# Raman Research Institute, Bengaluru

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**Established in 1948, Raman Research Institute is an autonomous research institute pursuing research in the basic sciences. The main areas of research at the Institute are Theoretical Physics (TP), Soft Condensed Matter (SCM), Light and Matter Physics (LAMP) and Astronomy and Astrophysics (AA), of which, special emphasis goes to AA for its ongoing participation in the global radio astronomy project, Murchison Widefield Array (MWA). MWA is a radio telescope located in Murchison Shire, Western Australia whose digital receivers were designed and built at RRI. It has been successfully operating in full scientific mode since mid-2013 and is expected to provide astronomers at RRI and in the US and Australia an insight into the dramatic evolution experienced by primordial cosmic gas into the very first stars and galaxies of the early universe.**

**Keywords:** Cosmic Dawn, digital receivers, Murchison Widefield array, radio telescope.

THE Raman Research Institute (RRI), Bengaluru is an autonomous institute pursuing research in basic sciences. Indian physicist and Nobel laureate C. V. Raman founded the Institute in 1948 to continue his studies and basic research after he retired from the Indian Institute of Science (IISc), Bengaluru. Its rich and unique history has ensured that RRI as a research institute has always stood apart from other research institutes in India. Located in the northern part of Bengaluru city and in close proximity to a slew of other research institutes like the IISc and Indian Institute of Astrophysics (IIA), RRI holds its own by dint of its extremely dynamic research staff, scientific staff and students from diverse backgrounds, and its academic mission of creating knowledge and adding to the understanding and scientific comprehension of natural phenomena right from the sub-atomic to mesoscopic to cosmological scales through experiments, theoretical modelling and an active combination of both.

Following Raman's demise in 1970, RRI was restructured in 1972 to become an aided autonomous research institute receiving funds from the Department of Science and Technology, Government of India. Historically, the two major groups that constituted the thrust areas of research at RRI were astronomy and astrophysics, and liquid crystals. Both these groups have earned considerable international repute through the quality and ingenuity of their research. Fast-forward three decades; the main areas of research at the institute are now theoretical physics (including foundations of quantum mechanics and quantum gravity), astronomy and astrophysics, light and matter physics, and soft condensed matter. Interdisciplinary work and collaborations within the four major groups is one of RRI's many strengths and the close-knit academic community at RRI has come together on more than one occasion to have made path-breaking progress in answering certain key questions in fields as varied as general relativity and relativistic astrophysics, cosmology, non-equilibrium statistical physics, soft condensed matter systems, including biological physics, and application of theoretical quantum mechanical concepts to light and matter physics.

To describe in greater detail the research currently underway at RRI, let us look individually at the broad research interests of each of the four groups.

Members of the astrophysics and astronomy (A&A) group at RRI are currently engaged in research on astrophysical problems like the development of cosmological models, hydrodynamic studies of galaxies and their surroundings, gravitational dynamics, magneto hydrodynamic turbulence, etc. Pulsars, radio galaxies, X-ray binaries, halo and relic radio sources are being studied through observational data culled from not only national but also international observatories so as to verify existing theoretical models and also ask new theoretical questions. RRI has also been involved in the design and development of several telescopes across the world. For instance, RRI has built a Decameter Wave Radio Telescope at Gauribidanur around 100 km north of Bengaluru along with IIA. Reconfigurable digital receivers designed and built at RRI have modernized the Ooty Radio Telescope, which is operated by the Tata Institute of Fundamental Research (TIFR). The receivers in the 20 cm wavelength band and specialized pulsar receivers were also designed and built at RRI for the Giant Meterwave Radio Telescope (GMRT) operated by TIFR. That apart, RRI has participated in international collaborations to build a radio telescope in Mauritius, has placed receivers atop the Green Bank Telescope in West Virginia, and is part of an international collaboration that has successfully commissioned and now operates the Murchison Widefield Array (MWA) radio telescope in Australia.

The light and matter physics (LAMP) group at RRI is pursuing research in areas of light–matter interactions

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which are a combination of atomic, molecular and optical (AMO) physics on one hand, and intense laser field studies of plasmas on the other. This group uses experiments, and numerical and theoretical analyses to study light and matter interactions. The questions at hand are the quantum and classical aspects of matter, their interactions with light and the quantum nature of light itself. In particular, the research stresses on demonstration of quantum logic using ultra-cold atoms loaded in optical lattices and various traps, study of transport and localization properties of light in various random media, ultra-fast laser-induced plasmas from liquid and solid targets, nonlinear optical properties of nano-materials, laser cooling and trapping of atoms, cold collisions, ion trapping, atoms in cavities, response of cooled atoms to external fields, quantum optics with neutral atoms and non-classical light sources, quantum walk of light, etc. A Quantum Information and Computing laboratory has been recently set up at RRI, which involved setting up for the first time in India an optics laboratory that has a 'clean room' environment. The laboratory has a class 10,000 clean room that involves control of temperature, humidity and dust through precision air-handling systems. This is ensured so as to enable precision experiments based on interferometry, and the production and application of designated single-photon sources.

