A Report on IUCAA Radio Physics Lab (RPL) Facility

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The Inter-University Centre for Astronomy and Astrophysics, Pune, India

10th Anniversary Year (2008 - 2018)

A UGC Funded Training & Educational Facility of IUCAA

1 Innovation in Educational and Training Infrastructure: The IUCAA-NCRA Radio-physics Laboratory Facility (RPL)

Joydeep Bagchi, conceived and has been operating this novel facility since 2008 in IUCAA, in collaboration with TIFR's National Centre for Radio Astrophysics (NCRA). The main goal of which is to impart practical hands-on training and education in specialized concepts of Radio Astronomy and other areas to University students and teachers. Also, an important goal is to make them technically trained and motivated enough to use the GMRT, VLA and other advanced radio telescope for high quality research work. Recently, in the current plan we have started to make innovative experiments available for Gravitational Wave Physics hands-on training, in view of LIGO-India facility being built in India near Pune.

To fulfil these goals, over the last few years very extensive efforts have been made by J.Bagchi and his NCRA colleague BhalChandra Joshi, towards implementation of the ideas envisaged for establishing this unique 'Radio-Physics Laboratory (RPL)'. In January 2008, with the signing of a formal MOU between IUCAA and NCRA towards bilateral co-operation, the RPL project had started to take shape exactly as planned. Currently, the laboratory set-up is fully operational and next expansion activities are in full swing at the labs located in both the institutes, involving active manpower provided by local science and engineering students (as integral part of their training). We have also involved skilled manpower selected from university sector. The IUCAA-NCRA Radio-physics Laboratory Project is being carried out in collaboration with Dr. Bhal Chandra Joshi and Dr. Subhashis Roy, both Faculty, at National Centre for Radio Astrophysics (NCRA-TIFR), Pune. RPL is one of the several facilities of IUCAA, and only one of its kind focusing on education and training.

Scientific background and the basic motivations

IUCAA with its strong emphasis on teaching, research and development in various branches of Astronomy and Astrophysics, aims at being a center for excellence within the university sector. Thus, it has an important role to play in introducing the students and teachers to various frontier areas of research and in helping them to realise their talent to the maximum extent. One important branch of astronomy - the Radio Astronomy, has undergone phenomenal growth over the last three decades. We have witnessed the completion of several very advanced research facilities such as the GMRT (Giant Meter Wave Radio Telescope) in India, the advanced VLA (Jansky VLA) and the large 100-mt GBT (Green Bank Telescope) antenna in US, and several other large radio telescopes across the world. Some even larger and extremely powerful facilities that are being planned, will be coming up in near future, like SKA, ALMA and LOFAR. With the very high sensitivity, better resolution and spectroscopic capability offered by such telescopes, a new window to the Universe has opened up - enabling one to obtain fundamentally new insights in solar, planetary and stellar physics, the stellar and galactic evolution, the structure formation and evolution of Universe, and the very high energy astrophysical frontiers of the early Universe. We at IUCAA, feel, that the motivated and highly talented students from *Indian universities* should seize this opportunity of conducting cutting-edge research in various front-line areas of Radio Astronomy and also in developing their original ideas which can be further tested by observations and theory.

However this is yet to happen in a major way in India as very few bright and motivated students from universities in India opt for research in radio astronomy in particular and astronomy and astrophysics in general. But the scene is changing rapidly. Through our close interaction with university students, we have observed that, although some students come with a broad understanding of an optical telescope and the modes of observation possible with it.

However, one finds in general that the fundamental principles of operation of a radio telescope, the type of data that one can obtain with it and the celestial sources that can be observed, all appear baffling to majority of them. This is mainly due to lack of exposure to radio astronomy in general and also in large measure due to the invisible nature of the radiation. Even though every student of level of M.Sc. Physics performs experiments with Michelson and other types of optical interferometers, many have great difficulty in understanding the operation of a radio-interferometer, which is actually based on Michelson's famous design of a stellar interferometer. Similarly, the nature of diffraction effects in radio antennas, the concept of angular resolution, the antenna and system temperatures, polarization of EM waves and antenna response, image formation by earth-rotation aperture synthesis interferometry etc. are all highly specialized concepts which need to be thoroughly understood by any newcomer who wants to use a radio telescope. A deep understanding of radio astronomical concepts; both instrumental and also those related to astrophysics (like various radiative processes) is essential for conducting any form of advanced radio research. In today's highly competitive world of astronomy with large telescopes, this has almost become essential. It is also expected that a student should understand the relationship between radio astrophysical processes and their imprint at other wavelengths for a deeper insight. In optical and near-IR wavelengths, IUCAA has already installed a large 2-m class optical telescope at Giravali observatory near Pune which is undergoing upgradation and repairs and it would soon become operational. This unique telescope is mainly available for training students and researchers from the university sector.

To fulfil its obligations to Indian Universities, the IUCAA has made substantial efforts through collaborative programmes with the neighbouring National Center for Radio Astrophysics (NCRA/TIFR). Recently the world's largest low-frequency radio telescope built by NCRA/TIFR - the GMRT - has become fully operational. Several IUCAA faculty/ student/post-doc members are actively using the GMRT for their research and a couple of university associates are also involved in these projects. However, it has been noted both by IUCAA and NCRA that although such an advanced facility is available to all, the enthusiasm for using the GMRT is far less than expected. It is not that there are not enough good people capable of using GMRT; we do get enthusiastic questions and enquiries from many bright students wanting to know what work they can do or how they can build small radio-telescopes in their educational institutes for their project work. Clearly, it is the lack of information and proper training in radio astronomy that keeps the bright talents away from advanced observational work. *As outlined above, the urgent need is to identify the young, enthusiastic students from the vast pool of talent available in universities and then to motivate and train them for undertaking radio astronomy research.* This is indeed a very challenging goal. In my view, a dedicated facility containing basic infrastructure, such as the proposed IUCAA radio-physics facility, is likely to be a step in the right direction. In order to realize this goal, we intend to have a collaborative venture with NCRA/TIFR in order to benefit from the considerable amount of technical and scientific know-how already available there. In return, IUCAA would motivate bright young students through an innovative approach that would appeal to their imagination and encourage them to take up research topics in radio and other branches of astronomy.

The IUCAA has very good computer and library facilities specific to radio astronomy work. However, we felt the need for the creation of a small scale but well focussed Radio Astronomy infrastructure in IUCAA itself, aimed at introducing the students from Indian universities to the basic concepts using the dedicated radio telescopes, along with experiments and observations. The proposed plan would also allow them the freedom to further develop their own ideas through interesting radio-physics experiments - both within the controlled environment of a laboratory and also by doing actual astronomy sky experiments. With the plan presented here this indeed would become a reality. Not only the student would be able to make actual astronomical observations of many celestial bodies such as the Sun, planets, the Milky Way, Galactic center, supernova remnants and active radio galaxies, but he/she can also perform electromagnetic experiments within the laboratory, analyse the data on powerful computers for scientific results and can also built actual electronic circuits and antennas for further explorations in their chosen areas of interest. I sincerely believe that once students undergo a good training using the facilities provided by IUCAA, some of them surely would get inspired and be motivated enough to take up radio astronomy as their career option in near future.

