. Thermodynamic study of a plastic columnar discotic material 2, 3, 6, 7, 10,11-hexabutyloxytriphenylene dispersed with gold nanoparticles under elevated pressure
Tripathi, Pratibha* ; Mishra, Mukesh* ; Kumar, Sandeep ; Dhar, Ravindra*
Journal of Thermal Analysis and Calorimetry **129**, 315, 2017

59. Phase behavior of a new class of Anthraquinone-based discotic liquid crystals
De, Joydip* ; Gupta, Santosh Prasad* ; Bala, Indu* ; Kumar, Sandeep ; Pal, Santanu Kumar*
Langmuir **33**, 13849, 2017

60. Synthesis and mesomorphism of ionic self-assembled complexes of anthraquinones
Swamynathan K ; Raghunathan V A ; Kumar, Sandeep
Liquid Crystals **44**, 2311, 2017

61. New symmetric azobenzene molecules of varied central cores: Synthesis and characterisation for liquid crystalline properties
Srinivasa H T
Liquid Crystals **44**, 1384, 2017

62. Synthesis and characterisation of some new chalcone liquid crystals
Srinivasa H T ; Kumar, Sandeep
Liquid Crytals **44**, 1506, 2017

63. Discotic liquid crystals derived from polycyclic aromatic cores: from the smallest benzene to the utmost graphene cores
Gowda, Ashwathanarayana ; Kumar, Manish ; Kumar, Sandeep
Liquid Crystals **44**, 1990, 2017

64. Recent advances in discotic liquid crystal-assisted nanoparticles
Gowda, Ashwath Narayana ; Kumar, Sandeep
Materials **11**, 382, 2018

65. Enhancement of nonlinear optical and temperature dependent dielectric properties of Ce:BaTiO3 nano and submicron particles
Senthilkumar P* ; Dhanushkodi S* ; Thomas, Anitta Rose ; Philip, Reji
Materials Research Express **4**, 085027, 2017

66. Facile preparation of poly(methylene blue) modified carbon paste electrode for the detection and quantification of Catechin
Manasa G* ; Mascarenhas, Ronald J* ; Satpati, Ashis K* ; Dsouza, Ozma J* ; Dhason A
Materials Science and Engineering **C 73**, 552, 2017

67. A novel and sensitive hexadecyltrimethylammoniumbromide functionalized Fe decorated MWCNTs modified carbon paste electrode for the selective determination of Quercetin
Erady, Veera* ; Mascarenhas, Ronald J* ; Satpati, Ashis K* ; Dhason A ; +3 Co-authors
Materials Science and Engineering **C 76**, 114, 2017

68. A search for long-time-scale, low-frequency radio transients
Murphy, Tara* ; Dwarakanath K S ; +25 Co-authors
Monthly Notices of the Royal Astronomical Society **466**, 1944, 2017

69. Constraining the X-ray AGN halo occupation distribution: implications for eROSITA
Singh, Priyanka ; Refregier, Alexandre * ; Majumdar, Subhabrata* ; Nath, Biman B
Monthly Notices of the Royal Astronomical Society **466**, 3916, 2017

70. A study of halo and relic radio emission in merging clusters using the Murchison widefield array
George, Lijo T ; Dwarakanath K S ; Johnston-Hollitt, M* ; +18 Co-authors
Monthly Notices of the Royal Astronomical Society **467**, 936, 2017

71. Clues to the origin of Fermi Bubbles from OVIII/OVII line ratio
Sarkar, Kartick Chandra ; Nath, Biman B ; Sharma, Prateek*
Monthly Notices of the Royal Astronomical Society **467**, 3544, 2017

72. Evolution of clustered supernovae
Vasiliev, Evgenii O* ; Shchekinov, Yuri A+ ; Nath, Biman B
Monthly Notices of the Royal Astronomical Society **468**, 2757, 2017

73. HI, star formation and tidal dwarf candidate in the Arp 305 system
Sengupta, Chandreyee* ; Scott T C* ; Paudel S* ; Dwarakanath K S ; Saikia D J* ; Sohn B W*
Monthly Notices of the Royal Astronomical Society **469**, 3629, 2017

74. Understanding the nature of the intriguing source X Persei: a deep look with a Suzaku observation
Maitra, Chandreyee * ; Raichur, Harsha* ; Pradhan, Pragati * ; Paul, Biswajit
Monthly Notices of the Royal Astronomical Society **470**, 713, 2017

75. A hot X-ray lament associated with A3017 galaxy cluster
Parekh V ; Durret F* ; Padmanabh P* ; Pandge M B*
Monthly Notices of the Royal Astronomical Society **470**, 3742, 2017

76. Orbital variations in intensity and spectral properties of the highly obscured sgHMXB IGR J16318-4848
Iyer, Nirmal ; Paul, Biswajit
Monthly Notices of the Royal Astronomical Society **471**, 355, 2017

77. Excess entropy and energy feedback from within cluster cores up to r200
Iqbal, Asif* ; Majumdar, Subhabrata* ; Nath, Biman B ; Ettori, Stefano* ; Eckert, Dominique* ; Malik, Manzoor A*
Monthly Notices of the Royal Astronomical Society **472**, 713, 2017

78. MACS J0553.4-3342: a young merging galaxy cluster caught through the eyes of Chandra and HST
Pandge M B* ; Bagchi, Joydeep* ; Sonkamble S S* ; Parekh, Viral ; + 5 Co-authors
Monthly Notices of the Royal Astronomical Society **472**, 2042, 2017

79. Lack of thermal energy in superbubbles: hint of cosmic rays?
Gupta, Siddhartha ; Nath, Biman B ; Sharma, Prateek* ; Eichler, David*
Monthly Notices of the Royal Astronomical Society **473**, 1537, 2018

80. On the incidence of Mg II absorbers along the blazar sightlines
Mishra S* ; Chand H* ; Gopal-Krishna* ; Joshi R* ; Shchekinov Y A+ ; Fatkhullin T A*
Monthly Notices of the Royal Astronomical Society **473**, 5154, 2018

81. The spectral energy distribution of powerful starburst galaxies - I. Modelling the radio continuum
Galvin T J* ; Seymour N* ; Dwarakanath K S ; +23 Co-authors
Monthly Notices of the Royal Astronomical Society **474**, 779, 2018

82. Changes in the pulse phase dependence of X-ray emission lines in 4U 1626-67 with a torque reversal
Beri, Aru+ ; Paul, Biswajit ; Dewangan, Gulab C*
Monthly Notices of the Royal Astronomical Society **475**, 999, 2018

83. Indication of a massive circumbinary planet orbiting the Low Mass X-ray Binary MXB 1658-298
Jain, Chetana* ; Paul, Biswajit ; Sharma, Rahul* ; Jaleel, Abdul* ; Dutta, Anjan*
Monthly Notices of the Royal Astronomical Society Letters **468**, L118, 2017

84. Phase-resolved X-ray polarimetry of the Crab pulsar with the AstroSat CZT Imager
Vadawale S V* ; Chattopadhyay T* ; Paul, Biswajit ; +14 Co-authors
Nature Astronomy **2**, 50-55, 2018

85. Curvature instability of chiral colloidal membranes on crystallization
Saikia, Lachit* ; Sarkar, Tanmoy* ; Thomas, Meera ; Raghunathan V A ; Sain, Anirban* ; Sharma, Prerna*
Nature Communications **8**, 1160, 2017

86. Actomyosin pulsation and flows in an active elastomer with turnover and network remodeling
Banerjee, Deb Sankar ; Munjal, Akankshi* ; Lecuit, Thomas* ; Rao, Madan*
Nature Communications **8**, 1121, 2017

87. Post-flare formation of the accretion stream and a dip in pulse profiles of LMC X-4
Beri, Aru+ ; Paul, Biswajit
New Astronomy **56**, 94, 2017

88. Smectic nano clusters in the nematic mesophases of dimeric compounds composed of rod-like azo moieties with lateral substituents
Manjunath, Monika* ; Roy, Arun; Prasad, Veena *
New Journal of Chemistry **41**, 11576, 2017

89. Thermal and nonlinear optical studies of newly synthesized EDOT based bent-core and hockey-stick like liquid crystals
Gowda, Ashwathanarayana ; Jacob, Litwin ; Joy, Nithin ; Philip, Reji ; Pratibha R ; Kumar, Sandeep
New Journal of Chemistry **42**, 2047, 2018

90. Features of globular cluster's dynamics with an intermediate-mass black hole
Ryabova, Marina V* ; Gorban, Alena S* ; Shchekinov, Yuri+ ; Vasiliev, Evgenii O*
Open Astronomy **27**, 1, 2018

91. Parameters of LC molecules' movement measured by dielectric spectroscopy in wide temperature range
Chausov D N* ; Kurilov A D* ; Belyaev V V* ; Kumar, Sandeep
Opto-Electronics Review **26**, 44, 2018

92. Discotic liquid crystals with Graphene: supramolecular self-assembly to applications
Kumar, Manish ; Gowda, Ashwathanarayana ; Kumar, Sandeep
Particle & Particle Systems Characterization **34**, 1700003, 2017

93. N-term pairwise-correlation inequalities, steering, and joint measurability
Karthik H S ; Usha Devi, A R* ; Tej, Prabhu J* ; Rajagopal A K* ; Narayanan, Andal
Physical Review A **95**, 052105, 2017

94. Critical features of nonlinear optical isolators for improved nonreciprocity
Roy, Dibyendu
Physical Review A **96**, 033838, 2017

95. Lepto-hadronic model of gamma rays from Eta Carinae and prospects for neutrino telescopes
Gupta, Nayantara ; Razzaque, Soebur*
Physical Review D **96**, 123017, 2017

96. Equilibrium of fluid membranes endowed with orientational order
Alageshan, Jaya Kumar ; Chakrabarti, Buddhapriya* ; Hatwalne, Yashodhan
Physical Review E **95**, 042806, 2017

97. Two-state model for nematic liquid crystals made of bent-core molecules
Madhusudana N V
Physical Review E **96**, 022710, 2017

98. Gaps between avalanches in one-dimensional random-field Ising models
Nampoothiri ; Jishnu N* ; Ramola, Kabir* ; Sabhapandit, Sanjib ; Chakraborty, Bulbul*
Physical Review E **96**, 032107, 2017

99. Unifying different interpretations of the nonlinear response in glass-forming liquids
Gadige P ; Albert S* ; Michl M* ; +8 Co-outhors
Physical Review E **96**, 032611, 2017

100. Stochastic efficiency of an isothermal work-to-work converter engine
Gupta, Deepak ; Sabhapandit, Sanjib
Physical Review E **96**, 042130, 2017

101. N-SmA-SmC phase transitions probed by a pair of elastically bound colloids
Rasi Muhammed M* ; Zuhail K P* ; Roy, Arun ; Dhara, Surajit *
Physical Review E, **97**, 032702, 2018

102. Exact extremal statistics in the classical 1D coulomb gas
Dhar, Abhishek* ; Kundu, Anupam* ; Majumdar, Satya N* ; Sabhapandit, Sanjib ; Schehr, Gregory*
Physical Review Letters **119**, 060601, 2017

103. Effects of polydispersity on the glass transition dynamics of aqueous suspensions of soft spherical colloidal particles
Behera, Sanjay Kumar ; Gadige, Paramesh ; Saha, Debasish ; Bandyopadhyay, Ranjini
Physical Review Materials **1**, 055603, 2017

104. Photon mass via current confinement
Vyas, Vivek M ; Panigrahi, Prasanta K*
Physics Letters B **771**, 588, 2017

105. Interstellar and intergalactic gas in the far IR and submillimeter spectral ranges
Shchekinov Yu A+ ; Lukash V N* ; Mikheeva E V* ; Pilipenko S V*
Physics Uspekhi **60**, 961, 2017

106. Low-frequency spectral energy distributions of radio pulsars detected with the Murchison Wide Field Array
Murphy, Tara* ; Kaplan, David L* ; Dwarakanath K S ; +25 Co-authors
Publications of the Astronomical Society of Australia **34**, e020, 2017

107. A high resolution foreground model for the MWA EoR1 field: model and implications for EoR power spectrum analysis
Procopio P* ; Wayth R B* ; Dwarakanath K S ; +22 Co-authors
Publications of the Astronomical Society of Australia **34**, e033, 2017

108. Calibration and stokes imaging with full embedded element primary beam model for the Murchison wide field array
Sokolowski M* ; Colegate T* ; Dwarakanath K S ; +22 Co-authors
Publications of Astronomical Society of Australia **34**, e062, 2017

109. Colloquium: Strongly interacting photons in one-dimensional continuum
Roy, Dibyendu ; Wilson C M* ; Firstenberg, Ofer*
Reviews of Modern Physics **89**, 021001, 2017

110. Enhanced ultrafast nonlinear optical response in ferrite core/shell nanostructures with excellent optical limiting performance
Perumbilavil, Sreekanth ; Lopez-Ortega, Alberto* ; Tiwari, Gaurav Kumar ; Nogues, Josep* ; Endo, Tamio* ; Philip, Reji
Small **14**, 1701001, 2018

111. Study of dynamical heterogeneities in colloidal nanoclay suspensions approaching dynamical arrest
Gadige P ; Saha, Debasish ; Behera, Sanjay Kumar ; Bandyopadhyay, Ranjini
Scientific Reports **7**, 8017, 2017

112. A vascular necrosis of femoral head: a metabolomic, biophysical, biochemical, electron microscopic and histopathological characterization
Narayanan, Aswath* ; Khanchandani, Prakash* ; Roy, Arun ; +11 Co-authors
Scientific Reports **7**, 10721, 2017

113. Lasing by driven atoms-cavity system in collective strong coupling regime
Sawant, Rahul ; Rangwala S A
Scientific Reports **7**, 11432, 2017

114. Relativistic inverse compton scattering of photons from the early universe
Malu, Siddharth* ; Datta, Abhirup* ; Subrahmanyan, Ravi; +4 Co-authors
Scientific Reports **7**, 16918, 2017

115. Low altitude solar magnetic reconnection, type III solar radio bursts, and X-ray emissions
Cairns I H* ; Deshpande A A ; Prabu T ; Udaya Shankar N ; Subrahmanyan, Ravi ; Srivani K S ; +40 Co-authors
Scientific Reports **8**, 1676, 2018

116. Mechanical hysteresis in actin networks
Majumdar, Sayantan ; Foucard, Louis C* ; Levine, Alex J* ; Gardel, Margaret L*
Soft Matter **14**, 2052, 2018

117. Optical nonlinearity and charge transfer analysis of pyrene adsorbed on silver: Computational and experimental investigations
Felscia, Reeta U* ; Rajkumar, Beulah JM* ; Sankar, Pranitha ; Philip, Reji ; Marya,Briget M*
Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy **184**, 286, 2017

