# Advancements of the ground-based radio telescopes in India

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DOI: 10.29322/IJSRP.13.02.2023.p13414
http://dx.doi.org/10.29322/IJSRP.13.02.2023.p13414

Paper Received Date: 18th December 2022
Paper Acceptance Date: 29th January 2023
Paper Publication Date: 6th February 2023

**Abstract-**It has been around 90 years since the discovery of the first radio waves. It was instrumental in the discovery of the stars, galaxies, quasars, pulsars and the cosmic background radiation. The worldwide radio facilities are mostly working on centimeter and decimeter parts of the radio regions after the interferometric baseline introduction, adoption of low-noise receivers' configuration and the usage of advanced electronics. These techniques improved angular resolution, are cost effective and able to provide results in real-time. A very few radio antennas are working in low frequency radio regions. However, India has successfully developed a cost effective and the most powerful radio telescope (GMRT) in this region(<1GHz). This review article is focused on how the challenges due to Indian terrain were overcome and subsequent development of all four radio astronomy facilities across India. Also, the review focuses on brief instrumental details about antennas, transmission lines and important discoveries made by these facilities. The present study is an attempt to summarize the evolution of radio astronomy in India and may be helpful for future radio researchers.

**Keywords:** Antenna, Interferometry, Radio Astronomy, Telescopes

## I. INTRODUCTION

Radio astronomy is the youngest branch of astronomy, which is about the detection and measurement of the energy associated with naturally occurring radio waves (long wavelength > 1 mm and frequency 3 x $10^{11}$ Hz), emitted from radio sources including stars, planets, galaxies and nebulas [1][2].

It was publicly speculated for the first time in 1894 by Sir Oliver Lodge, that long wavelength radiations might be reaching earth along with sunlight and starlight [1]. The optical astronomers could not detect radio waves for many years due to its long-wave. It was Karl G. Jansky in 1932, accidentally discovered that the source of radio emission was coming not from the sun or solar system, but from the surface of the Milky Way Galaxy (MWG) while he was working at the frequency 20.5 MHz with a wavelength 14.6 m [2-5]. Further research by Grote Reber included a frequency range of 10–160 MHz and wavelength range of 30 –2 m [6-10] and obtained radio mapping of MWG, in the form of constant intensity contours of radio waves. The radio emission was obtained from the constellations of Cygnus, Sagittarius, Casiopiea and Orion in 1947. Hey et al. (1946) also obtained the contour of the same pattern at 64 MHz with 4.7m[11]. The published results motivated worldwide researchers, especially in England and Australia, to get to know more about emission of radio waves from celestial objects such as the sun and other radio sources in MWG or in other galaxies.

In India, the foundation of introducing radio astronomy was laid down under the influential leadership of eminent Physicist Sh. K. S. Krishnan. During 1952-1962, a team of radio scientists associated with NPL was formed, who later on, contributed a significant part in the growth of radio astronomy [12]. In particular, TIFR (Tata Institute of Fundamental Research) founder director and known visionary, Dr. Homi Bhabha was credited to form an Indian radio astronomy group [13] in January 1962. The first radio astronomy group in India, finally came into existence at TIFR (Mumbai) during 1963-1965 under the leadership of distinguished physicist Dr. Govind Swarup.

In this review, the growth and challenges in the development of radio telescopes in India are discussed. Apart from Section 1 (Introduction), which covers the need for radio telescopes and a short overview of advent of radio astronomy in India., Section 2 covers the technology behind radio telescopes and Section 3 reviews the development of all the four radio telescopes designed and located India. The challenges faced are also covered in section3 with conclusion in section 4.

## II. RADIO TELESCOPES

A radio telescope (RT) is used to study radio signals emitted by extremely weak cosmic radio sources. Therefore, the diameter of radio telescopes is usually very large and operated with the usage of the most sensitive radio receivers available. In particular, a RT consists of large parabolic cylinders/dishes antenna, which is further connected to Computer systems for signal analysis.