LIGO-India: Another area that the Radio Physics Lab will contribute is in establishing a unique training facility for Gravitational Wave Physics. The major success of LIGO (Laser Interferometer Gravitational Wave Observatory) in USA and Europe (VIRGO) in detecting gravitational waves from black hole and neutron star mergers have electrified the world. With the upcoming LIGO- India facility being built in India (approved by Indian Government), in which IUCAA is a big stakeholder and taking a leading role as a nodal center for human resource development, training and data management, there is immediate requirement of man-power development via building training and educational facilities in this field. Since a gravitational wave detector is a highly sophisticated and relatively unknown instrument, we need to develop a pool of skilled students (both science and engineering) teachers and scientists in India for LIGO-India who will be carrying out the construction and perform the scientific observations using this extraordinary cutting-edge science facility coming up in near future. **A cutting edge project like this in India can serve as a local focus to interest and inspire students and young scientists. The LIGO-India project involves high technology instrumentation and its dramatic scale will spur interest and provide motivation to young students for choosing experimental physics and engineering physics as career options. The 'multi-spectral' reach to physics will attract a large number of talented and motivated young researchers and students to the program.**

The Basic Goals:

- To train motivated Bachelor/Masters and research level science and engineering students nationwide in the use of radio telescopes and introduce them to the specialized concepts of radio astronomy.
- To develop and promote both technical and cooperative project skills among students using the radio telescope medium as a vehicle.
- To motivate and prepare exceptionally talented students for advanced level research with the GMRT and other world class telescopes.
- To use radio astronomy, which is an interdisciplinary field, to study and understand concepts in physics, chemistry, biology, engineering and computer science.
- To set up basic laboratory and telescope facilities to enable interested students perform instructive experiments in electromagnetism, wave propagation, electro-optics, antenna engineering, and in other related subjects.
- To hold workshops, training schools and data analysis events locally and at other Universities.
- To appeal to students with broad range of talent, experience and commitment and training young scientists that will enrich science and society as a whole.

Overall, these objectives make the RPL an exceptional and unique facility in India for advancing astronomy education in general and Radio Astronomy education in particular.

The general approach is to transfer knowledge of existing well developed experiments to colleges and universities, while developing more sophisticated experiments to be used in RPL programs, thereby ensuring a gradual dissemination of information to colleges and improvement of the quality of our own programs.

Radio Physics Lab (RPL) is active in experimental areas in astronomy, physics and engineering. Our aim has been to design and demonstrate important experiments related to astronomy in an innovative way either for scientific purpose or for educating students, enthusiasts and general public. The areas being pursued range from cosmic ray particle detection to free space communication using LASER. Apart from this, RPL is also active in public outreach. Many public lectures and demonstrations are organized for university students and enthusiasts. An annual Radio Astronomy Winter School is conducted for undergraduate students to introduce them to basics in the field of radio astronomy. RPL has been very active for over past 10 years. RPL has conducted Radio Astronomy Winter School continuously for the 10 years, where over 400 bright students have been selected and provided training and motivation. Happily, nearly 50 of them have gone on to join as research scholars in astronomy and astrophysics in India and abroad. Apart from this, more than 40 MSc, ME, BE/BTech students have successfully completed their projects at RPL under the enthusiastic guidance of Joydeep Bagchi, who had visualized and set up the RPL in collaboration with National Centre for Radio Astrophysics (NCRA) in IUCAA.

2 Experiments

(i) Noise Fundamentals

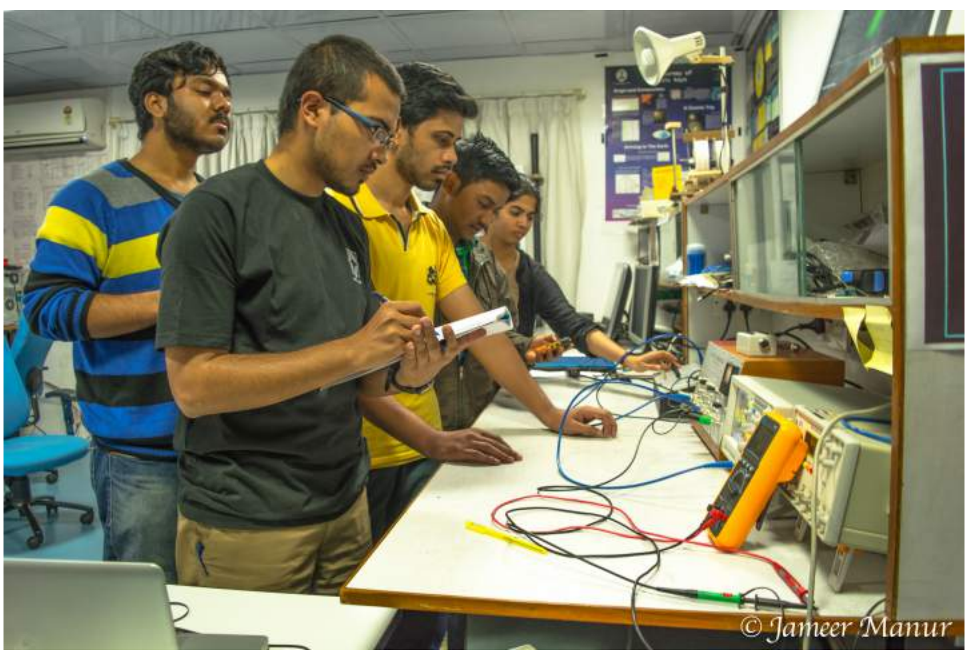


Figure 1: Students performing the Noise Fundamentals experiment in RPL

The Noise fundamental experiment is one of the most important tools to study the noise in any electronic system and instrument. The Jhonson-Nyquist noise present in all electronic signals limits the sensitivity of measurements, which is most important for radio astronomy. The thermal noise generated by a resistor at room temperature or the shot noise in diodes and transistors can also be studied by using this experiment. One may see noise on the display of an oscilloscope and also play with it by changing parameter of noise like resistivity, temperature, bandwidth and other parameters. The most important constants like the Boltzmann constant, Planck Constant, and charge of electron can be measured using this experiment.

(ii) Magnetic Torque on a Spinning Magnetic Dipole

Magnetic Torque offers students an opportunity not only to make quantitative measurements involving electromagnetism, torque and simple harmonic motion but also to study, quantitatively, the phenomenon of spin precession. This instrument is equally at home in an BSc Lab, or an MSc physics laboratory and, as an analog for Nuclear Magnetic Resonance, in either a Modern Physics or Advanced Senior Laboratory. Although every introductory physics textbook discusses the interactions of a current loop with magnetic fields, Magnetic Torque and Magnetic Force are the only teaching apparatus capable of demonstrating such interactions. Using small magnetized disks that act like magnetic dipoles, students measure phenomena that result from magnetic torque or magnetic force. Students can determine the dipole moment of the disk in a variety of ways using fundamental EM and mechanics principles. In addition, this experiment can be used to demonstrate basic principles of magnetic resonance including a Pulsed NMR spin-flip and spin flip transition in Hydrogen atom resulting in emission of 21cm Hygrogen line, which is at the corner stone of radio astronomy observations.