Papers In Conference Proceedings

1. Use and awareness of open access journals among physics researchers in Bangalore city: a study
Nagaraj M N ; Bhandi M K* ; Prakash N A*
Proceedings of Profuse 2017, National Conference, Edited by Khaisar Muneebulla Khan, *et al* , held at Mangalore University, Mangalore from April 27, 2017, p517, 2017

2. Web based information resources and services at REVA University: A case study
Vasantha B* ; Meera B M ; Dhanamjaya M*
Proceedings of the "International Conference on Future of Libraries: From promises to practice, Edited by M Krishnamurthy *et al*, held at Indian Statistical Institute, Bengaluru, from November 15-17th, 2017, p364, 2017

3. Library space: A boon or a bane? In digital era
Meera B M ; Kaddipujar, Manjunath
*Proceedings of International Library and Information Professionals Summit ILIP*S 2017, Edited by P Visakhi *et al*, held from April 6-8, 2017, IISER Mohali, p10, 2017

4. Changing dimensions of academic librarianship from ancient to digital era
Meera B M
Proceedings of National Conference on the Role of LIS Professionals in the Changing Academic Paradigm, Edited by Ishwara Bhat M & Sheshadri K N. held at Presidency University, Bengaluru, from February 17-18, 2017, p1, 2018

5. Use and awarness of arXiv open access preprint repository among physics researchers of Bangalore City : A study
Nagaraj M N ; Bhandi B K*
Proceedings of ROALER 2018 National Conference Edited by Pathak *et al*, held at IISER Bhopal from Jan 18-20, 2018, p155, 2018

6. Fabrication of micro-optical components using femtosecond oscillator pulses
Rodrigues, Vanessa R M*; Ramachandran, Hema ; Chidangil, Santhosh*; Mathur, Deepak*
SPIE Proceedings Vol 10449 p2V, 2017, *Proceedings of Fifth International Conference on Optical and Photonics Engineering* Edited by Anand krishna Asundi, 2017

7. Building an efficient linear-array imager prototype
Balasubramanyam R ; Jois, Swaroop ; Prakash, Ashwini
Proceedings of IEEE Radio and Antenna Days of the Indian Ocean (RADIO) conference held at Cape Town, South Africa from September 25-28, 2017, IEEE RADIO 2017, 2018

8. Synthesis, structural and morphological property of basno3 Nanopowder prepared by solid state ceramic method
John, Jibi* ; Mahadevan Pillai, V P*; Thomas, Anitta Rose ; Philip, Reji ; +3 Co-authors
Proceedings of 3rd International Conference on Structural Nano Composites (NANOSTRUC2016) 12-15 2016, held at Aberdeen , Scotland, UK. IOP Conference Series Vol.195. p012007, 2017

Books – In Press

1. Solar system in verses
Nath, Biman B
Ponytale Books

Popular Articles

1. Irreproducibility crisis in science
Nath, Biman B
Desh, 17 September 2017

2. Jeebbigyaner tonturjal
Sinha, Supurna
Kolpobigyan , September 2017

3. Stephen Hawking: A memoir
Philip, Reji
Shantham, Malayalam

Editorial

1. Editorial
Dipankar B* ; Dwarakanath K S; Konar, Sushan*
Journal of Astrophysics and Astronomy **38**, 36, 2017

Papers In Press – In Journals

1. Anisamide anchored lyotropic nano liquid crystalline particles with AIE Effect - A smart optical beacon for tumor imaging and therapy
Urandur , Sandeep* ; Teja Banala,Venkatesh* ; Shukla,Ravi Prakash * ; Mittapelly, Naresh * ; Pandey, Gitu* ; Kalleti , Navodayam* ; Mitra, Kalyan *; Rath, Srikanta Kumar* ;Trivedi, Ritu* ; Ramarao, Pratibha ; Mishra, Prabhat Ranjan*
ACS Applied Materials & Interfaces **10**, 12960, 2018

2. Supernova explosions of massive stars and cosmic rays
Biermann, P L* ; +Becker Tjus J* ; de Boer, W* ; Caramete, L I* ; Chieffi, A* ; Diehl, R* ; Gebauer, I* ; Gergely, L* ; Haug, E* ; Kronberg, P* ; Kun, E* ; Meli, A* ; Nath, Biman B ; Stanev, T*
Advances in Space Research, 2018
(https://doi.org/10.1016/j.asr.2018.03.028)

3. The quantum Cheshire cat effect: Theoretical basis and observational implications
Duprey Q* ; Kanjilal S* ; Sinha, U ; Home D* ; Matzkin A*
Annals of Physics; **391**, 1, 2018

4. Boundaries without boundaries
Samuel, Joseph ; Facchi, Paolo* ; Marmo, Giuseppe* ; Garnero, Giancarlo* ; Sinha, Supurna
Annals of Physics, **394**, 139, 2018

5. Saras 2 constraints on global 21-cm signals from the epoch of reionization
Singh, Saurabh ; Subrahmanyan, Ravi ; Shankar, Udaya N ; Rao, Mayuri Sathyanarayana ; Fialkov, Anastasia* ; Cohen, Aviad* ; Barkana, Rennan* ; Girish B S ; Raghunathan A ; Somashekar R ; Srivani K S
Astrophysical Journal **858**, 54, 2018

6. Scintillation-based search for off-pulse radio emission from pulsars
Kumar, Ravi ; Deshpande, Avinash A
Astrophysical Journal **859**, 22, 2018

7. Cytoskeletal mechanisms of axonal contractility
Mutalik, Sampada P* ; Joseph, Joby* ; Pullarkat, Pramod A ; Ghose, Aurnab *
Biophysical Journal 2018
(https://doi.org/10.1016/j.bpj.2018.07.007)

8. Mechanochemical feedback and control of endocytosis and membrane tension
Thottacherry J J* ; Pradhan, Susav ; Pullarkat , Pramod +12 Co-authors
Biorxiv, 2017 (https://doi.org/10.1101/201509

9. Self-assembled CNT - polymer hybrids in single-walled carbon nanotubes dispersed aqueous triblock copolymer solutions
Vijayaraghavan D ; Manjunath A S ; Poojitha C G
Brazillian Journal of Physics **48**, 130, 2018

10. Periodic grating-like patterns induced by self-assembly of gelator fibres in nematic gels
Topnani, Neha B ; Prutha N ; Pratibha R
ChemPhysChem **19** 1471, 2018

11. SARAS 2: A spectral radiometer for probing Cosmic Dawn and the Epoch of Reionization through detection of the global 21 cm signal
Singh, Saurabh ; Subrahmanyan, Ravi ; Shankar, Udaya N ; Rao, Mayuri Sathyanarayana ; Girish B S ; Raghunathan A ; Somashekar R ; Srivani K S
Experimental Astronomy **45**, 269, 2018

12. Entropy and geometry of quantum states
Shivam, Kumar ; Reddy, Anirudh ; Samuel, Joseph ; Sinha, Supurna
International Journal of Quantum Information **16**, 1850032, 2018

13. Steady state, relaxation and first-passage properties of a run-and-tumble particle in one-dimension
Malakar, Kanaya* ; Jemseena V * ; Kundu, Anupam* ; Kumar, Vijay K * ; Sabhapandit, Sanjib ; Majumdar, Satya N* ; Redner S* ; Dhar, Abhishek*
Journal of Statistical Mechanics: Theory and Experiment 043215, 2018

14. Partial entropy production in heat transport
Gupta, Deepak ; Sabhapandit, Sanjib
Journal of Statistical Mechanics: Theory and Experiment 063203, 2018

15. Measuring the masses of intermediate polars with NuSTAR: V709 as, Y Lup, and V1223Sgr
Shaw A W*; Heinke C O*; Mukai K* ; Sivakoff G R *; Omsick J A *; Rana V
Monthly Notices of the Royal Astronomical Society **476**, 554, 2018

16. Secular instabilities of Keplerian stellar discs
Kaur, Karamveer ; Kazandjian, Mher V* ; Sridhar S ; Touma, Jihad R*
Monthly Notices of the Royal Astronomical Society **476**, 4104, 2018

17. Deformation of the galactic centre stellar cusp due to the gravity of a growing gas disc
Karamveer, Kaur ; Sridhar S
Monthly Notices of the Royal Astronomical Society **477**, 112, 2018

18. Twin radio relics in the nearby low-mass galaxy cluster Abel l 168
Dwarakanath K S; Parekh V ; Kale R* ; George L T
Monthly Notices of the Royal Astronomical Society **477**, 957, 2018

19. Quantum Brownian motion in a magnetic field: Transition from monotonic to oscillatory behavior
Satpathi, Urbashi ; Sinha, Supurna
Physica A: Statistical Mechanics and its Applications **506**, 692, 2018

20. Light propagation through one-dimensional interacting open quantum systems
Manasi, Pooja ; Roy, Dibyendu
arXiv:1712.0447

21. Constraint algebra in Smolins' $G \to 0$ limit of 4d Euclidean gravity
Varadarajan, Madhavan
Physical Review D **97**, 106007, 2018

22. Modeling cell - substrate de –adhesion dynamics under fluid shear
Maan, Renu ; Rani, Garima ; Menon, Gautam I ; Pullarkat, Pramod A
Physical Biology **15**, 046006, 2018

23. A tale of two periods: determination of the orbital ephemeris of the super-Eddington pulsar NGC 7793 P13
Fuerst F * ; Walton D J* ; Heida M * ; Harrison F A*; Barret D* ; Brightman M* ; Fabian A C* ; Middltn M J *; Pinto C *; Rana V ; Tramper F*; Webb N *; Kretschmar P*
Astronomy & Astrophysics manuscript no. p13orbit_v05 May 16, 2018

Papers In Press

In Conference Proceedings

1. Optical spectroscopy of spin noise in alkali vapor
Swar, Maheswar ; Roy, Dibyendu ; Dhanalakshmi D ; Bhagyalakshmi D ; Chaudhuri, Saptarishi ; Roy, Sanjukta ; Ramachandran, Hema
International Conference on Molecular Spectroscopy Conference Proceedings, 2017

2. Institutional repository: Know-how of a decade in managing digital assets
Meera B M ; Krishnamurthy S ; Kaddipujar , Manjunath
Astronomy Librarianship in the era of Big Data and Open Science LISA VIII, Strasbourg, European Doctoral College, France, June 6-9, 2017

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

Conferences Attended And Institutions Visited

Appendix –II

Name	Conferences attended / Institutions visited	Title of paper/talk
Akash Kumar Patwa	Conference on Universe After the First 200 Million Years Presidency University, Kolkata 12 December 2017	On detecting redshifted HI 21cm signal from EoR using drift scan data from MWA
	36th Astronomical Society of India 2018 Meeting Osmania University, Hyderabad 6 February 2018	On detecting redshifted HI 21cm signal from EoR using drift scan data from MWA
Amit Kumar	EMBO Lecture Course on Experimental and Theoretical Approaches to Cell Mechanics Raman Research Institute, Bengaluru 23 April – 6 May 2017	
Andal Narayanan	International Conference on Open Quantum Systems International Centre for Theoretical Sciences Bengaluru 1 August 2017	Induced transparency in cyclic atomic systems in contact with a thermal bath
	Science Day Celebrations Gitam University, Bengaluru 24 February 2018	The quantum light: A brief description of quantum features of light (Invited)
Arasi Sathyamurthy	Conference on Keysight-EEs of Design Forum Hotel Vivanta by Taj, Bengaluru 26 October 2017	RF/microwave and digital applications
Ashish Kumar Mishra	Complex Fluids Symposium 2017 Indian Institute of Technology-Madras, Chennai 18 December 2017	
Avinash Deshpande	Homi Bhabha Center for Science Education Mumbai 1 – 2 April 2017	
	Indian Institute of Technology, Indore 20 – 22 June 2017	Sky watch array network: A strategic initiative
	Workshop on Selected Topics in Physics: Materials Science, Electronics and Astrophysics Jain University, Bengaluru 26 – 27 September 2017	Radio astronomy (*Invited*)
	Indian Institute of Technology, Indore 24 - 26 October 2017	Fascinating life-stories of cosmic light-houses
	Workshop on Radio Astronomy FISAT Centre for Astronomy & Astrophysics, Cochin 31 October – 1 November 2017	Radio astronomy
	Indian Institute of Technology, Indore 9 – 11 November 2017	a. Radio astronomy b. Sky watch array network: A strategic initiative

	Workshop on Multiwave Length Neutron Star Birla Institute of Technology & Science-Pilani Hyderabad 6 – 8 January 2018	a. A new technique to search for off-pulse emission from radio pulsars (*Invited*) b. Sky watch array network: A strategic initiative
	Indian Institute of Technology, Indore 14 – 21 February 2018	Pulsars and spiral arms
	National Workshop on Image Processing and Imaging Technologies Christ University, Bengaluru 22 – 23 February 2018	Imaging sky (*Invited*)
	National Centre for Radio Astrophysics and GMRT Pune 23 – 26 February 2018	
	Colloquium on Fascinating Life-stories of Cosmic Light-houses Indian Institute of Technology Madras, Chennai 28 February – 1 March 2018	Sky watch array network: A strategic initiative
	Jawaharlal Nehru University, New Delhi 13 – 14 March 2018	
	Homi Bhabha Center for Science Education Mumbai 18 March 2018	
	Delhi University, New Delhi 26 March 2018	Fascinating life-stories of cosmic light-houses
	St. Stephen's College, New Delhi 26 March 2018	Pulsar wind nebulae
Biman B Nath	International Centre for Theoretical Sciences Bengaluru 11 September 2017	Blowing in the galactic wind (*Invited*)
	36th Astronomical Society of India 2018 Meeting Osmania University, Hyderabad 8 - 9 February 2018	a.Galaxies and the intergalactic medium (Invited Plenary) b.A dung beetle's view of the Milky Way
	University of Hyderabad, Hyderabad 9 February 2018	Discovery of helium: The Indian connection (*Public talk*)
Biswajit Paul	Indian Institute of Science, Bengaluru 2 May 2017	Tale of X-ray eclipses (*Invited*)
	Tejpur University, Assam 9 – 11 November 2017	X-ray astronomy (*series of lectures*)
	Multi-wavelength Neutron Star Workshop Birla Institute of Technology & Science-Pilani Hyderabad 7 – 8 January 2018	Neutron star studies with POLIX