The soft condensed matter (SCM) group, or the erstwhile liquid crystals group at RRI, is engaged in active research on the synthesis, characterization and physical studies of liquid crystals, and also colloids, polymers, nano-composites, amphiphilic systems, complex fluids, and exciting new areas of biological physics and surface physics. Examples of research in the field of liquid crystals being conducted at RRI include synthesis and characterization of liquid crystals of various morphologies, phenomenological theories of liquid crystals and their phase transitions, instabilities, topological defects and pattern formation under shear flow or an external electric field, and liquid crystal displays (LCDs) and their intricacies. That apart, aging dynamics and relaxation time studies of colloidal systems, X-ray diffraction and polarizing light microscopy of the novel phases being induced by different types of counterions on regular ionic surfactants and also DNA–surfactant complexes, temperature–concentration phase diagrams, magnetic susceptibility studies of micellar solutions and other such investigations into the soft, solid-like nature of amphiphilic surfactants in aqueous solutions are some of the problems being actively pursued. In the field of biophysics, *in vitro* single-molecule dynamics, protein–membrane interactions and stem cell differentiation and patterning are some of the areas of interest to this group. Biophysicists at RRI are also interested in nanoscale molecular structures that dominate interactions in DNA, protein segregation and signalling at the cell membrane aided by active cellular dynamics. Novel experiments are being designed to provide a quantitative study of a variety of simplified cell systems in collaboration with biologists and theoretical physicists.

The theoretical physics (TP) group pursues research in the following four major areas – statistical physics, soft matter physics (including physics in biology), gravitation and general relativity, and foundations of quantum mechanics. Within statistical physics, the research interests mainly lie in the areas of mesoscopic physics and non-equilibrium statistical mechanics together with biophysics and soft condensed matter. Within general relativity, the problems currently being explored include gravitational waves and quantum gravity. In an example of an active collaboration between the LAMP and the TP group members, RRI has proposed a novel way of interpreting the classical quantum problem of a double-slit experiment that typically uses the standard superposition principle. Using the Feynman path integral formalism to quantify contributions from non-classical paths in quantum interference experiments, a measurable deviation from a naive application of the superposition principle has been found. A simple three-slit interference experiment has been proposed by RRI members to confirm the existence of non-classical paths.

Among all these projects, a recent and ongoing international project that has brought RRI and the members of its A&A group along with its Electronics Laboratory into the limelight in the past several years has been its active participation in the MWA project. The MWA radio telescope located in Murchison Shire in the Western Australian outback is an array of 128 antennas spread over several kilometres on the ground. Each antenna has 16 pairs of bow-tie-shaped elements arranged as square $4 \times 4$ tiles. The telescope consists of a total of 2048 dual-polarization wide-band elements that operate in the frequency range 80–330 MHz. The antenna distribution is designed for precision imaging of a wide field of several hundred square degrees of the sky at any instant and over a wide frequency band, as well as high time-resolution studies of transient and pulsating radio sources and solar emission. The antennas are connected to digital receivers which process the data before transmitting it via high-speed fibre optic cables to a centralized imaging system located 800 km away at Perth. The digital receivers that take the signals from the antennas and perform complex high-speed signal processing of the data prior to transmission to the central processing unit, which computes the imaging information, were designed and built at RRI. RRI along with Harvard and MIT in the US as well as institutions in Australia and New Zealand was jointly involved in the successful building, installing and commissioning of the telescope. RRI had assumed responsibility for the digital receivers when it entered into the MWA partnership several years ago.

Since the completion of its construction and commissioning in mid-2013, the MWA has now been in successful operation in the scientific mode for the past year – a fact that speaks volumes for the quality, reliability and ruggedness of the electronics systems designed, built, optimized and deployed by RRI.

The MWA has already begun gathering weak radio signals from deep space that will be analysed by scientists at RRI and in the US and Australia using massively parallel computing systems. The data are expected to provide astronomers an insight into the dramatic evolution experienced by primordial cosmic gas as the first stars and galaxies formed in the early universe. It is the first step towards a better understanding of the birth of the first stars and galaxies almost 13 billion years ago – or the 'cosmic dawn' so to speak. That apart, MWA data will help study the structure of the intergalactic hydrogen gas in our Milky Way galaxy and galaxies beyond, and the influence of the Sun on inter-planetary weather close to the Earth.

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

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


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