Figure 2: Magnetic Torque and Spin-flip Experiment

(iii) Faraday Rotation Experiment Used for Optical Communication

The polarization of light is quite frequently observed in nature and with other basic properties like amplitude, frequency and phase of an Electromagnetic (EM) wave, it constitutes one of the most fundamental quantities, which completely describes it. In Physics and Optics, the polarization of light is studied through "Faraday Rotation Effect" using optical materials like glass, crystals, chemicals etc. Its analogue in radio waves is transmission of polarized wave in ferrites materials and through magneto-ionic plasma. The idea of the experiment (built in our lab) is to study the potential of fast polarization modulation for data communication, which is not much explored yet. The study of polarization of light through Faraday Rotation Effect, rotation of plane of polarized wave when traveling through crystals (Terbium Galium Garnet or TGG) placed inside solenoid and subjected to a strong axial magnetic field can be a novel approach in space communication. Experiment shows conversion of polarization-modulated light into intensity-modulated light, and phase shifted demodulated wave form w.r.t. Input modulating signal. Insertion of properly matched and tuned circuit before coil and amplifier after demodulation leads to better reception of signal.

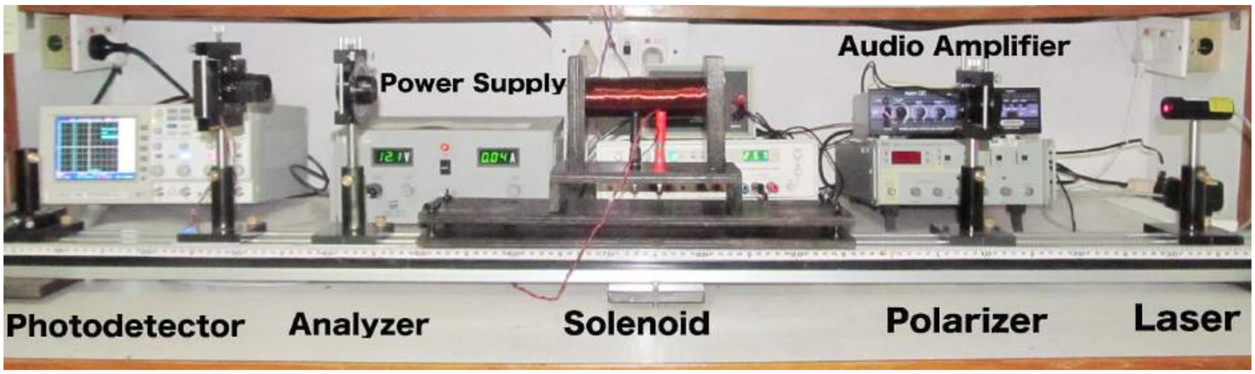


Figure 3: Faraday Rotation Experiment

The laser will act as a carrier and the audio is given as a modulating signal to the solenoid, the audio signal modulated in the presence of Faraday material (TGG crystal rod) and demodulated by converting polarization modulation into intensity modulation at the photo detector. The power requirement is very low as compare to the existing analog modulation techniques. The system is successfully working over the audio bandwidth.

(iv) A Home Made Horn Antenna for 21 cm Hydrogen Line Observations and for Teaching-Learning Applications

The 21 cm radio frequency line is a spectral line emitted by atomic hydrogen. Since hydrogen is the most abundant element in the universe, this makes the hydrogen line a very important spectral line in radio astronomy. A horn antenna was designed for detecting this line from our galaxy. A major limitation of radio astronomy is noise, either man-made or naturally occurring. Hence we require new techniques to reduce noise from our detector. The horn antenna is a high performance, high gain and low noise antenna specially designed for detection of 21 cm hydrogen line. The antenna is able to pick up radiation from the hydrogen clouds in our galaxy while suppressing terrestrial interferences due to the low side lobes of the antenna. The antenna is easy to handle and is superior to a parabolic dish in terms of noise performance.

The horn has enabled us to study hydrogen line profiles from the galaxy. The spiral structure of the galaxy can be estimated. It has also made it possible to estimate the rotation curve of the galaxy.

The antenna is a dual mode conical horn antenna. It was simulated using CAD FEKO electromagnetic design simulation.

It is easy to construct as compared to other antennas with similar noise performance. Construction of the antenna was done in NCRA workshop by engineering students.

Software Defined Radio (SDR) receivers were used with great success with this antenna. SDR is a new advancement in radio technology. The limitation of the conventional radios is inability to configure

Figure 4: 21cm Hydrogen Line Horn Antenna experiment demonstration for students

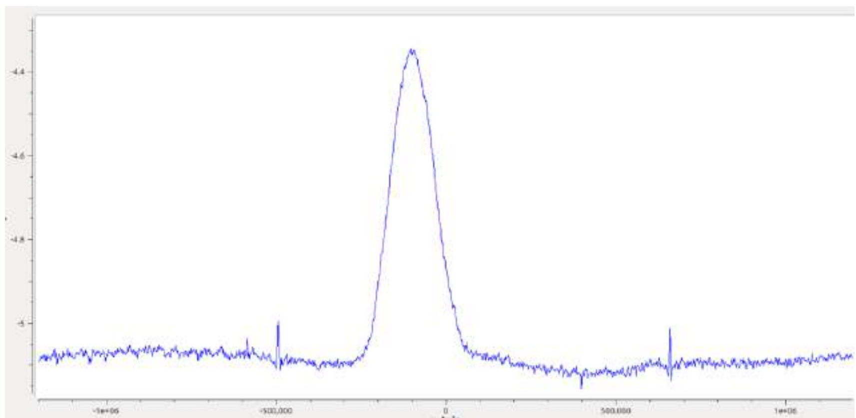


Figure 5: Hydrogen line detected from Milky-Way using Software Defined Radio (SDR) Receiver.

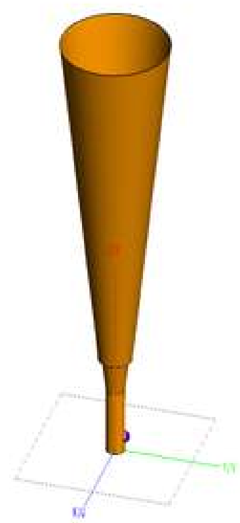
the hardware. SDR can be configured to serve any purpose of the user. Such a receiver was implemented successfully for detection of hydrogen line. Important techniques like Dicke switching were implemented with SDR. This has made the telescope low cost and hence accessible to amateur radio enthusiasts. The antenna has proven to be very reliable. It will be used in MSc practical in radio astronomy as well as coming Radio Astronomy Winter Schools. The antenna has also been used to demonstrate principles of radio astronomy to amateurs as well as for public outreach.