	Pulsar Astronomy with uGMRT Boot-Camp Birla Institute of Technology & Science-Pilani Hyderabad 3 – 6 January 2018	a. Basics of accreting X-ray pulsars b. Some key properties of accreting X-ray pulsars
	36th Astronomical Society of India 2018 Meeting Osmania University, Hyderabad 5 – 9 February 2018	X-ray timing, milliseconds to decades and time resolved spectroscopy / polarimetry (*Plenary*)
	Conference on Advances in Astroparticle Physics and Cosmology Saha Institute of Nuclear Physics, Kolkata 6 – 9 March 2018	Prospects of neutron star studies with an X-ray Polarimeter (POLIX) on a small satellite mission
Deepak Gupta	International Summer School on Fundamental Problems in Statistical Physics XIV Bruneck, Italy 16 – 29 July 2017	
	Program on Large Deviation Theory in Statistical Physics: Recent Advances and Future Challenges International Centre for Theoretical Sciences Bengaluru 21 August 2017	Stochastic efficiency of an isothermal work-to-work converter engine
	Program on Current and Future Trends in Stochastic Thermodynamics Nordic Institute for Theoretical Physics, Sweden 19 September 2017	Stochastic efficiency of an isothermal work-to-work converter engine
	Statphys Kolkata (India) IX Saha Institute of Nuclear Physics, Kolkata 13 – 16 December 2017	Fluctuation theorem for entropy production of a partial system in the weak coupling limit
	Indian Statistical Community Physics Meeting International Centre for Theoretical Sciences Bengaluru 16 – 18 February 2018	Stochastic efficiency of an isothermal work-to-work converter engine
Dibyendu Roy	Conference on Open Quantum Systems International Centre for Theoretical Sciences Bengaluru 17 July – 4 August 2017	An efficient method to study light propagation through nonlinear quantum media
	Indian Statistical Physics Community Meeting International Centre for Theoretical Sciences Bengaluru 17 February 2018	Driven-dissipative quantum dynamics of Heisenberg spin-1/2 chains
Dwarakanath KS	36th Astronomical Society of India 2018 Meeting Osmania University, Hyderabad 5 – 9 February 2018	Twin radio relics in the near-by low-mass galaxy cluster abell 168

Gautam V Soni	GCE-India Program, New Delhi 14 June 2017 Ramalingaswami Conclave National Institute of Plant Genome Research New Delhi 15 – 17 February 2018	Electrical detection of malaria infection in single red blood cells for high throughput low parasite density profiling Nanopore and AFM platform to study chromatin structure
Girish BS	Vainu Bappu Observatory, Kavalur 11 – 12 May 2017	
Gopalakrishna MR	3rd COSPAR Symposium 2017 International Conference Centre, Korea 18 – 22 September 2017	Signal processing electronics of POLIX – A Thomson X-ray Polarimeter
	Preliminary Design Review Meeting ISRO Satellite Centre, Bengaluru 11 December 2017	Processing electronics, charge division implementation in processing electronics, common electronics, science data, broadband data handler interface
Jacob Rajan	National Symposium on National Supercomputing Mission over Grid Centre for Development of Advanced Computing, Bengaluru 9 – 10 October 2017	
Janakee Raste	Conference on Post-Planck Cosmology: Enigma, Challenges and Visions Inter University Centre for Astronomy & Astrophysics Pune 9 – 12 October 2017	Analytically modelling 21-cm signal from early phase of epoch of reionization
	Conference on Universe After The First 200 Million Years Presidency University, Kolkata 11 – 13 December 2017	An analytical formalism for 2-point correlation of 21-cm signal from early phase of EoR
	Conference on Cosmological Signals from Cosmic Dawn to the Present Aspen Center for Physics, USA 5 – 9 February 2018 University of San Francisco, USA 12 – 14 February 2018 University of California, USA 17 February 2018	Heat conduction in harmonic and anharmonic lattices
Jishnu Nambissan	Space Application Centre, Ahmedabad 1 February 2018	
Joseph Samuel	Bangalore Area Strings Meeting International Centre for Theoretical Sciences, Bengaluru 31 July – 2 August 2017	Gravity and decoherence

	Chennai Mathematical Institute, Chennai 16 – 17 August 2017	Gravity and decoherence: The double slit experiment
	Virtual Institute of Astrophysics 22 September 2017	Gravity and decoherence: The double slit experiment
	Indian Institute of Science Education & Research Trivandrum 15 – 20 January 2018	Gravitation and decoherence: The double slit experiment revisited
	Indian Institute of Technology, Kharagpur 12 – 16 March 2018	Gravitation and decoherence: The double slit experiment revisited
	International Centre for Theoretical Sciences, Bengaluru 26 March 2018	Gravitation and decoherence: The double slit experiment revisited
Karamveer Kaur	Conference on Modelling and Observing Dense Stellar Systems Charles University, Czech Republic 18 – 22 September 2017	Response of the galactic centre nuclear star cluster to slow accumulation of gas
	Max Planck Institute for Extraterrestrial Physics Germany 24 – 26 September 2017	Secular dynamics of nuclear star clusters
	Max Planck Institute for Astronomy, Germany 27 – 30 September 2017	Response of the galactic centre nuclear star cluster to slow accumulation of gas
	University of Zurich, Switzerland 1 – 3 October 2017	Response of the galactic centre nuclear star cluster to slow accumulation of gas
	Universitat zu Koln, Hungary 4 – 7 October 2017	Response of the galactic centre nuclear star cluster to slow accumulation of gas
	Eotvos University, Hungary 8 – 12 October 2017	Response of the galactic centre nuclear star cluster to slow accumulation of gas
Mamatha TS	Conference on Keysight-EEs of Design Forum Hotel Vivanta by Taj, Bengaluru 26 October 2017	RF/microwave and digital applications
Manjunath M	International Conference on Knowledge Organization Library and Information Management 2017 Indian Institute of Technology-Madras, Chennai 23 – 27 October 2017	
	National Conference on Information for All: Scientometrics, infographics social media & public libraries Gandhi Bhavan, Bengaluru 21 – 23 December 2017	
Meena MS	14th Annual Microchip India MASTERs 2017 Le Meridian, Bengaluru 5 – 8 December 2017	

Meera BM	6th International Library and Information Professionals Summit 2017 on Dynamics of Library for Excellence in Electronic Revolution Indian Institute of Science Education and Research Mohali 6 – 8 April 2017	Library space: A boon or a bane in digital era
	Seminar on Copyright for Librarians and Educators Indian Institute of Management, Bengaluru 2 May 2017	
	International Museum Day Raman Research Institute, Bengaluru 18 – 31 May 2017	
	Conference on Library and Information Services in Astronomy VIII Observatoire Astromique, France 6 – 9 June 2017	Institutional repository: Know-how for a decade in managing digital assets
	125th Birth Anniversary of Dr. S.R. Ranganathan PES University Campus, Bengaluru 9 August 2017	
	J-gate Vision Group Meeting Informatics India P. Ltd., Bengaluru 19 – 20 August 2017	
	International Literacy Day Celebration Parikrama Centre for Learning, Bengaluru 8 October 2017	
	International Conference – Birth Anniversary of SR Ranganathan Indian Institute of Technology, Chennai 23 – 25 October 2017	
	National Symposium on Future of Public Libraries in Digital Society Department of Public Libraries, Bengaluru 30 October 2017	Public library promotion and advocacy *(Invited*)
	International Conference on Future of Libraries: From promises to practice Indian Statistical Institute, Bengaluru 15 – 17 November 2017	Digital library: Path traversed and future trends (*Invited*)
	National Conference on Social Responsibilities of Libraries and Librarians in the Internet Society: Challenges and issues Karnataka State Library, Dharmasthala 15 – 16 December 2017	Information needs of senior citizens in urban India: Responsibilities of public libraries (*Invited*)

	NDLI Partners Meet & National Workshop on Copyright Issues in Digital Libraries Indian Institute of Technology, Kharagpur 8 – 10 February 2018	
	Mangalore University, Mangalore 14 – 17 March 2018	a. International Information Systems b. Digital libraries
Meera Thomas	Training Course on Design of Colloidal Materials for Medical Applications Complutense University of Madrid, Spain 1 – 2 September 2017	
	31st Conference of European Colloid and Interface Society Complutense University of Madrid, Madrid 3 – 8 September 2017	
Madhavan Varadarajan	Delhi University, New Delhi 29 September 2017 20 October 2017 26 December 2017	
Manjunath Kaddipujar	International Conference on Knowledge Organization Library and Information Management 2017 Indian Institute of Technology-Madras, Chennai 23 – 27 October 2017	
	Library Technology Conclave 2018 Goa University, Goa and Informatics Group Bengaluru 23 – 25 January 2018	
Nagaraj MN	National Conference Profuse 2017 Mangalore University, Mangalore 27 – 28 April 2017	Use and awareness of open access journals among Physics researchers in Bangalore city: A study
	Seminar on Copyright for Librarians and Educators Indian Institute of Management-Bangalore, Bengaluru 2 May 2017	
	National Conference ROALER 2018 Indian Institute of Science Education & Research Bhopal 18 – 20 January 2018	Use and awareness of arXiv open access preprint repository among physics researchers of Bangalore city: A study
Nayantara Gupta	University of Johannesburg, South Africa 15 April – 6 May 2017 Deutsches Elektronen-Synchrotron, Germany 20 June – 20 August 2017	
Neha Topnani B	Complex Fluids Symposium 2017 Indian Institute of Technology-Madras Chennai 18 – 20 December 2017	Periodic orientation patterns induced by self-assembly of gelator fibres in nematic gels

Pramod Pullarkat	EMBO Lecture Course on Experimental and Theoretical Approaches to Cell Mechanics Raman Research Institute, Bengaluru 24 April – 6 May 2017	
	Indian Institute of Science Education and Research Pune 17 – 19 May 2017	Actin dynamics and actin in axons: Contributions to dynamics and mechanics
	National University of Singapore, Singapore 22 – 27 May 2017	Actin in axons: Contributions to dynamics and mechanics
	Conference on Dynamics of Complex Systems 2017 International Centre for Theoretical Sciences Bengaluru 12 – 23 June 2017	Actin in axons: Contributions to dynamics and mechanics (*Invited*)
	BioMembranes Meeting Indian Institute of Science, Bengaluru 4 – 6 August 2017	Myosin-II independent force generation by f-actin in axonal membrane nano-tube (*Invited*)
	EMBO Workshop on Frontiers in Cytoskeleton Research Indian Institute of Science Education and Research Pune 29 October – 1 November 2017	Actin in axons: contributions to dynamics and mechanics (*Invited*)
	Complex Fluids Symposium 2017 Indian Institute of Technology-Madras, Chennai 18 – 20 December 2017	
Pratibha R	14th European Conference on Liquid Crystals Moscow State University, Russia 25 – 30 June 2017	Cellular structures arising from viscoelastic phase separation in binary mixtures of thermotropic liquid crystals
	24th National Conference on Liquid Crystals Indian Institute of Science Education & Research, Mohali 11 – 13 October 2017	Cellular structures in dynamically asymmetric liquid crystalline mixtures (*Invited*)
	Complex Fluids Symposium 2017 Indian Institute of Technology-Madras, Chennai 18 – 20 December 2017	Cellular structures arising from viscoelastic phase separation in binary mixtures of liquid crystals (*Invited*)
Raghavendra Rao KB	36th Astronomical Society of India 2018 Meeting Osmania University, Hyderabad 5 – 9 February 2018	SWAN (Sky Watch Array Network) demonstrator: Development & status
Raghunathan A	Vainu Bappu Observatory, Kavalur 11 – 12 May 2017	
Raghunathan VA	10th Liquid Matter Conference University of Ljubljana, Slovenia 17 – 21 July 2017	Hexatic phase of self-assembled micellar polymers

	Workshop on Soft and Active Matter University of Hyderabad 12 – 17 February 2018	1.Self assembled structures of amphiphiles 2.Scattering techniques in soft matter
Ramesh Balasubramanyam	2017 IEEE Radio and Antenna Days of the Indian Ocean Protea Hotel, South Africa 25 – 28 September 2017	Building an efficient linear-array imager prototype
	Space Applications Centre Ahmedabad 26 February 2018	Minimum requirements for a ground based submillimeterwave telescope
Ranjini Bandyopadhyay	Summer School for College Students Jawaharlal Nehru Planetarium, Bengaluru 25 May 2017	The flow of everyday materials (*Invited*)
	Conference on Correlations and Disorder in Classical and Quantum Systems International Centre for Theoretical Sciences Bengaluru 31 May 2017	A study of dynamical heterogeneities in an aging colloidal suspension approaching kinetic arrest (*Invited*)
	Conference on Plasticity, Rheology and Nonlinear Response of Driven Amorphous Solids University of Grenoble, France 26 June 2017	A study of dynamical heterogeneities in an aging colloidal suspension approaching kinetic arrest (*Invited*)
	Conference on Physics at Small Scales and Advanced Materials University of Hyderabad, Hyderabad 9 September 2017	A study of dynamical heterogeneities in an aging colloidal suspension approaching kinetic arrest (*Invited*)
	8th World Science Forum: 23rd Meeting of the Centre for Freedom and Responsibility in the Conduct of Science International Council of Science, Jordan 6 – 11 November 2017	
	Complex Fluids Symposium 2017 Indian Institute of Technology-Madras, Chennai 18 – 20 December 2017	
	Indian Statistical Physics Community Meeting International Centre for Theoretical Sciences Bengaluru 16 February 2018	Electric field induced gelation in a colloidal nanoclay suspension
Reji Philip	Christ Junior College, Bengaluru 29 June 2017	Fundamentals of lasers
	International Conference on Emerging Areas in Materials Engineering 2017 Amal Jyothi College of Engineering, Kanjirappally 13 -15 July 2017	Ultrafast laser induced periodic surface structuring and its applications (*Invited*)

	Meeting on Ultrafast Laser Induced Plasmas: Physics and Applications University of Hyderabad, Hyderabad 17 July 2017	Laser induced plasma studies at RRI (*Invited*)
	Lady Doak College, Madurai 27 – 28 July 2017	a. Wave optics b. Molecular spectroscopy c. Consumer awareness on everyday appliances
	Universite Paris-Saclay, France 1 September 2017	Dynamics of atomic and ionic species in laser produced metal plasmas
	International Conference on Laser Ablation 2017 Palais du Pharo, France 3 - 8 September 2017	
	The 5th National Conference on Condensed Matter Physics and Applications 2017 The Canadian Medical Protective Association Canada 22 - 23 September 2017	Optical Limiting: Materials and methods (*Invited*)
	National Conference on Recent Trends in Applied Science and Technology 2017 Alliance University, Bengaluru 26 - 27 October 2017	Nonlinear Optics: Materials and methods (keynote lecture)
	Bangalore Institute of Technology, Bengaluru 30 October 2017	Nonlinear optics
	National Seminar on Frontiers and Developments in Materials Science Government Victoria College, Palakkad 13 - 14 November 2017	Optical limiting: Materials and methods (*Invited*)
	National Seminar on Recent Trends in Medical Physics Lady Doak College, Madurai 12 – 13 December 2017	Basics of medical physics (*Invited*)
	The 30th Kerala State Science Congress Govt. Brennan College, Kerala 28 - 30 January 2018	Light: An exciting journey (*Invited*)
	International Conference on Nanoscience and Nanotechnology 2017 Indian Institute of Science, Bengaluru 21 - 23 March 2018	
Rishin PV	3rd COSPAR Symposium 2017 International Conference Centre, Korea 18 – 22 September 2017	a. Status update of POLIX – An X-ray Polarimeter on a small satellite mission b. Signal processing electronics of POLIX – A Thomson X-ray Polarimeter