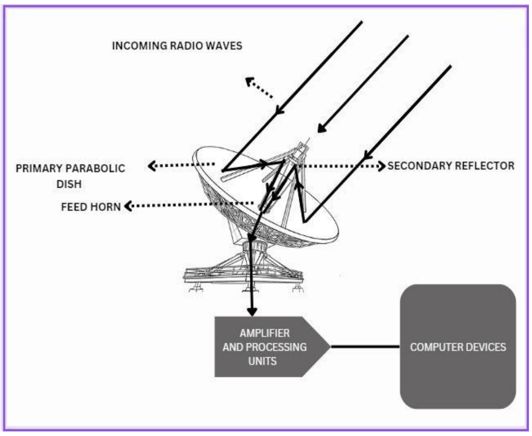


**Figure1**. Basic schematics of a radio telescope [15]

A Radio telescope has two basic units namely a large radio antenna and a sensitive receiver or radiometer (Figure1) having feed Horn. In particular, sensitivity, or its ability of measuring emissions due to weak radio sources, of a RT depends upon antenna's area, its efficiency and detection, and amplification ability of the radio receiver and its bandwidth (BW) in case of broadband (BB) continuous emission [14].
A parabolic reflector (or dish) is used in most of the RT, generally to collect and focus the incoming radio waves. The radio waves can be detected at the focus of the dish or reflected back through the middle of the dish and then directed towards the focus of the dish. A specific range of frequencies can be focused on a specially designed antennas called feed horns. These feed antennas convert electromagnetic waves in air into electromagnetic waves for transmission in receivers where receivers carry radio signal to computer system for further analysis [14][15].
Furthermore, a single radio antenna of very large sized diameter D(m) is required to achieve angular resolution (θ) for observing a long-wave λ(m), as given in equation (1),

angular resolution, $\theta \sim \lambda/D$ ………… (1)

It is very difficult to achieve angular resolution, practically in terms of handling large sized antennas and its high manufacturing cost. Therefore, observations of the radio astronomy field were shifted to shorter-waves (higher frequencies). In early 1946 [16][17][18][19], the diameter of radio antenna was increased by adopting cost effective interferometric approach which was comprised of large dipoles arrays or widely situated small sized dishes. Further, there was another harmful earth's ionospheric effect on incoming radio signals, making the maximum size of D with baseline ~5km (frequencies < 100MHz, λ> 3 m) [20]. This caused imposition on the usage of interferometry approach for higher frequencies until 1970.There are a few exceptions of using long-wave radio astronomy with frequencies < 100MHz, having India's Gauribidanur Radio Observatory (GEETEE) radio telescope [21][22] and the Ukrainian UTR-2 by 1980[23]. In particular, Radio observatory is preferably situated far from residential areas to avoid prevalent man-made radio interference or electromagnetic interference (EMI) generated from televisions, radio, other electronic devices and transport systems [13].

## III. RADIO TELESCOPES IN INDIA

To detect radio waves and measure the related radio energy of the electromagnetic spectrum, radio telescope facilities were developed in India. The four radio telescopes designed and located in India are discussed in the following section

### THE KALYAN RADIO TELESCOPE

**The Kalyan Radio Telescope** was placed at a location near Kalyan town ( Bombay) in 1965 to study the active and quiet parts of sun at a 610 MHz frequency [12]It was the first interferometer radio telescope of grating type with 32 parabolic dishes (1.7meter diameter), Fig.1[24], which were gifted to NPL by Australia's CSIRO( Commonwealth Scientific and Industrial Research) and finally shifted to TIFR in 1963.Out of 32 parabolic dishes, 24 parabolic dishes were situated along east-west (E-W) baseline (630 meter in length) and 8 parabolic dishes along north-south (N-S) baseline (256 meter in length). This arrangement worked to form two radio interferometers [12]. Further, these two radio signals taken from dipoles of parabolic dishes employing directional couplers, were brought to a central receiver using transmission lines of 630 meter stretched long pairs of Cu (Copper) wires for the both arrays E-W and N-S [25]. This particular placement of 32 dishes resulted in angular resolution 2.3 arcmin X 5.2 arcmin [26].

**Figure 2**. Kalyan Telescope located at Kalyan, taken from NCRA-TIFR archives [24]

Through this telescope, the sun's quiet and active regions were observed for 3 years during 1965-68 and solar radio bursts and limb-brightening of quiet sun at 610 MHz were found. The temperature of the solar corona was also measured to be ~$10^6$K[25]. The Kalyan telescope was demobilized in 1968.