(v) A 3 Meter Dish Antenna built for Radio Astronomy Teaching

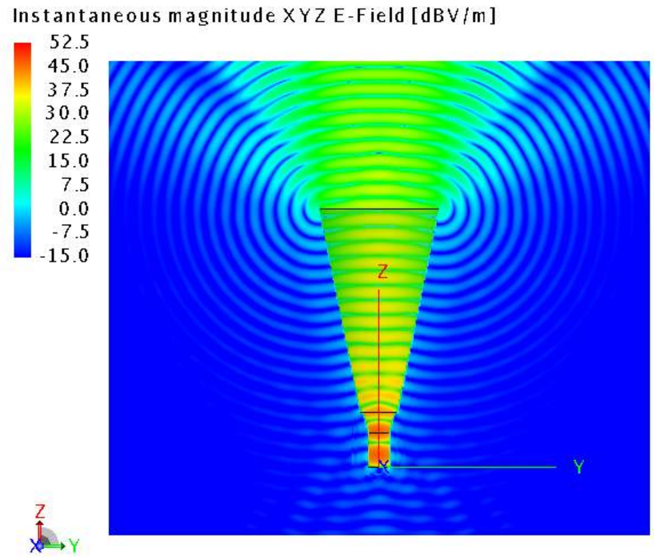
The newly installed 3 meter dish antenna at Radio Physics Lab is being used for experiments in radio astronomy. Experiments like detection of 21 cm hydrogen line and observation of solar activities are regularly carried out with this antenna. It has control system which enables one to point and track celestial objects. The antenna is extensively used in many education activities carried out at RPL. The 3 meter dish provides a large collecting area and a sufficeint resolution for galactic 21cm Hydrogen line work.

(vi) Cosmic Ray Muon Detector(CRMD: Catching the High Energy Messengers of Distant Universe

The cosmic ray muon detector (CRMD) is a particle detector which can detect and observe by products of cosmic ray particles which were created and accelerated by very violent mechanisms in the Universe. The



(a) Simulated horn in Computer



(b) Electric field in horn antenna

(a) Flare construction

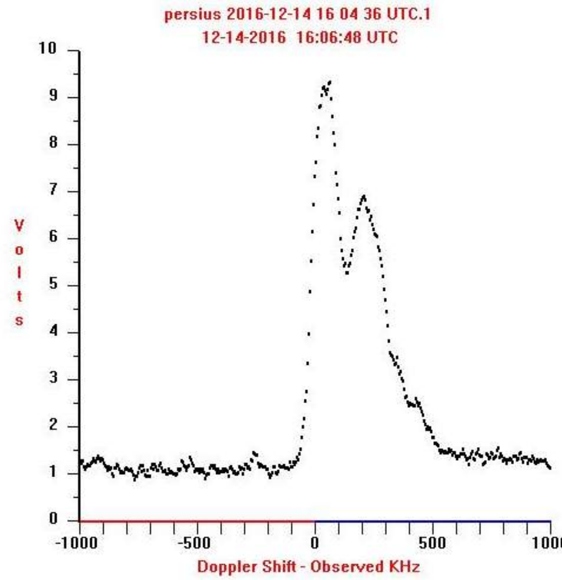
(b) Waveguide construction

CRMD at IUCAA Radio physics lab is one of its kind and was built in 2011 by bachelor level students. It is the only detector of its type running in entire ASIA. The material to build the detector was procured from FERMILAB in USA. This detector is used to take readings of muon flux and to determine the mean muon lifetime, which is extremely short, of the order of 2.2 micro seconds. This requires accurate high-speed timing of the Muon events with a GPS disciplined laboratory clock of high accuracy. It is quite an interesting experiment as it enables students to not only study high energy astroparticle physics but also learn a lot about the standard model of nuclear and particle physics in general. Mean muon lifetime also serves as a test for Einstein's special theory of relativity. Since 2012 the detector has been used for experiments in Pune University M.Sc Astronomy & Astrophysics special courses as well during the Radio astronomy winter school. We plan to install more such detectors in near future.

(vii) Affordable Small Radio Telescope

ASRT is a simple experimental set-up aimed at educating radio astronomy to students and general public in the easiest possible way. All the materials to make ASRT are easily available in electronics market at

(a) 3meter dish antenna being erected on IUCAA roof top



(b) Hydrogen line detected with the 3mt dish

cheaper price.

This method of hands on astronomy allows us to observe the celestial objects like sun easily. It is an important experiment in educating fundamentals of radio astronomy to students and enthusiasts.

(viii) Molecular Raman Spectroscopy

In RPL we have a CCD Based Laser Raman Spectrometer apparatus available. Raman spectrometer is designed for recording Raman spectra of both solids and liquid samples. Raman spectroscopy (or Raman Effect) discovered by C.V. Raman in 1928 is a pioneering spectroscopy technique. It is based on Raman Effect, i.e., wavelength of a small fraction of scattered radiation is different from wavelength of monochromatic incident radiation. It is based on the inelastic scattering of incident radiation through its interaction with rotating-vibrating molecules. It probes the molecular rotational vibrational energy levels. This will produce a different range of frequencies, namely Stokes and anti Stokes lines which have lower and higher wavelengths than the primary incident radiation, which is strongly elastic scattered along the central Rayleigh Scattered line. Rayleigh and Raman scattering can be explained both classically and using quantum mechanically. It has proved extremely difficult to observe Raman Scattered lines in Astrophysical settings, but it is possible in near future with more advanced instruments and bigger telescopes.

(ix) Lock-in Amplifier/Signal Processing

The Signal Processor / Lock-In Amplifer was developed to help students understand the process of extracting weak signals that are embedded in a noisy environment. It allows them to experiment with a variety of "electronic strategies," as well as to become familiar with some of the uses of phase-sensitive detection.

(a) Cosmic Ray Muon Detector construction

(b) CRMD demonstration for students

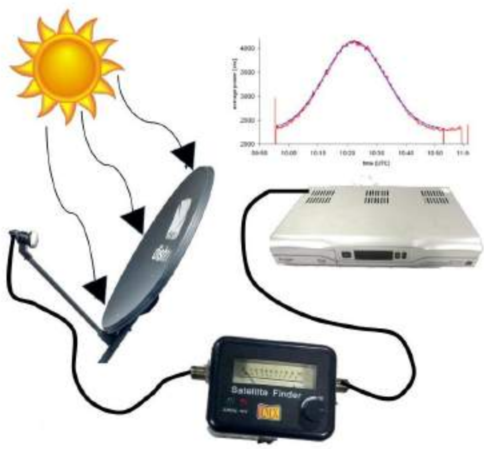


Figure 10: Extremely Simple! An Affordable Small Radio Telescope

The experimental set up is the antithesis of the modern commercial research lock-in amplifiers. These elegant devices are essentially "black boxes" to the user (student), since they automatically adjust almost all of their parameters to achieve optimum signal-to-noise. They are designed for ease of operation and to achieve optimal signal recovery, but not to make what we call the "electronic strategies" transparent to the user. In short, wonderful as they are, they were obviously not designed for teaching.

3 Some Key Projects Under Development

Radio Physics Lab aims at developing educational and semi-research projects. These projects help in understanding the fundamentals of various aspects of instrumentation in physics. A few projects that are under development are described below.

(a) Radio Interferometry

Radio interferometry has become a fundamental technique in radio astronomy. Radio interferometers are not readily available for students due to the complexity and cost of such an instruments. We are developing a low cost radio interferometer which is easy to assemble and operate. This instrument will be used to demonstrate concepts of radio interferometry. It is essential that the receiver used is a coherent receiver.