	Preliminary Design Review Meeting ISRO Satellite Centre, Bengaluru 11 December 2017	POLIX payload components: Detectors and overall electronics
Sadiq Rangwala	Laboratory Amie-Cotton, France 14 – 28 May 2017	
	Laboratoire de Physique des, France 17 May 2017	
	Conference on Spectroscopy, Dynamics and Applications of Cold Molecular Ions Les Houches Physics School, France 28 May – 2 June 2017	Production, trapping and cooling of RB+2 and other alkali atomic and molecular ions
	Conference on Open Quantum Systems International Centre for Theoretical Sciences Bengaluru 17 July – 4 August 2017	Interacting quantum systems in hybrid traps
	Birla Institute of Technology & Science Pilani Goa 25 October 2017	Atoms as refrigerator
	Conference on Advances in Atomic and Molecular Physics: Indian Perspective Hotel Meridian – La Oasis & La Opus, Goa 26 – 27 October 2017	Equilibrium between trapped ions and cold trapped atoms?
	7th Topical Conference of the Indian Society of Atomic and Molecular Physics Indian Institute of Science Education and Research and Indian Institute of Technology, Tirupati 6 – 8 January 2018	Atoms, molecules and ions in cavities
	Nobel Prize Series 2018 Rashtrapati Bhawan, New Delhi 5 February 2018	
	2018 Conference on Cold and Controlled Molecules and Ions University of Georgia, Greece 25 – 29 March 2018	Resonant charge exchange as an ion cooling mechanism
	Georgia Institute of Technology, USA 30 March 2018	Refrigeration of ions with atoms
Sandhya P	Conference on Keysight-EEs of Design Forum Hotel Vivanta by Taj, Bengaluru 26 October 2017	RF/microwave and digital applications
Sandeep Kumar	Central College, Bengaluru 24 April 2017	

	National Conference on Materials for Sustainable Development and New Technology Central University of Jammu, Jammu 28 – 29 April 2017	Liquid crystalline nanocomposites as advanced materials for opto-electronics
	Indian Institute of Science, Bengaluru 19 July 2017	
	International Conference on Emerging Trends in Chemical Sciences Manipal Institute of Technology, Manipal 14 – 16 September 2017	Liquid crystals: The intriguing fourth state of matter (*Key note*)
	National Symposium on Materials for Flexible Devices BMS College, Bengaluru 25 September 2017	Discotic liquid crystals: past, present and future
	Lecture Workshop on Selected Topics in Physics Jain University, Bengaluru 26 – 27 September 2017	Liquid crystals: The intriguing fourth state of matter
	24th National Conference on Liquid Crystals Indian Institute of Science Education & Research Mohali 11 – 13 October 2017	Search of new discotic liquid crystals
	Acharya Nagarjuna University, Guntur 29 November 2017	Liquid crystals: The intriguing fourth state of matter (*Invited*)
	Central University of Jammu, Jammu 20 January 2018	
	Workshop on Synthesis, Characterization and Applications of Nano Materials 2018 Sri Jai Narain College, Lucknow 6 – 12 March 2018	i. Liquid crystals: the beautiful fourth state of matter ii. Discotic liquid crystals
	International Conference on Nanoscience and Technology 2018 Centre for Nano & Soft Matter Sciences Bengaluru 21 – 23 March 2018	
	International Workshop on Soft Materials & Devices Central University of Jammu, Jammu 24 – 25 March 2018	Supramolecular nanocomposites
	SDM College, Ujire 28 March 2018	Liquid crystals: The intriguing fourth state of matter (*Invited*)
Sanhita Kabiraj	National Conference on Recent Trends in the Study of Compact Objects – Theory and Observation III Indian Institute of Space Science & Technology Thiruvananthapuram 5 – 7 June 2017	

	Chandra/CIAO Workshop National Centre for Radio Astrophysics, Pune 23 – 27 October 2017	
Sanjib Sabhapandit	Workshop on Stochastic Dynamics Out of Equilibrium Institut Henri Poincare, France 12 – 24 June 2017	
	Bangalore School on Statistical Physics International Centre for Theoretical Sciences Bengaluru 28 June – 14 July 2017	Stochastic processes (*Invited*)
	ICTS Workshop on Large Deviation Theory in Statistical Physics: Recent Advances and Future Challenges International Centre for Theoretical Sciences Bengaluru 14 August – 13 October 2017	Fluctutation theorem for entropy production of a partial system in the weak coupling limit (*Invited*)
	Sir P T Sarvajanik College of Science, Surat 18 - 30 December, 2017	Quantum statistical mechanics (*6 lectures*)
	Workshop on Correlations, Fluctuations and Anomalous Transport in Systems Far From Equilibrium Weizmann Institute, Israel 31 December 2017 – 12 January 2018	Large deviations in the thermodynamics of small systems
	Indian Statistical Physics Community Meeting International Centre for Theoretical Sciences Bengaluru 16 – 18 February 2018	Exact distributions of cover times for N independent random walkers in one dimension (*Invited*)
Sanjukta Roy	ISRO Inertial System Unit, Thiruvananthapuram 9 – 10 August 2017	
	Indian Institute of Space Science and Technology, Thiruvananthapuram 10 August 2017	Anderson localization and atom interferometry with Bose-Einstein condensates
	Lindau Alumni Meeting DFG, German Research Foundation, New Delhi 1 – 2 December 2017	
Saptarishi Chaudhuri	Conference on Open Quantum Systems International Centre for Theoretical Sciences Bengaluru 17 July – 4 August 2017	Quantum gases with tunable interactions and non-perturbative measurements (*Invited*)
	ISRO Inertial Systems Unit, Trivandrum 9 – 10 August 2017	Ultra-cold atoms in random potentials
	International Topical Meeting on Applied and Adaptive Optics 2017 Indian Institute of Space Science & Technology Thirivananthapuram 11 – 13 August 2017	Optical spectroscopy of spin noise in neutral atomic vapor (*Invited*)

Sayantan Majumdar	Jawaharlal Nehru Centre for Advanced Scientific Research, Bengaluru 31 October 2017	Dynamic jamming in dense particulate suspensions (*Invited*)
	Statistical Physics Community Meeting International Centre for Theoretical Sciences Bengaluru 16 – 18 February 2018	Dynamic jamming in dense particulate suspensions (*Invited*)
Sridhar S	University of California, USA 4 – 9 June 2017	Stellar dynamics in galactic nuclei
	Conference on Plasma Universe and its Structure Formation Inter-University Centre for Astronomy and Astrophysics Pune 30 August – 1 September 2017	Some explorations of shear dynamos (*Invited*)
	Young Astronomers Meeting 2017 Inter-University Centre for Astronomy and Astrophysics Pune 11 – 14 September 2017	Stellar dynamics and thermodynamics (*Invited*)
Srinivasa HT	Workshop on Global Initiative of Academic Networks BMS College of Engineering, Bengaluru 19 February – 2 March 2018	
Srivani KS	Vainu Bappu Observatory, Kavalur 11 – 13 May 2017	
Sumati Surya	Perimeter Institute, Canada 10 April – 10 December 2017	Order plus number geometry: A Lorentzian approach to quantum gravity
	Conference on Making Quantum Gravity Computable Perimeter Institute, Canada 19 – 23 June 2017	Numerical questions in causal set quantum gravity (*Invited*)
	International Summer School for Young Physicists Perimeter Institute, Canada 26 July 2017	The light cone habitat
	Phys10 Undergraduate Seminar Series University of Waterloo, Canada 6 October 2017	The causal structure of a physicist
	McGill University, Canada 22 - 29 October 2017	Scalar field propagators on a causal set
	Conference on The Path Integral for Gravity Perimeter Institute, Canada 13 – 17 November 2017	Covariant observables and (quantum) extension theorems (*Invited*)

	Conference on Quantum Gravity on the Computer The Nordic Institute for Theoretical Physics, Sweden 5 - 9 March 2018	Causal set quantum gravity on the computer (*Invited*)
Supurna Sinha	Bangalore Area Strings Meeting International Centre for Theoretical Sciences Bengaluru 31 July – 2 August 2017	
	ICTS at Ten International Centre for Theoretical Sciences Bengaluru 4 – 6 January 2018	
Sushil Dubey	EMBO Lecture Course on Experimental and Theoretical Approaches to Cell Mechanics Raman Research Institute, Bengaluru 23 April – 6 May 2017	Mechanical responses of axonal cytoskeleton
	Paris Diderot University, France 4 – 5 October 2017	
	Cytomorph Lab, France 6 October 2017	
	Laboratoire Interdisciplinaire de Physique France 9 October 2017	
	Conference on Cell Physics 2017 Saarland University, Germany 11 – 13 October 2017	Mechanical responses of axonal cytoskeleton
	Institute of Cell Biology, Germany 16 – 17 October 2017	Actin-spectrin skeleton regulates mechanical tension in neurons
	Georg-August-Universitat, Germany 19 October 2017	
	Conference on Frontiers in Cytoskeleton Research Indian Institute of Science Education and Research Pune 29 October – 1 November 2017	Mechanical responses of neurons
	Conference on Current Trends in Intracellular Transport & Molecular Motors 2017 Indian Institute of Technology Bombay, Mumbai 21 – 23 December 2017	Mechanical responses of axonal cytoskeleton
Urbashi Satpathi	Conference on Frontiers of Quantum and Mesoscopic Thermodynamics 2017 Pyramida Hotel, Czech Republic 9 – 15 July 2017	A quantum diffusion law

	Indian Statistical Physics Community Meeting 2018 International Centre for Theoretical Sciences Bengaluru 16 – 18 February 2018	Quantum Brownian motion in a magnetic field: Transition from monotonic to oscillatory behaviour
	Conference on Frontiers of Statistical Physics by ISI Kolkata & Presidencyy University, Kolkata 26 – 28 February 2018	A quantum diffusion law
Urbasi Sinha	Indian Institute of Science Education and Research Trivandrum 15 May 2017	Spatially correlated qutrits (*Invited*)
	Indian Institute of Space Science and Technology Trivandrum 16 May 2017	Fascinating world of photons, superposition and entanglement (*Invited*)
	Indian Space Research Organisation, Trivandrum 16 May 2017	Fascinating world of photons, superposition and entanglement (*Invited*)
	International Conference on Women in Physics University of Birmingham, UK 16 – 18 July 2017	A tale of three slits: From superposition to quantum computing (*Invited*)
	Student Conference on Optics and Photonics 2017 Physical Research Laboratory, Ahmedabad 1 – 2 September 2017	A tale of three slits: From superposition to quantum computing (*Invited*)
	International OSA Network of Students 2017 Cochin University of Science and Technology Cochin 11 – 14 September 2017	Fascinating world of photons, superposition and entanglement
	Presidency University, Kolkata 8 November 2017	Measuring a deviation from superposition principle in interference experiments (*Invited*)
	Indian Institute of Science Education and Research Kolkata 9 November 2017	Correlated photonic qutrit pairs for quantum information and communication (*Invited*)
	International Conference on Quantum Foundations 2017 National Institute of Technology, Patna 4 – 9 December 2017	Quantum technology with photons (*Invited*)
	PRAVEGA Innovation Summit Indian Institute of Science, Bengaluru 19 January 2018	Fascinating world of photons, superposition and entanglement
	Indian Institute of Technology Madras, Chennai 24 January 2018	

	International Symposium on New Frontiers in Quantum Correlations 2018 S.N.Bose National Centre for Basic Sciences, Kolkata 29 January – 2 February 2018	Observing and tuning the effect of Feynman paths in a classical regime (*Invited*)
	International Centre for Theoretical Physics, Italy 13 February 2018	A tale of three slits: From superposition to scalable quantum computing (*Award Lecture*)
	Jawaharlal Nehru Planetarium, Bengaluru 25 February 2018	Fascinating world of photons, superposition and entanglement (*Public Lecture*)
	American Physical Society, USA 1 March 2018	Manipulating light quanta
	American Physical Society March Meeting 2018 American Physical Society, USA 5 – 9 March 2018	Measuring a deviation from the Superposition Principle in slit based interference experiments: Towards a non-zero Sorkin parameter (*Invited*)
	Louisiana State University, USA 13 March 2018	On superposition, interface and Feynman paths
Vijayaraghavan D	International Conference on Molecular Spectroscopy 2017 Mahatma Gandhi University, Kerala 8 – 10 December 2017	^{1}H NMR studies on single-walled carbon nanotubes dispersed surfactant solution (*Invited*)
Vinutha C	Astronomical Society of India 2018 Meeting Osmania University, Hyderabad 5 – 9 February 2018	SWAN (Sky Watch Array Network) demonstrator: Development & status
Vivek M Vyas	Indian Institute of Science Education & Research, Kolkata 9 December 2017	Light matter interaction and Bose-Einstein condensation of light (*Invited*)
	Conference on Condensed Matter Physics 2018 Physics Research Laboratory, Ahmedabad 16 March 2018	Photon mass out of current confinement (*Invited*)
Yashodhan Hatwalne	Indian Institute of Science Education and Research Pune 15 July 2017 – 29 January 2018	

Colloquia And Seminars

Name	Title	Date
Dipankar Home Bose Institute, Kolkata	Some basic aspects of quantum mechanics	4 April 2017
Tata BVR University of Hyderabad, Telangana	Stimuli responsive dense microgel crystals: structure and dynamics	7 April 2017
Juan M Uson Institutto de Astropfisica de Canarias, Spain	Living on the edge: Superthin galaxies and the cosmic UV background	10 April 2017
Kshitija Kelkar University of Nottingham, UK	Galaxy structure, star formation history and environment	11 April 2017
Stephan Herminghaus Max-Planck-Institute for Dynamics & Self-Organization Germany	Complex fluids in complex environments	17 April 2017
Roop Mallik Tata Institute of Fundamental Research Mumbai	Tiny machines, big tasks	4 May 2017
Debanjan Bose Sungkyunkwan University, South Korea	Neutrino astronomy with ice cube neutrino detector	11 May 2017
Apoorva D Patel Indian Institute of Science, Bengaluru	Understanding the born rule in weak measurements	24 May 2017
Ravi P Rau Louisiana State University, USA	Quantum correlations, especially entanglement and discord	20 June 2017
Santanu Kumar Pal Indian Institute of Science Education and Research, Mohali	Liquid crystal in optoelectronic and biosensor applications	22 June 2017
Rajaraman R Jawaharlal Nehru University, Delhi	Current status of nuclear energy	6 July 2017
Durai Murugan Kandhasamy Georgia State University, USA	Polyelectrolyte dynamics in different timescales: From structural relaxation to solvent reorganization	7 July 2017
Sile Nic Chormaic Okinawa Institute of Science and Technology, Japan	Nonlinear optics and Rydberg atom generation using an optical nanofiber embedded in a 87Rb MOT	19 July 2017
Johannes Hecker Denschlag Universität Ulm, Germany	State-to-state chemistry with ultracold Rb atoms	20 July 2017
Urna Basu Scuola Internazionale Superiore di Studi Avanzati, Italy	Frenetic aspects of nonlinear response: theory and experiment	20 July 2017
Vimal Simha Centre for Extragalactic Theory South Africa	Equilibrium semi-analytic model of galaxy formation	25 July 2017