### OOTY RADIO TELESCOPE

The equatorial **Ooty Radio telescope (ORT)** , was aligned with Nilgiris hills range, at its natural slope of ~11$^o$ latitude, 23 arcmin, located near the Muthorai village, Ooty(Tamil Nadu) operated since 1970.Its unique feature is its long axis lying along N-S direction, that makes it parallel about earth's rotation axis, resulted into tracking of radio sources continuously for 9.5 hours per day using parabolic frames' mechanical rotation in E-W way [12].

The ORT consisted of a 530meter length in N-S direction and 30 meter wider in E-W direction, asymmetric parabolic cylinder antenna (Fig. 2 [) where the antenna's reflecting surface was composed of 1100 stainless wires connected in parallel with focal length 16.5meter. It was operated at the frequency range 322-328 MHz [12][26] with an effective collecting area of ~8500 meter$^2$. Further, 1054 dipoles were installed along the focal line, where a phase shifter was connected to each dipole making theses enabled to point within ±45$^o$ declination [26].

Naming a few prominent achievements at 327 MHz, a nonthermal diameter of (~ 20pc) of radio halo was discovered around Galactic Centre (GC) using lunar eclipse observations of GC, Sagittarius A source [27]. The IPS (Inter Planetary scintillation) observations of radio sources using ORT, observed a prominent emission occurring from compact components with angular resolution < 0.5 arcsec [28][29]. Also, 2-D non thermal and thermal emission was determined for the first time from Sagittarius A using high frequency information and also estimated radio galaxy ages [30]. At 327 MHz, Ooty lunar occlusion survey achieved its best resolution for angular sizes, in a range of 0.5-10 arcsec for projected 3C and 4C (~900 in no.) and uncatalogued weaker radio sources up to 1978[12]. Another prominent step was to give the upper limit of a supercluster's HI mass [31]. ORT has been used for the study of protogalaxies, recombination lines, pulsars and solar wind successfully due to its large collecting area and sensitive feed system [32].

**Figure3**.Ooty radio telescope adapted from NCRA-TIFR Archives [24]

At 327 Hz, radio recombination lines from sources in MWG [33] and upper limit on deuterium-to-hydrogen ratio (D/H) toward the GC was placed [12][34].

Further at 327 Hz in 1980, OSRT (Ooty Synthesis Radio Telescope) was developed [35] and it played an important part in taking observations of 2-D radio sources' images, supernova remnants (SNRs), structures and clusters of radio galaxy structures, discovery of a radio galaxy 0503–286 [36].Furthermore, microwave antennas industry and satellite communication system was achieved based upon the design and working of ORT, in India.

GAURIBIDANUR RADIO TELESCOPE

**Gauribidanur Radio Telescope** (GEETEE) is a decameter -wave radio telescope, operating at a low-frequency 34.5 MHz, situated at Longitude :77.44° E, Latitude:13.60° N in Gauribidanur near Bangalore (Tamil Nadu). IIA (Indian Institute of Astrophysics) in alliance with RRI (Raman Research Institute) has been operating GEETEE since 1976[37].

GEETEE's antenna system is shaped in T-configuration, consisting of 1000 dipoles. 640 dipoles are arranged in 1.4 km along E-W long array and remaining 360 dipoles are arranged in 0.45 km along South direction. The angular resolution from a single beam is 26´X 42´ [38][39][40].

This telescope was able to achieve mapping of 2-D radio emission images of slowly changing distinct radio sources existing in the outer solar corona. Further an all sky survey in declination range ~ - 30° S - 60° N at 34.5MHz and carbon recombination lines (low frequency) in the celestial sources, exploding stars' gaseous remnants, study of pulsars and evidently vacant space in between members of a cluster of galaxies,[41][42] was also possible with this telescope.

**Figure 4**. GEETEE radio telescope at Gauribidanur [43]

Since GEETEE is a single -beam radio telescope (Fig.4), requiring a greater observing time for a wide field survey resulted in reduced surveying sensitivity in comparison to multi-beam facility. Further, at low frequency 34.5 MHz (decameter-wave),there is time-variable shifts in apparent positions of celestial source due to Earth's ionospheric effects and also there is reduced observing time due to destructive man-made radio interference. Therefore, a digital correlation receiver consisting of 128-channels using Double-Side Band (DSB) technique was used with a telescope which made it possible to receive interference free observations of a large area for a long time 39].