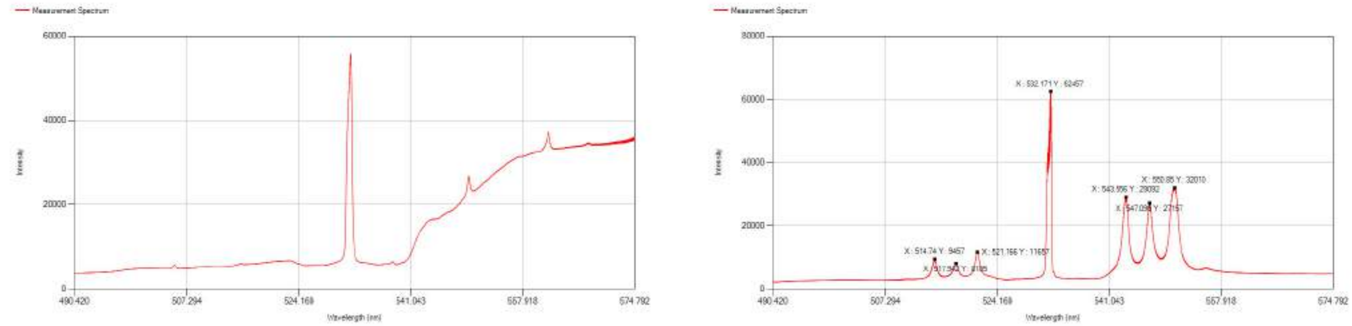


Figure 11: Molecular Raman Scattering lines recorded from Benzene (left) and Titanium Oxide (right) showing Rayleigh line in the centre and Raman-Stokes and Raman anti-Stokes lines flanking it.

Figure 12: The Lock-in Ampplifier/Signal Processing Experiment

Multiple receivers can be synchronised using a single master clock. The output samples will be correlated on a computer to produces fringes. Initial design will consist of 2 elements which will later be upgraded to include multiple elements.

(b) Phased Array Antenna Concept

Low frequency radio astronomy requires large antennas which are impractical to construct. Hence low frequency radio astronomy is dominated by phased array.

A phased array is a combination of multiple antennas phased together to form a single antenna. It allows control over entire aperture of the array which in turn allows controlling the far field characteristics. It is possible to form multiple beams to scan multiple sources. Beam steering can be done by phasing the antennas appropriately. Coherent receivers are required for building a phased array. The proposed phased array will be used to demonstrate the above mentioned features of a phased array.

(d) A Pulsar Radio Telescope

Pulsars are fast rotating neutron stars which produce periodic radio pulses. These are very faint sources of radio waves which are of great astrophysical importance. It is possible to detect a few of the strongest

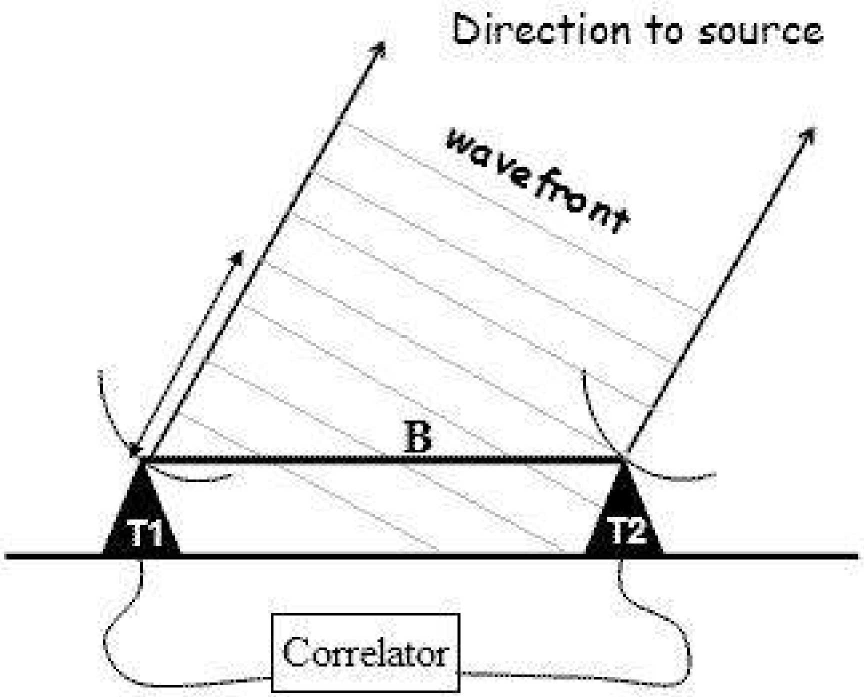


Figure 13: 2 element radio interferometer

pulsars with a small radio telescope with simple components like an LNA, filter and a radio receiver. Ongoing work focusses on simple antenna design which will allow detection the available tools.

(e) A Low-cost Educational Radio Telescope for Schools/Colleges

Radio astronomy is a fairly technical field and requires knowledge about radio instrumentation and signal processing. The tools required for experimenting with radio astronomy are not readily available for students at an affordable price. The aim of this project is to design a simple radio telescope which will be very easy to make and operate. It will be an educational kit which students can assemble and observe and study the radio sky. All the components will be low cost and easily available in market.

(f) Plan for a LIGO-India Related University Level Experimental Facilities

Interferometry/Optics educational/training experiments for the LIGO-India

It is proposed to build a few advanced optical interferometer in the our lab like the Michelson, Sagnac, Mach-Zender and other new type of interferometers, to teach the basic concepts and clarify the principles of optical interferometry and its fundamental limitations. Advanced LIGO-India project, which is a giant 4-km scale, ultra sensitive optical interferometer, is one of the most ambitious project ever taken by Indian scientist and engineers in setting up a cutting-edge gravitational wave detector laboratory. LIGO is one of the most complex and ambitious experiments ever done in science to detect extremely weak gravitational waves. LIGO is a very sensitive and challenging instrument to build and operate hence it involves novel techniques to reduce background noise and detect the extremely weak signals. Since students in our science and engineering colleges are not exposed to such techniques due to lack of such facilities