Name	*Title*	*Date*
Pawan Kumar University of Texas, Austin	The mystery of fast radio bursts, and its possible resolution	28 July 2017
Kartick Chandra Sarkar Raman Research Institute, Bengaluru	The Fermi bubbles	1 August 2017
Baladitya Suri Chalmers University of Technology Sweden	Superconducting artificial atoms interacting with photons and phonons	3 August 2017
Victor Mukherjee Weizmann Institute of Science, Israel	Control in open quantum systems out of equilibrium	16 August 2017
Zoltan Haiman Columbia University, USA	Merging supermassive black hole binaries	17 August 2017
Ravi P Rau Louisiana State University, USA	Observing parrots in Australia	22 August 2017
Sourav Dutta Raman Research Institute, Bengaluru	A tiny atomic refrigerator for cooling of trapped ions	24 August 2017
Babu Reddy J N University of California, USA	Molecular mechanisms behind the surprising force adaptation of motors on intracellular vesicles	29 August 2017
Sammy McSweeny Curtin University, Australia	Making 3D maps of pulsar radio emission	31 August 2017
Sarika	Role of solution thin film instabilities in nano-scale self-assembly	11 September 2017
Arif Mohd University of Maryland, USA	Asymptotic symmetries, soft limits and holography	12 September 2017
Venkatasubramani TL Formerly at National Research Foundation, South Africa	The roadmap towards success in SKA in Africa	14 September 2017
Govindarajan TR Institute of Mathematical Sciences Chennai	New perspectives of asymptotic symmetries, QED and infrared divergences	15 September 2017
Krishna Venkateswara University of Washington, Seattle	Exploring the gravitational universe with LIGO and Torsion-balance experiments	18 September 2017
Yuri A Shchekinov Lebedev Physical Institute, Moscow	Stellar feedback: Creative & destructive	19 September 2017
Hari Dass ND TIFR Centre for Interdisciplinary Sciences, Hyderabad	What are weak values, and what is the big deal about them?	20 September 2017

Name	*Title*	*Date*
Vandna Gokhroo University of Washington, USA	Spin-orbit coupling and hydrodynamics experiments with Bose-Einstein condensates	25 September 2017
Syamsundar De Laboratoire Kastler Brossel, CNRS-UPMC, France	From classical to quantum metrology with optical frequency combs	12 October 2017
Prabhakar Tiwari Technion-Israel Institute of Technology, Israel	Radio galaxy clustering: Biasing and evolution	16 October 2017
Benoy Anand University of Pittsburgh, USA	Photophysics of nano- and microstructured materials: Nonlinear optical applications and ultrafast dynamics	24 October 2017
Prakash Gaikwad National Centre for Radio Astrophysics, Pune	Constraints on HI photoionization rate and escape fraction at z<0.5 from Lyman-alpha forest	3 November 2017
Manabendra Nath Bera ICFO-The Institute of Photonic Sciences, Spain	Universal laws of thermodynamics	6 November 2017
Daniel Comparat Laboratoire Aimé Cotton, France	Ultra cold beam: electrons / ions / atoms / molecules	8 November 2017
Olivier Dulieu Laboratoire Aimé Cotton, France	Ultracold molecules: a playground for quantum control	9 November 2017
Nishant Kumar Singh Max Planck Institute for Solar System Research, Gottingen	Solar magnetism and its effects on surface gravity modes: Implications for space weather	17 November 2017
Vaibhav H Wasnik University of Geneva, Switzerland	Positional information readout in Ca2+ signaling	24 November 2017
Neal Katz University of Massachusetts, USA	Letting the data speak for themselves: What observations tell us about galaxy formation	6 December 2017
Sowgat Muzahid Leiden Observatory, The Netherlands	Probing the circumgalactic medium: A galaxy-centric approach	7 December 2017
Amit Shukla University of Würzberg, Germany	Revealing the properties of jet physics through Blazar observations	11 December 2017
David Wilkowski Nanyang Technological University, Singapore	Resonant light - atom interaction: Cooperative emission, dark states and quantum vacuum engineering	13 December 2017
Amit Kumar Pal Swansea University, UK	Entanglement under noisy environments: From quantum computation to quantum many-body physics	13 December 2017
Haida Liang Nottingham Trent University, UK	Radio astronomy and soft matter physics in a study of painting materials and techniques	14 December 2017
Joseph Kuruvilla University of Bonn, Germany	On the streaming model for redshift-space distortions	15 December 2017

Name	*Title*	*Date*
Anders Kastberg Universite Nice Sophia Antipolis, France	A revisionist's view on laser cooling mechanisms and long-tail velocity distributions	18 December 2017
Arun Kannawadi Jayaraman Leiden Observatory, The Netherlands	Probing dark energy with gravitational lensing	18 December 2017
Oindrila Ganguly Institute of Physics, Bubhaneswar	Hawking radiation, superradiance and Lense-Thirring effect in the laboratory	19 December 2017
Kshitij Thorat Rhodes University, South Africa	Seize the means of reduction: Making containerized pipelines for radio interferometric data	19 December 2017
Aru Beri University of Southampton, UK	Swift J1357.2-0933 as seen with Swift and NuSTAR during its 2017 outburst	26 December 2017
Nirmal Kumar Iyer KTH Royal Institute of Technology, Sweden	Design and development of a SPHiNX, a gamma-ray burst polarimeter	4 January 2018
Renu Malhotra The University of Arizona, USA	The early history of our solar system	8 January 2018
Pascal Neveu CNRS Laboratoire Aime Cotton, France	Phase sensitive amplification enabled by coherent population trapping in metastable helium	9 January 2018
Igor Muševič University of Ljubljana, Slovenia	Nematic liquid-crystal colloids	10 January 2018
Shri R Kulkarni California Institute of Technology, USA	The Zwicky transient facility	11 January 2018
Nidhi Pashine University of Chicago, USA	Exotic metamaterials from disorder	12 January 2018
Prasenjit Saha University of Zurich, Switzerland	Revisiting Hanbury Brown and Twiss	12 January 2018
Chandrasekhar Bhamidipati Indian Institute of Technology, Bhubaneswar	Critical heat engines and black holes in AdS	12 January 2018
Arijit Sharma Johannes Gutenberg Universität, Germany	Towards a search for dark matter candidates using atomic dysprosium	12 January 2018
Igor Muševič University of Ljubljana, Slovenia	Liquid-crystal microlasers	16 January 2018
Jishad Kumar Weizmann Institute of Science, Israel	Thermodynamics of small systems – facts and some puzzles	16 January 2018
Igor Muševič University of Ljubljana, Slovenia	Topology and nematic liquid crystals	17 January 2018

Name	*Title*	*Date*
Igor Muševič University of Ljubljana, Slovenia	Nematic liquid-crystal colloids	18 January 2018
Ramesh Bhat Curtin University, Australia	Pulsar science and survey plans with the MWA	18 January 2018
Ravi Kunjwal Perimeter Institute, Canada	How to go from the Kochen-Specker theorem to experimentally testable signatures of contextuality	19 January 2018
Mark Birkinshaw University of Bristol, UK	The low-redshift 3c=CRR radio galaxies	19 January 2018
Rapol Umakant D Indian Institute of Science Education and Research, Pune	Experiments with ultracold atoms at IISER-Pune	6 February 2018
Rick Mukherjee Rice University Texas, United States	Study of many-body quantum dynamics using Rydberg atoms	9 February 2018
Rana Adhikari California Institute of Technology, USA	The next decade of gravitational wave astronomy	21 February 2018
Karthik Sasihithlu Imperial College, London	Near-field heat transfer via coupled surface polaritons and transmission of bulk acoustic phonons	23 February 2018
Kabir Ramola Brandeis University, USA	Entropy, disorder and scaling near the unjamming transition	14 March 2018

EMBO LECTURE COURSE
Experimental and Theoretical Approaches to Cell Mechanics 24 – 28 April 2017

Name	*Title*
24 April 2017	
Gautam Menon	Brownian motion, Langevin equation, Fokker-Planck equation, Fluctuation-dissipation Theorem. Detailed balance
Rhoda Hawkins	Active Brownanian particles, non-Boltzmann distribution. Applications to molecular motors and cell motility
Jean-Francois Joanny	Hydrodynamics. Low Reynold number
Stephan Grill	Passive pattern formation
25 April 2017	
Gautam Menon	Polymer models. Random walk. Bead-spring/Gaussian. Persist. Length
Rhoda Hawkins	Actin polymerization-depolymerization kinetics. Treadmilling. Microtubule instability.
Stephan Grill	Research talks
Jean Francois Joanny	Linear non-equilibrium thermodynamics. Constitutive equations activity.
Stephan Grill	Active mechanochemical pattern formation.
26 April 2017	
Pierre Sens	Membrane energy, tension fluctuations
Frank Jűlicher	Coarse-grained descriptions of tissues
Patricia Bassereau	Research talk
Sriram Ramaswamy	Dry vs Wet. Toner-Tu
27 April 2017	
Jean Francois Joanny	Active gel theory
Frank Jűlicher	Physics of morphogenesis development
Daniel Riveline	Research talk
Pierre Sens	Domains, tension regulation and recycling
Patricia Bassereau	GUVs, tethers, particle tracking
28 April 2017	
Daniel Riveline	Contacts, forces and adhesions
Sriram Ramaswamy	Active membranes, polymers and colloids
Pierre Sens	Research talk

Visitors

Appendix – IV

Sl. No.	*Name and Institution*	*Duration of Stay*
1	Anders Kastberg Universite Nice Sophia Antipolis, France	15 January 2017 - 15 January 2018
2	Asha K Kuvempu University, Shimoga	1 April 2017 - 31 March 2018
3	Dipankar Home Bose Institute, Kolkata	1 - 6 April 2017 22 - 26 March 2018
4	Ujjwal Sen Harish-Chandra Research Institute, Allahabad	2 - 5 April 2017 8 - 10 April 2017
5	Tata BVR University of Hyderabad, Hyderabad	6 - 8 April 2017
6	Juan Uson Astrophysical Observatory-IAU, Spain	8 - 23 April 2017
7	Rosa Astrophysical Observatory-IAU, Spain	8 -23 April 2017
8	Kshitija Kelkar University of Nottingham, Nottingham	10 -12 April 2017
9	Sujay Mate Indian Institute of Technology-Mumbai, Mumbai	15 April - 15 May 2017 26 August -2 September 2017
10	Smijesh Nadarajan Achary University of Griffith, Australia	2 - 4 May 2017
11	Kavya H Rao University of Griffith, Australia	2 - 4 May 2017
12	Debanjan Bose Sungkyun University, South Korea	9 -12 May 2017
13	Ravi P Rau Louisiana State University, USA	11 - 23 June 2017 21-22 August 2017
14	Buddhapriya Chakrabarti University of Scheffield, UK	10 - 24 June 2017
15	Kishore Sridharan National Institute of Technology, Surathkal	16 - 18 June 2017
16	Jebaratnam C S.N. Bose National Centre for Basic Sciences, Kolkata	19 - 26 June 2017
17	Ramanath Cowsik Washington University, USA	21 June - 4 July 2017

Sl. No.	Name and Institution	Duration of Stay
18	Vanessa Rodrigues Manipal University, Manipal	28 June – 7 July 2017 7 – 22 December 2017
19	Lutfor Rahman University Malaysia Pahang, Malaysia	7 – 14 July 2017
20	Fabien Bretenaker CNRS Laboratoire Aime Cotton, France	13 – 27 July 2017 3 – 12 January 2018
21	Urna Basu Scuola Internazionale Superiore di Studi Avanzati, Italy	19 – 22 July 2017
22	Pawan Kumar University of Texas, USA	27 – 30 July 2017
23	Ishwar Chandra National Centre for Radio Astrophysics, Pune	27 – 28 July 2017
24	Yuri Shchekinov Lebedev Institute, Russia	2 August – 11 October 2017
25	Baladitya Suri Chalmers University of Technology, Sweden	3 – 4 August 2017
26	Kiran Michal Christ College, Bengaluru	11 – 12 August 2017 18 – 28 October 2017
27	Ashley Jose Christ College, Bengaluru	11 – 12 August 2017 18 – 28 October 2017
28	Sampada Mutalik Indian Institute of Science Education and Research, Pune	14 - 16 August 2017
29	Samuel Mcsweeney Curtin University of Radio Astronomy, Western Australia	14 – 29 August 2017
30	Victor Mukherjee Weizmann Institute of Science, Israel	15 – 18 August 2017
31	Joby Joseph University of Hyderabad, Hyderabad	15 - 16 August 2017
32	Arka Chatterjee Indian Centre for Space Physics, Kolkata	28 August – 1 September 2017
33	Nissim Kanekar National Centre for Radio Astrophysics, Pune	6 – 10 September 2017
34	Govindarajan TR Institute of Mathematical Sciences, Chennai	13 – 16 September 2017
35	Krishna Venkateswara University of Washington, USA	18 September 2017

Sl. No.	*Name and Institution*	*Duration of Stay*
36	Hari Dass ND TIFR-TCIS, Hyderabad	20 - 22 September 2017
37	Vandna Gokhroo Washington State University, USA	24 – 25 September 2017
38	Srianand R Inter-University Centre for Astronomy and Astrophysics, Pune	25 – 28 September 2017
39	Gulaab Chand Dewangan Inter-University Centre for Astronomy and Astrophysics, Pune	25 – 28 September 2017
40	Ranjeev Misra Inter-University Centre for Astronomy and Astrophysics, Pune	25 – 28 September 2017
41	Ruta Kale National Centre for Radio Astrophysics, Pune	3 – 10 October 2017
42	Syamsundar De Laboratoire Kastler Brossel, France	11 - 12 October 2017
43	Francois R Bouchet Institut d'astrophysique de Paris, France	13 October 2017
44	Jacques Delabrouille University of Paris, France	13 October 2017
45	Zeeshan Ahmed Stanford University, USA	13 October 2017
46	Tarun Souradeep Inter University Centre for Astronomy & Astrophysics, Pune	13 October 2017
47	Prabhakar Techion-Israel Institute of Technology, Israel	16 – 19 October 2017
48	Benoy Anand University of Pittsburgh, USA	24 October 2017
49	Prakash Gaikwad National Centre for Radio Astrophysics, Pune	1 – 5 November 2017
50	Daniel Comparat Laboratoire Aime Cotton, France	2 - 11 November 2017
51	Olivier Dulieu Laboratoire Aime Cotton, France	3 - 13 November 2017
52	Manabendra Nath Bera The Institute of Photonic Sciences, Spain	5 - 7 November 2017
53	Priyanka Singh Inter-University Centre for Astronomy and Astrophysics, Pune	11 – 19 November 2017