GIANT METREWAVE RADIO TELESCOPE (GMRT)

**Giant Metrewave Radio Telescope (GMRT)** the most powerful RT (Fig.5) and the largest world's aperture-synthesis array in meter-wave radio astronomy [13]. It is situated near Narayangaon (Maharashtra) at 19º06´ N latitude,74º03´ E longitude and 650meter altitude. The novel change in its design is replacement of parabolic cylinders with parabolic dishes, resulting in reduced cost of manufacturing and improvement in reliability, getting more frequency and sky coverage.

It operates at meter wavelengths, consisting of 30 fully steerable parabolic dishes, 45meter in diameter,since 2001. The SMART(Stretched Mesh Attached to Rope Trusses) system is employed for making wire mesh panels as parabolic reflectors [13][31]. The 14 parabolic dishes out of 30 dishes, are placed in central area of ∼1 km X 1 km, for taking observations of extended attributes of celestial sources and left 16 parabolic dishes are placed in Y-configuration array, in ~25-km region where each arm of y-shape is extended in ∼15 km in length for observing radio sources with angular resolutions in range of ∼2 arcsec, for 1,400 MHz- ∼20 arcsec for 150 MHz. To take observations of one of five frequency bands, antenna feeds were mounted on a rotating turret near focal point of 45-m dishes.: The observations are made in any one of five frequency bands of bandwidth 32MHz,130MHz,235 MHz, 325 MHz, 619 MHz, and 1,430 MHz, where each band is of 32 MHz of bandwidth. Its effective area (30 GMRT antennas) for low frequency band is ∼30,000 $m^2$ and for 1430 MHz band is ∼18,000 $m^2$. GMRT was further upgraded, called uGMRT, to give a response over a range of frequency from ~130 to 1430 MHz with increased BW ~ 400MHz with enhanced sensitivity, using optical fibers for transmission of RF signals to the central laboratory. The self calibration and CLEAN closure phase techniques are developed for synthesis RT [25][44. In particular, the upgraded uGMRT makes the 10 hours observation of an astrophysical radio source equivalent to the results obtained using a 25 km sized parabolic dish.

Figure5. GMRT located at Naryangaon adapted from NCRA-TIFR Archives [24]

Apart from observing Sun, Planets or exoplanets and Sun, various radio emitters in MWG, such as pulsars, quasars, radio galaxy clusters, and many astronomical bodies , have also been identified with GMRT. It also released the sky survey at 150 MHz and included around 0.6 million radio sources [45]. Further radio galaxy was detected with a redshift of 5.72 [46] investigated Venus's polarizations and brightness temperature measurements using GMRT[47]. At a redshift of 0.37, HI, has been detected using the uGMRT with 445 galaxies stacking [48]. While 6,400 galaxies were stacked by to find HI at the redshift 1 [50]. One of the missions for the development of the telescope was to observe the redshifted 21-cm HI line. This telescope is frequently used by astronomers from around the world to examine a wide variety of astronomical phenomena, including galaxies, supernovae, pulsars, Sun, HII regions and solar winds.

In August 2018, GMRT discovered the farthest galaxy yet discovered, at a distance of 12 billion light years. It assisted in the detection of the Ophiuchus Supercluster explosion, which is the largest explosion in the history of the cosmos, which occurred in February 2020[12].

It initially seemed to be very difficult to develop a cost-effective technology and a system of bringing radio signals far from a very large synthesis RT at meter-wave (stretch ~25 Km) to central laboratory due to Indian terrain and dense populated land area, as compared to developed high cost technology backed facility VLA (Very Large Arrays),USA where it was possible (stretch ~35 km) having comparatively flat plane (required for keeping straight waveguides) and low populated land area[12].The optical fibers and Lasers were used for the communication purpose and a cost-effective SMART system was used for assisting wire-mesh panels of a parabola reflector.

## IV. CONCLUSIONS

Telescopes are among the most important tools that researchers use to enhance their knowledge of our cosmos. The current study attempts to describe how radio telescopes are one of the most important tools for gaining a deeper understanding of our universe. The evolution of a radio telescope from a single antenna to a vast array of antennas in order to acquire good angular resolution of astronomical radio sources is quite complex. The operation of early radio telescopes and their evolution in India over time has been reported in the present study. Furthermore, emphasizing on how India's advent into the radio astronomy research field, established India as a world leader, particularly in the metre wavelength (low frequency) radio zone. We believe that many unsolved challenges and critical concerns about space will continue to fascinate society for decades to come.

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