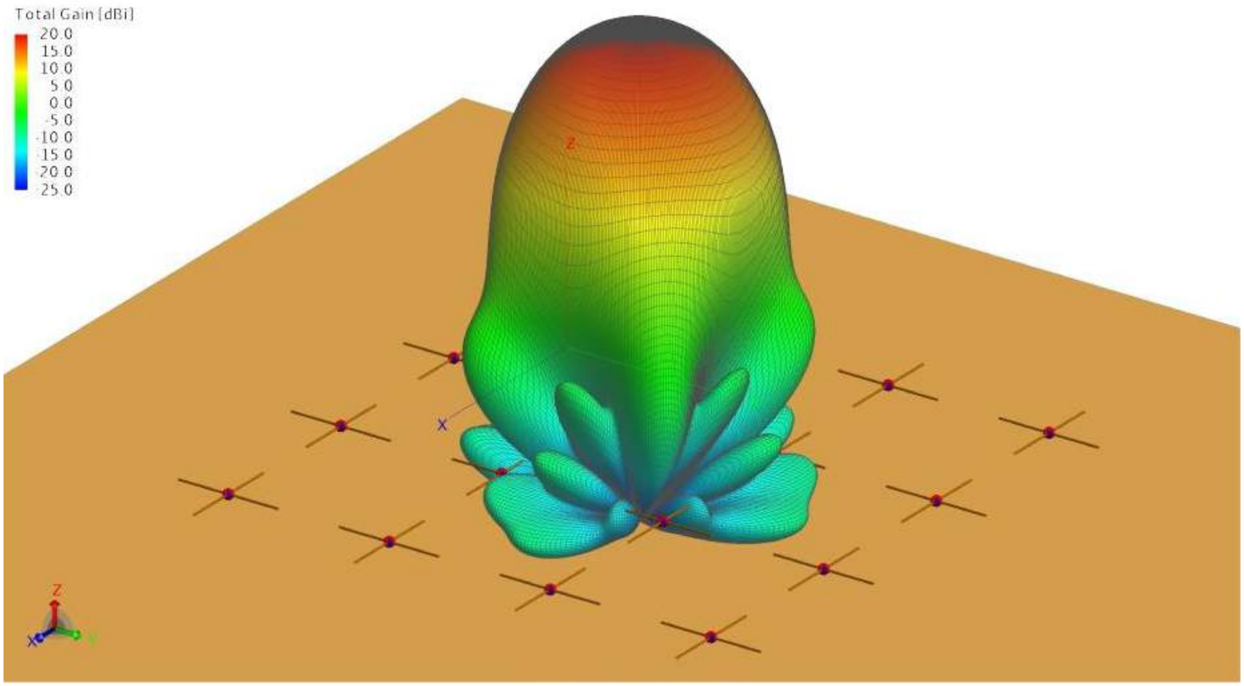


Figure 14: A 4 by 4 dipole phased array with radiation pattern

accessible to them, it is proposed that IUCAA provides a platform to educate students in the field of ultra precise optical interferometry and gravitational wave detection and the challenges one faces in detection of gravitational waves. Along with conventional methods of teaching and experimentation we will also encourage and guide students to think independently out-of-box and implement some new and innovative techniques, which can be tested using the RPL facility and possibly some can be implemented in future for more sensitive detectors like advanced LIGO.

4 Educational & Public Outreach Programs

National Science Day at IUCAA

Science day (28th February) is an important event in IUCAA and other institutes across country. It is the time of the year when IUCAA is open to general public all day along and all the staff of IUCAA is involved in activities related to public outreach. Our Radio Physics Lab has been demonstrating and explaining various astronomy related experiments over the years. This year (2017) we presented the **horn antenna** designed for detection of atomic hydrogen in our galaxy at 21 cm wavelength. Interestingly, a similar horn antenna (but larger!) was used to discover the Cosmic microwave background radiation by Penzias and Wilson back in in 1960s from Bell Telephone Laboratory. The antenna came in handy to explain the radio telescopes work to the public. We also demonstrated the recently installed 3 meter dish antenna at RPL. A live demonstration of hydrogen line detection was presented.

The Cosmic Ray Muon Detector was also on display showing live detection of Muon particles created by interaction of cosmic rays in upper atmosphere.

We presented a simple and low cost radio telescope using a Direct to Home (DTH) dish TV antenna. Posters on history of radio astronomy, activities of Radio Physics Lab and a video display of upcoming radio telescopes was also presented.

Figure 15: Experiments demonstrated on National Science Day (2017) at IUCAA

Pune University Masters (MSc) Program

Pune University Masters (MSc) students perform astronomy experiments as a part of the curriculum. This requires a specialized lab and telescopes (radio and optical). The students have to appear for practical exam to complete their course. The majority of these experiments are conducted every year in Radio Physics Lab. Every year 3 to 4 experiments are performed by the students under RPL. Some of the existing experiments are Antenna radiation pattern measurement, Detection of 21 cm hydrogen line, Faraday rotation, Noise fundamentals and Muon Physics experiment. These have been a great success and will continue to be so with acquiring/building new experiments. Some of these will be:

- Gamma and X-Ray Spectroscopy
- Laser Raman Spectroscopy, IR Rotational, Vibrational Molecular Spectroscopy
- Ultra sensitive optical interferometry as training ground for LIGO-India
- Gravity experiments

Some of the existing experiments are Antenna radiation pattern measurement, Detection of 21 cm hydrogen line, Faraday rotation, Noise fundamentals and Muon Physics experiment.

Annual Radio Astronomy Winter School

Radio Astronomy Winter School (RAWS) has been organized every year, jointly by IUCAA and NCRA, since 2008. The school is largely meant for undergraduate students in science, pursuing B.Sc. (Physics / Electronics /Astronomy), and Engineering (B.E./ B.Tech.). Bright and highly motivated high school/junior college students involved in amateur Astronomy, have been also encouraged to apply. Through lectures and hands-on Radio Astronomy experiments, the school exposes the participants to Astronomy in general, and Radio Astronomy in particular.

The subject matter ranged from Radio Telescopes, Astronomical Coordinate Systems, Great Discoveries, the Sun, Milky-way, Pulsars, Dark-matter, Radio Galaxies, Astrobiology, Search for Extraterrestrial Intelligence (SETI) - to Quasars, Cosmic Microwave Radiation, Gravitational Waves, Cosmology and Big-bang theory. The school has been immensely popular, and so far nine such schools have been organized since 2008. The experiments are conducted by Radio Physics Lab (RPL). The hands-on experiments included (1) Observations of Sun with the 4 m and 3 m telescope to determine the antenna power pattern,

(2) Observations of HI 21-cm line to neutral hydrogen from the Galaxy, and (3) Measuring power patterns of various types of antennas using the antenna trainer kit (4) Understanding Noise fundamentals (5) Cosmic ray Muon detector. These experiments are designed to educate the students about techniques and instrumentation used in radio astronomy and other related fields. The programme exposed the young students to the excitement of observations with small and large telescopes. Throughout the school, the students showed tremendous enthusiasm and curiosity for learning new subjects.

Figure 16: Students from Radio Astronomy Winter School (2016) testing the Affordable Small Radio Telescope (ASRT) they have built themselves hands-on.

Pulsar Observatory for Students (POS)

This is another major university educational program conducted by RPL which uses the giant 530 mt x 30 mt Ooty Radio Telescope of TIFR. Pulsar Observatory for Students(POS) is a program conducted at the Radio Astronomy Center Ooty, and uses the large Ooty Radio Telescope in pulsar observation, search and data analysis training programs for college and university students (Fig. 18). It is a continuation of the Radio Astronomy Winter School held in IUCAA or NCRA every year. POS allows students to use a professional radio telescope for pulsar observation and hands-on data analysis, and thus get a real feel for importance of pulsars for Astronomy and Astrophysics and General Relativity research. Moreover, the students also participate in search for new pulsars using the existing data.

Refresher Course and Vacation Students' Programme Hands-on Sessions

Refresher Course and The Vacation Students' Programme are regularly conducted programmes at IUCAA for teachers and students. RPL conducts hands-on session as a part of these courses. The session is divided into two parts, observation session and data analysis session. 21cm Hydrogen line observations are carried out in the observation session. The data is analysed in the data analysis session. Analysis involves baseline correction, calibration and curve fitting.