Sl. No.	*Name and Institution*	*Duration of Stay*
54	Nishant K Singh Max-Planck Institute for Solar System Research, Germany	14 - 25 November 2017
55	Jayaram Chengalur National Centre for Radio Astrophysics, Pune	24 - 26 November 2017
56	Rafael D Sorkin Perimeter Institute, Canada	6 December 2017 - 8 January 2018
57	Amit Shukla Universität Würzburg, Germany	7 - 17 December 2017
58	David Wilkowski Nanyang Technological University, Singapore	12 - 15 December 2017
59	Amit Kumar Pal Swansea University, UK	12 - 15 December 2017
60	Kabir Ramola Brandeis University, USA	14 - 15 December 2017 14 March 2018
61	Lisa Glaser The University of Nottingham, UK	16 - 22 December 2017
62	Kshitij Thorat Rhodes University, South Africa	17 - 20 December 2017
63	Igor Musevic University of Ljubljana, Slovenia	21 December 2017 - 20 January 2018
64	Oindrilla Ganguly Institute of Physics, Bhubaneswar	17 - 19 December 2017
65	Srinivasan S Central University of Tamil Nadu, Thiruvarur	27-29 December 2017
66	Nirmal Kumar Iyer KTH Royal Institute of Technology, Sweden	27 December 2017 - 6 January 2018
67	Nishant K Singh Max-Planck Institute for Solar System Research, Germany	30 December 2017 - 6 January 2018
68	Shri Suman Bala Inter-University Centre for Astronomy & Astrophysics, Pune	1 - 15 January 2018
69	Zeeshan Ahmad Stanford University, California	6 - 10 January 2018
70	Renu Malhotra University of Arizona, USA	7 - 9 January 2018
71	Narasimhaswamy T CSIR-Central Leather Research Institute, Chennai	9 -12 January 2018

Sl. No.	Name and Institution	Duration of Stay
72	Ashmita Dalal University of Calgary, Canada	7 January - 31 March 2018
73	Abhirup Datta Indian Institute of Technology, Indore	7 - 11 January 2018
74	Pascal Neveu Laboratoire Aime Cotton, France	8 - 17 January 2018
75	Arijit Sharma Johannes Gutenberg Universität, Germany	9 - 12 January 2018
76	Ajit K Kembhavi Inter-University Centre for Astronomy & Astrophysics, Pune	10 - 11 January 2018
77	Kulkarni SR California Institute of Technology, USA	10 - 11 January 2018
78	Prasenjit Saha Eidgenössische Technische Hochschule Zurich, Switzerland	10 - 17 January 2018
79	Chandrasekhar Bhamidipati Indian Institute of Technology, Bhubaneswar	12 January 2018
80	Ramesh Bhat Curtin University, Australia	12 -18 January 2018
81	Prosenjit Singha Deo SN Bose National Center for Basic Sciences, Kolkata	16 - 27 January 2018
82	Chinmay Hemant Joshi Indian Institute of Science Education and Research, Thiruvananthapuram	17 January - 4 March 2018
83	Ravi Kunjwal Perimeter Institute, Canada	18 - 19 January 2018
84	Mark Birkinshaw University of Bristol, UK	19 January 2018
85	Kartick C Sarkar Hebrew University of Jerusalem, Israel	20 - 30 January 2018
86	Parvathy N Mahatma Gandhi University, Kerala	29 January - 3 February 2018
87	Sandeep S Mahatma Gandhi University, Kerala	29 January - 3 February 2018
88	Krishna Kumar E Tata Institute of Fundamental Research, Mumbai	1 February - 31 March 2018
89	Rapol Umakant D Indian Institute of Science Education and Research, Pune	5 - 7 February 2018

Sl. No.	*Name and Institution*	*Duration of Stay*
90	Pragati Pradhan Penn State University, USA	10 – 17 February 2018
91	Magal Mahato North-Eastern Hill University, Shillong	15 -19 February 2018
92	Subhabrata Majumdar Tata Institute of Fundamental Research, Mumbai	16 – 19 February 2018
93	Soebur Razzaque University of Johannesburg, South Africa	24 – 28 February 2018
94	Shilpi Chakraborty Indian Institute of Technology, Indore	2 – 17 March 2018
95	Satya Majumdar University of Paris Sud, France	4 – 17 March 2018
96	Surajit Dhara University of Hyderabad, Hyderabad	11 - 13 March 2018
97	Abhirup Datta Indian Institute of Technology, Indore	20 – 23 March 2018
98	Rishi Khatri Tata Institute for Fundamental Research, Mumbai	25 – 26 March 2018
99	Joydip Ghosh University of Wisconsin-Madison, USA	31 March 2018

RRI Science Forum

Sl. No.	*Discussed by*	*Paper discussed*	*Date*
1	Nirmal Iyer	Navigation in space- The pulsar solution	13 April 2017
2	Urbashi Satpathi	A quantum violation of the second law?	11 May 2017
3	Raghunathan A	Overcoming the Rayleigh's curse in an optical system through quantum measurement	25 May 2017
4	Sujith Kumar Nath	Brownanian motion after Einstein	22 June 2017
5	Joseph Samuel	Rotational superradiant scattering in a vortex flow	13 July 2017
6	Sanjukta Roy	Observation of supersolidity with Bose-Einstein condensates	27 July 2017
7	Viral Parekh	Saraswati, an extremely massive ~ 200 Mpc scale supercluster	10 August 2017
8	Nayantara Gupta	Extended jets of active galactic nuclei	14 September 2017
9	Ranjini Bandyopadhyay	Soft matter food physics – the physics of food and cooking	12 October 2017
10	Saptarishi Chaudhuri	Observation of Josephson effect in ultra-cold fermi gases	26 October 2017
11	Andal Narayanan	Coherent frequency conversion between microwave and optical regimes	9 November 2017
12	Supurna Sinha	Construction and optimization of a quantum analog of the Carnot cycle	23 November 2017
13	Avinash Deshpande	Phase-resolved X-ray polarimetry of the Crab pulsar with the AstroSat CZT imager	28 December 2017
14	Biswajit Paul	Cyclotron line energy variations in X-ray pulsars	8 February 2018
15	Nupur Biswas	Impact of big data analytics in biology	22 February 2018
16	Saurabh Singh & Janakee Raste	First detection of signature from cosmic dawn	8 March 2018
17	Vivek M Vyas	Bose-Einstein condensation of photons in an optical microcavity	22 March 2018

Visiting Students' Programme

Appendix – VI

Mentor	*Student*		
Andal Narayanan	Charudatta Manwatkar		
Arun Roy	Irabati Chakraborty		
Deshpande A A	Akhil Jaini Akshita Gupta Bhawana Bansal Dwaipayan Debnath Harsh Grover	Jaikhomba Singha Jigishakumari Vallabhbhai Pratik Kumar Rahul Rana Ramlal U	Shubham Gupta Sourita Saha Urvashi Nakul Nishi Tiwari Samina Mansuri
Dibyendu Roy	Adithyan Radhakrishnan	Keerthy Menon	Lakshmi P N
Gautam Soni	Aakanksha Agarwal Mahesh B L	Manohara M Monica Thankur	Priyanka Arunachalam Satish Kumar Mehta
Hema Ramachandran	Akhil V K Anisa Aftab Anju Mauraleedharan Arvind Ganesh Binodbihari Panda	Divyajyoti Harsha S Mary Ida Melody K S Neha S Prasad	Rashmi A.M Sukanya Mahapatra Thippeswamy H U Vakula P
Nayantara Gupta	Vaishnavi Kanamarlapudi	Samaresh Mondal	
Pramod Pullarkat	Sabahat Shaikh	Sahana K S	
Pratibha R	Avani Tiwari	Prutha Raj	Saranya Narayanan
Raghunathan A	Akhil Raj Akhil Reddy Amarnath Reddy	Jalli Joshma Kshitij Sadasivan Mahendranath Reddy	Ramyasri N S Uma Maheshwara Rao
Ramesh B	Arya P N Ashwini P Geethu Paulose	Kuldeep Singh Neha Vinayak Thigala	Pavan M S Sandeep H
Ramesh B (for Hema Ramachadran)	Sandeep K		
Ranjini Bandyopadhyay	Ananya Saha	Jannet Joy	Manikantha Sai Ganesh
Ravi Subrahmanyan	Samskruti Ganjam		
Reji Philip	Agnes George Alina Peetan	Anjali V Murali Joel K Jose	Jyothis Thomas Subam Rai
Sandeep Kumar	Alakananda Patra Deepika Dinesh Ram	Hari Shanker K Kavita R Rathod	Litwin Jacob Vaibhav Paul
Saptarishi Chaudhuri	Anindya Sundar Paul	Dixith M	Rohit Prasad Bhatt
Urbasi Sinha	Neha K Naskar	Rakshita R M	

RAMAN RESEARCH INSTITUTE

Audited Statements of Account
2017 - 2018

GRSM & ASSOCIATES
Chartered Accountants

No. 8/90, 1st Floor, Pampa Mahakavi Road,
Shankarapuram, Bangalore-560 004.
Ph : +91-80-41312149 / +91-80-2660 2810

INDEPENDENT AUDITOR'S REPORT

To
The Members of Raman Research Institute

Report on the Financial Statements

We have audited the accompanying financial statements of **M/s Raman Research Institute, ("Institute")**, Sir C V Raman Avenue, Sadashivanagar, Bangalore 560080, which comprises of the Balance Sheet as at March 31, 2018, the Income & Expenditure Account for the year then ended, the Receipts and Payment Account for the year then ended, a summary of significant Accounting policies and other explanatory information.

Management's Responsibility for the Financial Statements

The Institute's Management is responsible for the preparation of these financial statements that give a true and fair view of the financial position, financial performance and cash flows of the Institute in accordance with the accounting principles generally accepted in India. This responsibility includes the design, implementation and maintenance of internal controls relevant to the preparation and presentation of the financial statements that give a true and fair view and are free from material misstatements, whether due to fraud or error.

Auditor's Responsibility

Our responsibility is to express an opinion on these financial statements based on our audit. We have 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 judgement, 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 entity's preparation and fair presentation of the financial statements in order to design audit procedures that are appropriate in the circumstances, but not for the purpose of expressing an opinion on the effectiveness of the entity's internal control. 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.

[...contd]

Opinion

In our opinion and to the best of our information and according to the explanations given to us, the financial statements 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 Institute as at March 31, 2018;

b) in the case of the Income and Expenditure Account, of the excess of Income over Expenditure for the year ended on that date; and

c) in the case of Receipts & Payments account, the receipts and payments of the Institute for the year ended on that date.

For GRSM & Associates
Chartered Accountants
Firm's Registration Number: 000863S

GRSM & ASSOCIATES · Bangalore · Chartered Accountants ·

V. Madhavan
Partner
M.No.028113

Place: Bengaluru
Date: 04-07-2018

RAMAN RESEARCH INSTITUTE, BENGALURU
BALANCE SHEET AS AT 31ST MARCH 2018

(Amount in INR)

CORPUS/CAPITAL FUND AND LIABILITIES	Schedule	Current Year	Previous Year
Corpus/Capital Fund	1	106,78,29,204	101,97,11,772
Reserves & Surplus	2	-	-
Earmarked & Endowment Funds	3	59,49,76,437	55,06,03,391
Secured Loans & Borrowings	4	-	-
Unsecured Loans & Borrowings	5	-	-
Deferred Credit Liabilities	6	-	-
Current Liabilities & Provisions	7	1,89,01,532	1,95,90,914
TOTAL		**168,17,07,173**	**158,99,06,077**
ASSETS			
Fixed Assets	8	92,10,51,006	93,56,95,065
Investments- from earmarked & endowment funds	9	57,69,98,344	52,68,61,268
Investments-Others	10	1,00,00,000	1,00,00,000
Current Assets, Loans & Advances	11	17,36,57,823	11,73,49,744
TOTAL		**168,17,07,173**	**158,99,06,077**
Significant Accounting Policies	24		
Contingent Liabilities and Notes on Accounts	25		

As per our report of even date
for M/s GRSM & Associates
Chartered Accountants
FRN 000863S

(C. S. R. Murthy)
Administrative Officer

(Ravi Subrahmanyan)
Director

(V. Madhavan)
Partner
M No. 028113

BENGALURU / 4th July 2018

RAMAN RESEARCH INSTITUTE, BENGALURU

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31ST MARCH 2018

(Amount in INR)

INCOME	Schedule	Current Year	Previous Year
Income from Sales/Services	12	-	-
Grants/Subsidies	13	44,98,23,193	38,83,55,280
Fee/Subscriptions	14	-	-
Income from Investments for earmarked/endowment funds)	15	-	-
Income from Royalty	16	-	-
Interest Earned	17	28,25,167	32,84,372
Other Income	18	15,09,731	14,99,441
Increase/Decrease in stock of finished goods	19	-	-
TOTAL (A)		**45,41,58,091**	**39,31,39,093**
EXPENDITURE			
Establishment Expenses	20	24,97,09,368	22,85,74,400
Other Administrative Expenses	21	11,38,60,765	11,90,50,629
Expendtiture on Grants/Subsidies	22	-	-
Interest	23	-	-
Depreciation (Net as per Schedule 8)		6,17,74,193	5,86,22,280
TOTAL (B)		**42,53,44,326**	**40,62,47,309**
BALANCE-SURPLUS/(DEFICIT) CARRIED TO CORPUS/CAPITAL FUND (Sch. 1(2b))		**2,88,13,765**	**(1,31,08,216)**
Significant Accounting Policies	24		
Contingent Liabilities and Notes on Accounts	25		

As per our report of even date
for M/s GRSM & Associates
Chartered Accountants
FRN 000863S

(C. S. R. Murthy)
Administrative Officer

(Ravi Subrahmanyan)
Directo

(V. Madhavan)
Partner
M No. 028113

BENGALURU / 4th July 2018

RAMAN RESEARCH INSTITUTE, BENGALURU
RECEIPTS AND PAYMENTS STATEMENT FOR THE YEAR ENDED 31ST MARCH 2018

(Amount in INR)