Figure 17: Students from Radio Astronomy Winter School (RAWSC-2016) visiting the GMRT facility

Workshops on Astronomy-Themed Experiments for Educators

Recently the RPL in association with the Teaching-Learning Centre (TLC) of IUCAA has started this new training program for University teachers who are interested in introducing Astronomy themed experiments in their college/university course curriculum. Such know-how is not available generally to teachers and thus it is one of the goals of RPL and TLC.

Objectives of the workshop: Astronomy is rarely taught in B.Sc. and M.Sc. Physics courses in India. This workshop is aimed at identifying and developing portions of standard BSc and MSc syllabi that are amenable to design astronomy themed experiments e.g. optics, EM wave theory, Radio Astronomy etc. These experiments should be preferably chosen keeping in mind cost and easy availability of materials as well as level of Physics rigour necessary for it to be passed by Board of Studies of Physics Departments. Experiments should be astronomy focused, for departments both with and without available small sized telescopes. We hope to come up with a major plan to implement these experiments in selected colleges on a trial basis, in liaison with UGC (University Grants Commission) for formal syllabus incorporation when successful. The Workshop will not be made up of Classroom-like lectures. Rather, there will be brainstorming sessions where people present, discuss and document experiments to build the repository, that we plan as the main outcome of this Workshop.

Two such workshops were recently conducted:

- (1) Workshop on Radio Observations Using 21cm Hydrogen line (1420 MHz) Horn Antenna (March 09 - 11, 2019, IUCAA, Pune)
- (2) Workshop on Night Sky Photometer Fabrication (March 12 - 16, 2019, IUCAA, Pune)

Figure 18: 530 mt x 30 mt Ooty Radio Telescope. This is used for Pulsar Observatory for Students (POS) program of RPL.

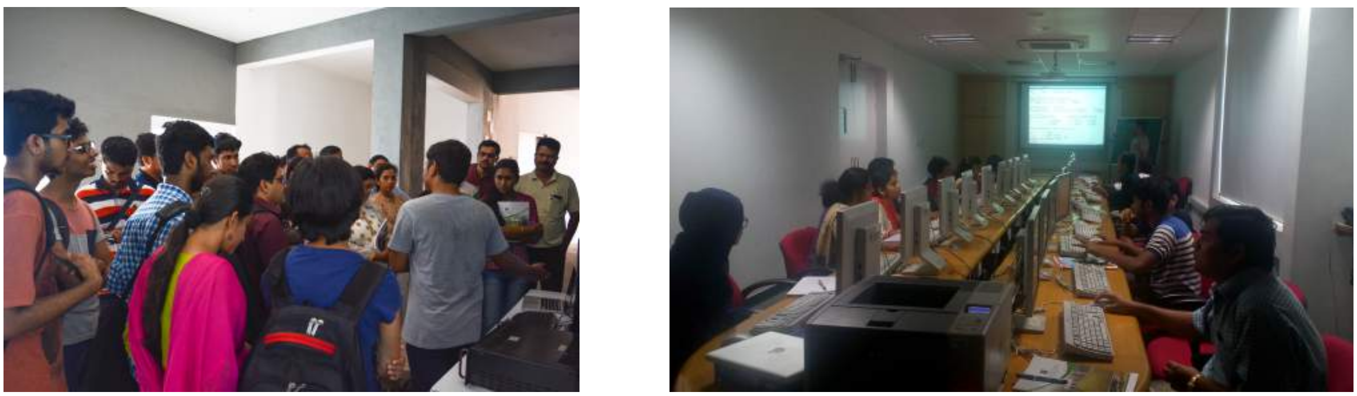


Figure 19: Hands-on session for Refresher Course and VSP

Impact of Radio Physics Lab: Students inspired by various RPL programs

- Various highly innovative programs and projects organised by RPL have been very successful in educating and inspiring college and University students from across the country. Over 400 students have participated in Radio Astronomy Winter Schools and Pulsar Observatory for Students programs so far. Many of them select Astronomy and Astrophysics as their future career.

- **We point out that over 40 students are pursuing PhD in various fields out of which, over 20 students are pursuing PhD in astronomy in India (including IUCAA and NCRA/TIFR) and abroad (notably, Leiden University, several Max Planck Institutes, Stanford University etc.). This is a direct indicator of positive impact of RPL in University education field (see Table 1 of some students guided by me).**

- Other than the above mentioned programs RPL has opened its doors to students aspiring to work on projects related to astronomy, communication and physics. RPL builds a strong foundation for students in pursuing career in various fields. Over the years many students have completed their

Figure 20: Workshops on Astronomy-Themed Experiments for Educators (21 cm Horn Antenna Making)

projects under RPL. The impact made by RPL is reflected in the highly successful careers of its students.

Present PhD Students (Astrophysics and Engineering Branch)

- Pratik Dabhade (IUCAA) (PhD student, Leiden Observatory, Leiden University, PhD thesis to be submitted)

- Shishir Sankhyayan, IISER, Pune (PhD thesis submitted)

- Biju K. George, Newman College, Thodupuzha (M.G. University, PhD Obtained)

- Mousumi Mahato, IUCAA (PhD work Ongoing)

- Jameer Manur, IUCAA (PhD work Ongoing)

5 Public Talks

RPL gives special attention to public outreach programs and is open to enthusiastic individuals for any help/advice they require regarding astronomy related activity. RPL members frequently deliver informative lectures related to astronomy and instrumentation in astronomy in various schools and colleges to make students aware of the career opportunities in astronomy and major discoveries. They are also educated and informed with the latest developments of this field.

Following are some of the talks given by RPL members in various colleges/organizations very recently:

Talks by **Jameer Manur**

– **Application of Engineering in Astronomy**, D. Y. Patil College of Engineering, Pune.
– **Introduction to Observational Astronomy**, Army Institute of Technology, Pune.
– **Introduction to Astronomy Tools**, Vishwakarma Institute of Technology, Pune.
– **Need of Telescopes**, Jnana Prabodhini, Pune

Table 1: **Mentoring of Masters (M.Sc.) & Engineering (B.Tech/M.Tech.) Students**