RECEIPTS	Current Year	Previous Year	PAYMENTS	Current Year	Previous Year
I. Opening Balances			**I. Expenses**		
a) Cash in hand	-	2,092	a) Establishment Exp	21,24,83,972	19,41,66,244
b) Bank Balances	1,59,60,630	3,11,24,247	b) Admin Expenses	2,60,09,351	3,43,72,512
c) Deposits	21,51,89,105	17,06,51,352	c) PF-Final Settlement	67,70,880	14,29,055
d) Stamps (Franking M/C)	1,582	25,226	d) Pension Payout	-	1,18,25,523
II. Grants Received			**II. Payments made against projects**	3,73,65,648	9,73,758
a) From Govt. of India	46,85,72,000	40,39,00,000			
b) From State Govt.	-	-	**III. Investment and deposits made**		
c) From other sources	7,10,38,149	61,55,764	a) Out of earmarked funds	-	-
			b) Out of own funds (investment-others)	-	-
III. Income on Investments from					
a) Earmarked & Endowment Funds	-	-	**IV. Expenditure on Fixed Assets & CWIP**	8,91,05,822	7,46,90,929
b) Own Funds	-	-			
			V. Refund of surplus money / loans		
IV. Interest Received			a) To Govt. of India	-	-
a) On Bank deposits	1,46,02,797	2,03,30,555	b) To State Govt	-	-
b) on Loans, Advances etc.	1,962	6,863	c) To other fund providers	-	-
V. Other Income (Specify)	-	-	**VI. Finance charge (Interest)**	-	-
VI. Amount Borrowed	-	-	**VII. Other Payments (Specify)**	-	-
VII. Any other Receipts (Specify)			a) TDS Receivable	2,55,550	2,36,283
a) Advances	2,06,68,199	22,20,741	b) Advances	2,38,900	32,91,416
b) Receivables	40,86,938	1,43,45,492	c) Investments (Nett)	2,18,985	3,32,671
c) Accrued Interest	4,75,729	2,752	d) EMD, SD, CD (Deposits)	18,60,450	-
d) Investments (Nett)	9,64,717	1,13,66,999	e) Bills Payable	12,51,54,772	8,12,03,489
e) Overheads	21,76,118	-	f) Payroll Recoveries	3,77,19,944	3,78,09,736
f) Deposits	-	30,92,035	g) Deposits (for services)	21,000	6,55,000
g) Pension Corpus	-	52,65,320	h) Duties & Taxes	14,25,850	10,53,816
h) Employees's subscription	1,65,22,100	1,59,45,500	i) Provision	14,47,868	8,20,000
			j) PF-Withdrawals	1,00,53,600	86,02,000
			h) CPF (Emplyr Share)-Trf to Pension	23,09,442	18,21,189

RAMAN RESEARCH INSTITUTE, BENGALURU
RECEIPTS AND PAYMENTS STATEMENT FOR THE YEAR ENDED 31ST MARCH 2018

(Amount in INR)

RECEIPTS	Current Year	Previous Year	PAYMENTS	Current Year	Previous Year
			VIII. Closing Balances		
			a) Cash Balance	-	-
			b) Bank Balances		
			i) Deposit Accounts	25,57,33,900	21,51,89,105
			II) Current/Savings Account	2,20,83,126	1,59,60,630
			c) Postal franking machine	966	1,582
TOTAL	**83,02,60,026**	**68,44,34,938**		**83,02,60,026**	**68,44,34,938**

-

As per our report of even date
for M/s GRSM & Associates
Chartered Accountants
FRN 000863S

(C. S. R. Murthy)
Administrative Officer

(Ravi Subrahmanyan)
Director

(V. Madhavan)
Partner
M No. 028113

BENGALURU / 4th July 2018

RAMAN RESEARCH INSTITUTE, BENGALURU

SCHEDULES FORMING PART OF BALANCE SHEET AS AT 31ST MARCH 2018

(Amount in INR)

Schedule 1- Corpus/Capital Fund		Current Year		Previous Year
(1) CAPITAL FUND REPRESENTING ASSETS CREATED OUT OF GRANTS				
As per last account	104,72,88,885		103,08,66,224	
Addition during the year	14,09,17,761		13,52,20,272	
Less: Deductions during the year *(Includes Capital Work-in-progress)*	5,18,04,559		6,01,75,331	
Less: Depreciation chargeable	6,17,74,193		5,86,22,280	
BALANCE AS AT THE YEAR END		107,46,27,894		104,72,88,885
(2) GRANT BALANCES				
(a) NON-RECURRING GRANT				
Balance as at the beginning of the year		1,16,31,109		1,16,88,932
Add: Contributions during the year	8,05,23,000		7,41,67,000	
Add: Interest earned on LC Margin Money & Term Deposits	5,54,860	8,10,77,860	8,20,118	7,49,87,118
Less: Expenditure incurred during the year		8,91,13,202		7,50,44,941
BALANCE AS AT THE YEAR END		35,95,767		1,16,31,109
(b) RECURRING GRANT				
Balance as at the beginning of the year	(3,92,08,222)		(2,61,00,006)	
Transferred from Income & Expenditure-	2,88,13,765		(1,31,08,216)	
-Account for the year				
BALANCE AS AT THE YEAR END		(1,03,94,457)		(3,92,08,222)
TOTAL (1+2)		**106,78,29,204**		**101,97,11,772**

Schedule-2- Reserves & Surplus		Current Year		Previous Year
NOT APPLICABLE		-		-
TOTAL		**-**		**-**

RAMAN RESEARCH INSTITUTE, BENGALURU
SCHEDULES FORMING PART OF BALANCE SHEET AS AT 31ST MARCH 2018

Schedule 3- Earmarked/Endowment Funds

(Amount in INR)

Sl No	Funding Agency	Project Name	Opening Balance	Additions during the year	Utilisation			Total Utilisation	Balance as on 31/03/18
					Capital Expenditure	Recurring Expenditure	Advances/ Receivables		
Funded by Government Agencies									
1	CSIR	Dr. Bhatnagar Award-Prof. Madan Rao	(1,80,000)	1,80,000	-	-	-	-	-
2		Dr. Bhatnagar Award-Dr. Sadiq Rangwala	-	1,80,000	-	1,80,000	-	1,80,000	-
3		Dr. Bhatnagar Award-Prof Deshpande	-	1,80,000	-	1,80,000	-	1,80,000	-
4	DBT	Biomechanics of Synaptogesis-Dr Pramod	7,321	-	-	-	-	-	7,321
5		Ramalingaswamy Fellowship- Dr. Gautam	(2,64,963)	2,23,000	-	4,76,179	-	4,76,179	(5,18,142)
6	DST	DST-MWA Project- Prof Shiv Sethi	36,269	-	-	-	-	-	36,269
7		Ramanujan Fellowship- Dr Pramod	2,06,447	-	-	-	-	-	2,06,447
8		Indo-Aus BMWF Jt. Research	70,579	-	-	-	-	-	70,579
9		Indo-Aus Strategic Res. Fund- Dr Reji	(4,820)	-	-	-	-	-	(4,820)
10		Indo-Russia Joint Project- Prof Biman Nath	4,73,600	-	-	-	-	-	4,73,600
11		DST-Indo-Russia-P/270-Prof Biman	-	2,50,000	-	-	-	-	2,50,000
12		DST-Indo-Russia-P/276-Prof Shiv	-	2,32,600	-	-	-	-	2,32,600
13		DST-BRICS-Travel-Dr. Hema	-	7,00,000	-	4,14,564		4,14,564	2,85,436
14	IFCPAR	CEFIPRA Grant- Prof Hema R	1,37,525	-	-	-	-	-	1,37,525
15		CEFIPRA Grant- Dr. Sadiq Rangwala	42,61,600	-	37,07,121	5,74,400	-	42,81,521	(19,921)
16	ISRO	ISRO-Polix Project-Prof Biswajit	41,88,992	-	-	36,50,235	-	36,50,235	5,38,757
17		ISRO-Polix Payload-Prof Biswajit	-	4,34,69,987	3,75,00,000	10,69,681	-	3,85,69,681	49,00,306
18		ISRO-QKD-Project-Dr. Urbasi	-	2,46,92,248	-	22,09,000	-	22,09,000	2,24,83,248
19	IUSSTF	IUSSTF Grant-Prof Shiv	-	6,00,000	-	82,498	-	82,498	5,17,502
20	SERB	Inspire Fellowship-Dr. Saurav Datta	(81,803)	-	-	8,85,368	-	8,85,368	(9,67,171)
21		Inspire Fellowship-Dr. Dibyendu	(1,10,266)	17,80,000	-	9,49,336	-	9,49,336	7,20,398
22	TIFR	TIFR-Grant-Prof. Krishnakumar	-	91,549	-	-	-	-	91,549
SUB TOTAL			**87,40,481**	**7,25,79,384**	**4,12,07,121**	**1,06,71,261**	**-**	**5,18,78,382**	**2,94,41,483**

Schedule 3- Earmarked/Endowment Funds

(Amount in INR)

Sl No	Funding Agency	Project Name	Opening Balance	Additions during the year	Utilisation			Total Utilisation	Balance as on 31/03/18
					Capital Expenditure	Recurring Expenditure	Advances/ Receivables		
Funded by other than Government Agencies									
1	FQXi	FQXi- Dr. Sumati Surya	(3,65,085)	3,65,085	-	-	-	-	-
2	IKP	GCE Grant-Dr. Gautam Soni	-	18,03,728	-	-	-	-	18,03,728
3	IAGRG	IAGRG Grant-Dr. Sumati Surya	902	-	-	902	-	902	-
4	CNRS	CNRS-Dr. Urbasi Sinha	(1,03,002)	-	-	94,000	-	94,000	(1,97,002)
SUB TOTAL			**(4,67,185)**	**21,68,813**	**-**	**94,902**	**-**	**94,902**	**16,06,726**
Retirement Funds									
1	-	Gratuity Fund	6,70,30,006	50,10,733	-	55,22,443	-	55,22,443	6,65,18,296
2		Leave Salary Fund	5,61,10,641	42,02,792	-	53,03,030	-	53,03,030	5,50,10,403
3		Pension Commutation Fund	19,85,31,516	1,53,55,001	-	41,50,772	-	41,50,772	20,97,35,745
4		RRI Pension Fund	8,89,37,752	1,00,85,455	-	53,38,467	-	53,38,467	9,36,84,740
5		RRI Provident Fund	13,17,20,180	1,62,08,385	-	89,49,521	-	89,49,521	13,89,79,044
SUB TOTAL			**54,23,30,095**	**5,08,62,366**	**-**	**2,92,64,233**	**-**	**2,92,64,233**	**56,39,28,228**
GRAND TOTAL			**55,06,03,391**	**12,56,10,563**	**4,12,07,121**	**4,00,30,396**	**-**	**8,12,37,517**	**59,49,76,437**

Continued on the next page

RAMAN RESEARCH INSTITUTE, BENGALURU
SCHEDULES FORMING PART OF BALANCE SHEET AS AT 31ST MARCH 2018

(Amount in INR)

Schedule 4- Secured Loans & Borrowings	Current Year		Previous Year	
NOT APPLICABLE	-	-	-	-
TOTAL		**-**		**-**

Schedule-5- Unsecured Loans & Borrowings	Current Year		Previous Year	
NOT APPLICABLE	-	-	-	-
TOTAL		**-**		**-**

Schedule 6- Deferred Credit Liabilities	Current Year		Previous Year	
NOT APPLICABLE	-	-	-	-
TOTAL		**-**		**-**

Schedule-7- Current Liabilities & Provisions	Current Year		Previous Year	
A. CURRENT LIABLITIES				
1. Sundry Creditors				
a) for goods	-		-	
b) Others	1,66,878	1,66,878	4,61,368	4,61,368
2. Earnest Money Deposit		21,90,000		39,10,035
3. Advances Received		1,02,13,898		1,00,00,000
4. Statutory Liabilities				
a) Overdue				
b) Others	-		-	
5. Other Current Liabilities (Incl. Security Deposit)	22,49,480	22,49,480	17,87,391	17,87,391
TOTAL (A)		1,48,20,256		1,61,58,794
B. PROVISIONS				
1. Gratuity	1,41,756		88,224	
2. Superannuation / Pension	1,94,970		96,396	
3. Accumulated Leave Encashment	-		-	
4. Others (Specify)	37,44,550		32,47,500	
TOTAL (B)		40,81,276		34,32,120
TOTAL (A+B)		**1,89,01,532**		**1,95,90,914**

RAMAN RESEARCH INSTITUTE, BENGALURU
SCHEDULES FORMING PART OF BALANCE SHEET AS AT 31ST MARCH 2018

Schedule 8- Fixed Assets											(Amount in INR)
Description		**GROSS BLOCK**				**DEPRECIATION**				**NET BLOCK**	
	Rate	Cost /Valuation as at the beginning of theyear	Additions During the year	Deductions during the year	Cost / Valuation at the end of the year	As at the beginning of the year	On additions during the year (Incl. on the OB)	On deductions during the year	Total upto the year end	As at the end of current year	As at the end of Previous Year
A. Fixed Assets											
1. Land											
a) Freehold											
Malleshwaram	-	3,78,735	-	-	3,78,735	-	-	-	-	3,78,735	3,78,735
RMV II Stage	-	31,19,436	-	-	31,19,436	-	-	-	-	31,19,436	31,19,436
HMT Jalahalli	-	8,00,63,261	-	-	8,00,63,261	-	-	-	-	8,00,63,261	8,00,63,261
2. Buildings											
a) On freehold land	1.63	17,73,33,675	30,00,102	-	18,03,33,777	3,28,77,828	29,30,589	-	3,58,08,417	14,45,25,360	14,44,55,847
3. Canteen Infrastructure	4.75	43,68,271	-	-	43,68,271	14,26,159	2,07,493	-	16,33,652	27,34,619	29,42,112
4. Plant Machinery, Equipment	4.75	91,65,82,737	5,18,07,619	75,027	96,83,15,329	38,08,98,105	4,50,07,912	75,027	42,58,30,990	54,24,84,339	53,56,84,632
5. Vehicles	9.50	74,51,930	-	-	74,51,930	53,62,182	7,07,933	-	60,70,115	13,81,815	20,89,748
6. Furniture & Fixtures	6.33	1,49,38,251	9,395	-	1,49,47,646	91,09,014	9,46,154	-	1,00,55,168	48,92,478	58,29,237
8. Computer Peripherals	16.21	15,91,57,950	26,74,137	-	16,18,32,087	15,40,82,920	11,37,924	-	15,52,20,844	66,11,243	50,75,030
9. Library Books	4.75	22,93,71,756	4,88,496	-	22,98,60,252	12,20,19,644	1,09,11,215	-	13,29,30,859	9,69,29,393	10,73,52,112
Total Fixed Assets		**159,27,66,002**	**5,79,79,749**	**75,027**	**165,06,70,724**	**70,57,75,852**	**6,18,49,220**	**75,027**	**76,75,50,045**	**88,31,20,679**	**88,69,90,150**
B. Work in Progress											
Capital Assets		4,87,04,915	4,09,54,944	5,17,29,532	3,79,30,327	-	-	-	-	3,79,30,327	4,87,04,915
Total Capital Work in Progress		**4,87,04,915**	**4,09,54,944**	**5,17,29,532**	**3,79,30,327**	**-**	**-**	**-**	**-**	**3,79,30,327**	**4,87,04,915**
Grand Total		**164,14,70,917**	**9,89,34,693**	**5,18,04,559**	**168,86,01,051**	**70,57,75,852**	**6,18,49,220**	**75,027**	**76,75,50,045**	**92,10,51,006**	**93,56,95,065**

RAMAN RESEARCH INSTITUTE, BENGALURU
SCHEDULES FORMING PART OF BALANCE SHEET AS AT 31ST MARCH 2018

(Amount in INR)