A Representative List of Students Mentored by me at the Radio Physics Laboratory

Student	College/University	Year	PhD Complete/Registered
Humeshkar N. B	Loyola College, Chennai	2000	PhD, Wayne State University, USA
N. Kirubanand	Gandhigram Rural Institute	2000	PhD, Gandhigram Rural Institute, TN
Vaishnavi T.S.	The Madura College, Madurai	2004	Data Not Available
Nikhil Pawar	Univ. of Pune	2005	M.Phil., University of Cambridge
Vaibhav Prakash	Pune University, Space Sciences	2005	PhD, JawaharLal University, N. Delhi
Surajit Paul	Pune University, Dept. of Physics	2005	PhD, Wuerzburg University, Germany
Sukilima Guha Niyogi	Pune University, Dept. of Physics	2005	PhD, Univ. Missouri-Columbia, USA
Viral Parekh	Fergusson College, Pune	2006	PhD, Univ of Cape Town, SA
Siddharth Hegde	Fergusson College, Pune	2006	PhD, Max Planck Institute, Heidelberg, PostDoc Stanford
Aditya Rotti	Pune University, Dept. of Physics	2008	PhD, IUCAA, Pune
Ali Dariush	TWAS Fellow, Iran	2008	PhD, The University of Birmingham
Samir Dhurde	Pune University, Dept. of Physics	2008	MSc, Joined IUCAA in Public Outreach Dept.
Jaydeep Belapure	Fergusson College, Pune	2009	PhD, Max Planck Institute, Garching
Shishir Shankyayn	Pune University, Dept. of Physics	2010	PhD, IISER, Pune
Biju Koonammakkil George	Newman College, Kerala	2013	PhD, M.G. University, Kerala
Ashmeet Singh	Indian Institute of Tech. Roorkee	2013	PhD, California Inst. of Tech., USA
Mohini Nagardeolekar	VIT, Pune	2014	M.Tech. (Joined Industry)
Partik Dabhade	Pune University, Dept. of Physics	2014	PhD, IUCAA & Leiden University, Netherlands
Madhuri Gaikwad	Pune University, Dept. of Physics	2015	PhD, Max Planck Institute, Bonn
Jameer Manur	VIIT, Pune	2015	M.Tech, (Joined IUCAA, Research Trainee)
Ashish Mhaske	K.K. Wagh Eng. College, Nashik	2015	B.tech., Joined LIGO-India Project at IUCAA
Suraj Dhiwar	Pune University, Dept. of Physics	2015	J. Res. Fellow, Dayanand Science College, Latur
Prajwal Padmanabh	BITS, Pilani (Goa Campus)	2016	PhD, Max Planck Institute, Bonn

Talks given by **Ashish Mhaske**

- **Radio Astronomy**, K. K. Wagh College of Engineering, Nashik.
- **Antenna Fundamentals**, K. K. Wagh College of Engineering, Nashik.
- **Introduction to Radio Astronomy**, Vishwakarma Institute of Technology, Pune

Sample of Talks given by **Joydeep Bagchi**

- **'Saraswati': A Giant Supercluster of Galaxies in Distant Universe**, Public Talk, Vishwakarma Institute of Technology, Pune.
- **'Saraswati': A Possible Largest Structure in the Universe**, Public Talk at IUCAA Chandrasekhar Auditorium, Pune
- **A Giant Supercluster called 'Saraswati' discovered in India**, Public Talk, Indian Space Research Organization, Ahmedabad
- **Relativistic Jets from Super Massive Black Holes**, IISER Tirupati

We also have initiated the process of making videos for general public which will describe key radio astronomy concepts in lucid manner and documenting the working of big international facilities run by India like the GMRT (which is one the world's largest radio telescope). All these material will be freely available on our RPL website and YouTube channel. RPL has also launched pages on the social media like Facebook and YouTube for propagation of radio astronomy in India.

Figure 21: Public Lecture at IUCAA by Joydeep Bagchi (Left) and by Jameer Manur at VIT Pune (Right).

Awards and Publications

Astronomical Society of India

Astronomical Society of India (ASI) Meeting is an annual event which provides a platform for presenting and propagating research in the field of astronomy. This year the ASI meeting was held at Jaipur in March. RPL presented 2 posters i.e. 1) Hands on Approach to Radio Astronomy 2)

Figure 22: Public Lectures at Engineering College in Nashik by Ashish Mhaske.

Dual Mode Horn Antenna for Galactic 21 cm Hydrogen Line Observations. **The Dual Mode Horn Antenna poster won the best poster award in instrumentation category.** We got a good response regarding the activities carried out at RPL.

Paper Presentation and Competition

We have developed an innovative technique for communication using Faraday Rotation effect in lasers. This work has been published in a conference and has won first prize in competition organised by IEEE.
The Conference paper titled **"Polarization Modulation for Communication"** was presented at the **Second International Conference on Information Engineering, Management and Security** held at IIT Madras campus in August.

IEEE Pune chapter to all M.E/M.Tech from Pune University organized the project Competition. **Jameer Manur stood First in the IEEE COMSOC PG-Project Competition 2015.**

Distinguished Visitors to RPL

The lab has been visited several times by eminent astronomers and educators, over the years, from all parts of the world. We take special pride in inviting them to RPL, discuss various research and educational programs and benefit from their advice. Some of them have also given talks for the students and teachers.

The work done in the lab was very much appreciated by our visitors. We will continue to invite distinguished personalities from all walks of life to the lab.

Notable visitors to RPL in recent years have been:

Prof. Jocelyn Bell Burnell, Univ. of Oxford, world renowned radio astronomer and discoverer of

Pulsars

Prof. Luis Ho, Director and University Chair Professor, Kavli Institute for Astronomy and Astrophysics Peking University

Prof. Helen Mason, University of Cambridge

Prof. Nick Kaiser, University of Hawaii

Prof. Changbom Park, Korea Institute for Advanced Study (KIAS), Korea

Prof. Tomaso Belloni, INAF, Osservatorio Astronomico di Brera

(a) Prof. Jocelyn Bell Burnell in RPL with RPL team

(b) Prof. Luis Ho in RPL with team members

(a) Prof. Helen Mason with students in RPL

(b) Prof. Luis Ho in RPL, signing the visitors book

Online Resources

Radio Physics Lab IUCAA Website: http://www.iucaa.in/IUCAA-RPL.html

Facebook Page: Radio Physics Lab, IUCAA
https://www.facebook.com/Radio-Physics-Lab-IUCAA-224301091329735/?ref=bookmarks

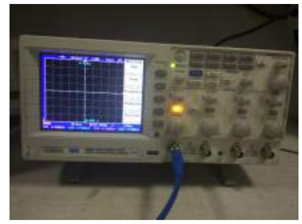
Youtube Channel: Radio Physics Lab IUCAA
https://www.youtube.com/channel/UCAEAh0s6MPMfDaUdPannnxg

NCRA/TIFR RPL Website: http://www.ncra.tifr.res.in/rpl

Pictures of Some Instrumentation and Experiments in RPL

(a) CRMD scintillator

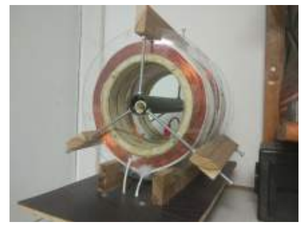
(b) H-line filter



(c) Digital Oscilloscope

(a) Function Generator

(b) GPS Disciplined Oscillator

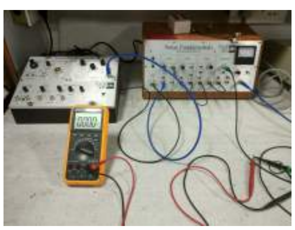


(c) Helmholtz Coil

(a) Low Noise Amplifier

(b) Lock-in Amplifier

(c) Magnetic Torque Set-up



(a) Noise Fundamentals Set-up

(b) DC Power Supply

(c) H-line Receiver

(a) SDR Receiver

(b) Spectrum Analyser

(c) Waveguide Horn