Schedule 9- Investments from Earmarked/Endowment Funds	Current Year	Previous Year
1. In Fixed Deposits		
RRI Pension Fund	8,88,74,375	8,38,58,227
RRI Provident Fund	12,75,59,525	12,13,30,878
Extra Mural Grants	2,93,00,000	-
2. Other Approved Securities	-	-
3. Shares	-	-
4. Debentures / Bonds	-	-
5. Subsidiaries and Joint Ventures	-	-
6. Retirement funds invested in SBI Life Insurance Limited	33,12,64,444	32,16,72,163
TOTAL	**57,69,98,344**	**52,68,61,268**

Schedule-10 Investment (Others)	Current Year	Previous Year
1. In Government Securities	-	-
2. Other Approved Securities	-	-
3. Shares	-	-
4. Debentures / Bonds	-	-
5. Subsidiaries and Joint Ventures	-	-
6. Others (Specify)-Fixed Deposits	1,00,00,000	1,00,00,000
TOTAL	**1,00,00,000**	**1,00,00,000**

RAMAN RESEARCH INSTITUTE, BENGALURU

SCHEDULES FORMING PART OF BALANCE SHEET AS AT 31ST MARCH 2018

(Amount in INR)

Schedule 11- Current Assets, Loans & Advances	Current Year		Previous Year	
A. CURRENT ASSETS				
1. Inventories		8,10,114		13,43,893
2. Cash balances in hand (Including cash imprest)		-		-
3. Unused stamp value on Postal Franking Machine		966		1,582
4. Bank Balances				
Main Account				
In Current Accounts	1,07,96,267		11,88,426	
In Savings Bank Account	17,36,255	1,25,32,522	41,20,243	53,08,669
Pension Fund Account				
In Current Accounts	16,66,969		29,60,718	
In Savings Bank Account	2,23,761	18,90,730	1,74,535	31,35,253
Provident Fund Account				
In Current Accounts	68,97,264		69,50,247	
In Savings Bank Account	7,62,610	76,59,874	5,66,462	75,16,709
Extra Mural Grants				
In Savings Bank Account	16,23,728	16,23,728	-	-
TOTAL (A)		2,45,17,934		1,73,06,106
B. LOANS/ADVANCES AND OTHER ASSETS				
1. Advances and other amounts recoverable in cash				
On Capital Account				
a) Land	8,89,61,800		8,89,61,800	
b) Capital Assets	4,19,83,068	13,09,44,868		
Deposits		41,78,632	39,80,106	
Others		72,23,598	16,23,736	9,45,65,642
2. Income Accrued				
Main Account	13,69,632		4,46,329	
Provident Fund Account	8,11,567		21,33,376	
Pension Fund Account	22,44,909	44,26,108	15,20,651	41,00,356
3. Claims Receivable				
Main Account	6,58,286		2,14,802	
Extra Mural Grants	1,80,000		-	
Provident Fund Account	8,53,671		7,39,217	
Pension Fund Account	6,74,726	23,66,683	4,23,621	13,77,640
TOTAL (B)		14,91,39,889		10,00,43,638
TOTAL (A+B)		**17,36,57,823**		**11,73,49,744**

RAMAN RESEARCH INSTITUTE, BENGALURU

SCHEDULES FORMING PART OF INCOME & EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31ST MARCH 2018

(Amount in INR)

Schedule 12- Income from Sales/Service	Current Year	Previous Year
NOT APPLICABLE	-	-
Total	**-**	**-**

Schedule 13- Grants/Subsidies	Current Year	Previous Year
1. Central Government		
Grants-in-aid		
i) Non-Plan	-	10,00,000
ii) Deferred Grant (To the extent of depreciation chargeable)	6,17,74,193	5,86,22,280
iii) Plan-Recurring	38,80,49,000	32,87,33,000
Total	**44,98,23,193**	**38,83,55,280**

Schedule 14- Fees/Subscriptions	Current Year	Previous Year
NOT APPLICABLE	-	-
Total	**-**	**-**

Schedule 15- Income from Investments	Current Year	Previous Year
Interest on Investment from Earmarked / Endowment Fund	3,92,33,372	4,62,59,103
Less: Transferred to Earmarked / Endowment Fund	3,92,33,372	4,62,59,103
Total	**-**	**-**

Schedule 16- Income from Royalty/Publication	Current Year	Previous Year
NOT APPLICABLE	-	-
Total	**-**	**-**

Schedule 17- Interest Earned	Current Year	Previous Year
1) On Term Deposits		
a) With scheduled banks	25,28,582	28,26,891
2) On Savings Accounts		
a) With Scheduled banks	1,47,886	2,20,894
3) On Loans/Advances		
a) Employees	1,48,699	2,36,587
Total	**28,25,167**	**32,84,372**

RAMAN RESEARCH INSTITUTE, BENGALURU

SCHEDULES FORMING PART OF INCOME & EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31ST MARCH 2018

(Amount in INR)

Schedule 18- Other Income	Current Year	Previous Year
1) Profit on sale/disposal of assets		
a) Own Assets	-	-
b) Assets acquired out of grants	-	-
2) Miscellaneous Income	15,09,731	14,99,441
Total	**15,09,731**	**14,99,441**

Schedule 19- Increase/(Decrease) in stock of finished goods	Current Year	Previous Year
NOT APPLICABLE	-	-
Total	**-**	**-**

Schedule 20- Establishment Expenses	Current Year	Previous Year
a) Salaries & Wages	9,54,91,595	7,89,47,559
b) Allowances & Bonus	9,28,48,301	10,20,50,708
c) Contrbution to Provident Fund	14,49,509	14,00,118
d) Contribution to NPS	30,61,808	25,55,357
e) Staff welfare expenditure	1,03,23,131	85,42,354
f) Retirement/Terminal benefits	4,65,35,024	3,50,78,304
Total	**24,97,09,368**	**22,85,74,400**

Schedule 21- Other administrative expenses	Current Year	Previous Year
1) Advertisement	5,32,521	1,78,493
2) Amenities	19,91,180	21,11,512
3) Audit Fee	78,200	57,500
4) Bank Charges	46,489	21,344
5) Campus Maintenance	1,67,45,656	94,65,511
6) Conveyance	4,80,577	6,69,574
7) Corporation Taxes	2,41,386	2,99,766
8) Creche	3,00,000	1,05,000
9) Electricity Charges	1,33,80,924	1,19,93,127

Schedule 21- Other administrative expenses (Continued)	Current Year	Previous Year
10) Entertainment & Hospitality	1,62,251	1,07,581
11) Freight	4,33,254	3,01,771
12) Honorarium & Professional Fee	55,18,324	67,75,542
13) Inter Institutional Collaboration	-	2,38,378
14) Journal Subscription	33,76,703	32,24,174
15) Lease Rent (Gauribidanur Land)	4,70,830	4,06,348
16) Miscellaneous Expenses	7,02,723	8,03,991
17) Outreach	11,63,036	10,50,131
18) Patent Fee	3,14,500	7,38,675
19) Payroll Processing Charges	4,68,156	4,12,227
20) Ph.D Programme Expenditure	13,19,763	19,98,703
21) Postage & Courier Charges	1,62,468	1,94,512
22) Printing & Stationery	10,29,939	6,87,016
23) Project Working Expenses	-	9,59,500
24) Repairs & Maintenance	1,12,82,304	89,47,223
25) Security	93,82,335	80,09,658
26) Seminar/Conference/Summer School	12,07,940	26,32,392
27) Stores & Consumables	2,65,48,542	3,61,05,695
28) Telephone & Communication Charges	15,33,871	24,86,774
29) Travel Expenditure	73,14,681	75,83,098
30) Uniform & Livery	90,464	1,38,225
31) University Affiliation Fee	6,00,000	-
32) Vehicle Maintenance/Transport	26,37,557	26,72,030
33) Visiting Students Programme	35,70,795	45,51,033
34) Wages	-	14,32,800
35) Water Charges	7,73,396	16,91,325
Total	**11,38,60,765**	**11,90,50,629**

Schedule 22- Expenditure on Grants / Subsidies	Current Year	Previous Year
NOT APPLICABLE	-	-
Total	**-**	**-**

Schedule 23- Interest	Current Year	Previous Year
NOT APPLICABLE	-	-
Total	**-**	**-**

RAMAN RESEARCH INSTITUTE, BANGALORE

Schedule-24

SIGNIFICANT ACCOUNTING POLICIES

1. General

The Financial Statements have been prepared under the historical cost convention, on accrual basis of accounting and in accordance with generally accepted accounting principles. The presentation of final accounts is as per the Uniform Accounting Format for Central Autonomous Bodies as prescribed by Controller General of Accounts, Government of India

2. Fixed Assets

Fixed Assets are stated at cost of acquisition that includes inward freight, duties, taxes and incidental expense to bring the asset to use. To confirm with presentation in the Uniform Accounting Format, advance payments for procurement of capital assets have been shown in Schedule-8 (fixed assets) Capital work-in-progress. No depreciation is charged on such items. Utilisation of grants received under the component, Grants for Creation of Capital Assets is shown in Schedule-1 (Capital Fund). The value of assets, as stated in Schedule-8, is nett of depreciation.

3. Depreciation

Depreciation is charged on **STRAIGHT LINE BASIS** at the following rates

a. Buildings @ 1.63 %
b. Capital Equipment, Canteen Infrastructure and Books @ 4.75%
c. Computer & Peripherals @ 16.21%
d. Vehicles @ 9.50%

Depreciation is charged in the Income & Expenditure account. Full depreciation is charged on assets added before 30th September. Depreciation on assets added after 30th September is charged at 50%. In respect of asset blocks that end with a book value less than Re 1/- on applying depreciation, the book balance is closed with a notional value of Re 1/- by limiting depreciation charged to the notional book value.

4. Inventory

Stock on hand, such as spares, stationery and consumables are valued at cost

5. Government Grants

Grants received from Department of Science & Technology, Govt. of India under Plan and Non-Plan is Accounted for as Core Grants.

Grants with specific sanction for recurring expenditure is shown under Income & Expenditure Account. Unspent balance, which is nett of expenditure incurred during the year, is reported in the balance sheet under Schedule 1 (Grant Balances-Recurring Grant).

Grants received for Creation of Capital Assets received during the year is added to the previous year's balance in the Balance Sheet. Unspent balance, which is nett of utilisation during the year, is shown under Schedule-1 (Grant Balances-Non Recurring Grant). Funds utilised to Create Capital Assets is shown as an addition in the Capital Fund as per AS-12.

The Institute also receives Extra Mural Grants from various funding agencies. Such grants are shown as part of Schedule 3 (Earmarked / Endowment Funds).

6.	Foreign Currency Transactions	Transactions denominated in Foreign Currency are accounted for at the rates prevailing on the date of actual transaction. No provision is made to account for gains and losses arising out of exchange fluctuations.
7.	Retirement Benefits	The Institute's contribution to Provident Fund and Pension Fund are charged to Income & Expenditure Account. Deficit, if any, in the Provident Fund and Pension Account is being provided for in the books to the extent not met out of reserves

Schedule-25

CONTINGENT LIABILITIES AND NOTES ON ACCOUNTS

A. Contingent Liabilities

1.	Claims against the Institute not acknowledged as debt	The Institute has established Letters of Credit favouring Anton Paar, CAD Instruments and Japan Analytical Instruments towards procurement of instruments. These LCs would be retired in FY-18-19
2.	Bank guarantees given by the Institute	NIL
3.	Disputed demands in respect of taxes	An amount of **Rs. 3,51,480/-** is shown as due from the Institute on TRACES portal. The Institute has reconciled the details and is in the process of filing necessary information on the portal.

B. Notes on Accounts

1.	Current Assets, Advances & Deposits	Current Assets, Advances and Deposits have a value on realisation in the ordinary course of activities. The extent of realisation is equal atleast to the aggregate amount appearing in the Balance Sheet
2.	Employees' Retirement Benefits	a. Institute's contribution to the Provident Fund account are charged to Income & Expenditure Account of the institute b. As prescribed by the Govt. of India, the Institute has subscribed to Pension funds managed by SBI Life Insurance Company Limited, in respect of quantifiable liabilities of service benefits like Gratuity and Cash equivalent of Earned Leave. The Institute has also covered its liabilities for Commuted Value of Pension c. The amounts standing to the credit of the funds in SBI Life Insurance Company Limited are held in the name of the Institute in a fiduciary capacity. Balances appearing in the fund statements as at the close of financial year is shown under Schedule-3 (Earmarked/Endowment Funds-Retirement Funds). Interest earned, if any, during the year is treated as an Addition to the fund and reported accordingly in Schedule-3. Payouts on retirement on account of Gratuity, Cash equivalent of Earned Leave and Commutted value of Pension is through the fund. d. In pursuance of the directions of the Council, the amount representing Institute's contribution to the CPF in respect of eligible Senior Scientific and Technical staff members (who joined the Institute before 01/01/2004) on

contractual terms are allowed to exercise an option to opt for the Institute's pension scheme, on periodic renewal of their contracts for continuous engagement in the Institute upto superannuation. PF balances standing to the credit of such members is transferred to the Pension corpus. The income generated on the corpus is used to partially fund the pension liability. Deficit, if any, is met out of regular grants-in-aid.

e. Employees who have joined the Institute after 01/01/2004, are compulsorily enrolled under the New Pension Scheme

3. Advance for purchase of land

The Institute has deposited Rs. 8,89,61,800/- with M/s Hindustan Machine Tools Limited, being full value of a land, in pursuance of a sale agreement entered into between the Institute and HMT Limited on 13th March 2009. The conveyance deed is yet to be signed pending a formal approval from Government of India. It is to be noted that a part of this land is earmarked for Indian Academy of Sciences. The Academy has made a token remittance of Rs. 1,00,00,000/-. This is shown as part of Schedule 7 (A)-Sundry Creditors (for others) that forms part of the Balance Sheet. A matching current asset, in form of an investment, has been created in the books as shown in Schedule 10.

4. Schedules 1 to 25 are annexed to and form an integral part of the Balance Sheet as at 31st March 2017 and the Income & Expenditure Account for the year ended on that date.

5. Following the changeover in financial reporting as per Uniform Format of Accounts, numbers pertaining to the previous years have been regrouped and rearranged to conform to current year figures

As per our report of even date
For **M/s GRSM & Associates**
Chartered Accountants
FRN 000863S

(C. S. R. Murthy)
Administrative Officer

(Ravi Subrahmanyan)
Director

(V. Madhavan)
Partner
M. No. 028113

BANGALORE / July 4, 2018

For further information, please write to:
The Director
Raman Research Institute
C. V. Raman Avenue
Sadashivanagar
Bengaluru 560 080, India.

Phone : +91 (80) 23611012
Fax : +91 (80) 23610492
e-mail : root@rri.res.in
library@rri.res.in
URL : http://www.rri.res.in
ISSN : 0972-4117

Raman Research Institute,
Annual Report: 2017 – 2018
Bengaluru, RRI.