The Giant Metre-wave Radio Telescope

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Radio astronomy:

Radio astronomy is the study of distant objects in the universe by collecting and analyzing the radio waves emitted by those objects. Just as optical astronomers make images using the light emitted by celestial objects such as stars and galaxies, radio astronomers can make images using the radio waves emitted by such objects, as well as by gas, dust and very energetic particles in the space between the stars. Radio astronomy has been a major factor in revolutionizing our concepts of the universe and how it works. Radio observations have provided a whole new outlook on objects we already knew, such as galaxies, while revealing exciting objects such as pulsars and quasars that had been completely unexpected. From revealing the remnant of the Big Bang to showing the afterglows of the super energetic Gamma Ray Busters, radio observers have provided science with insights unobtainable with other types of telescopes. Radio telescopes today are among the most powerful tools available for astronomers studying nearly every type of object known in the universe.

Radio telescopes:

Radio telescopes are used to study naturally occurring radio emission from stars, galaxies, quasars, and other astronomical objects between wavelengths of about 10 meters (30 megahertz [MHz]) and 1 millimetre (300 gigahertz [GHz]). Radio telescopes vary widely, but they all have two basic components: (1) a large radio antenna and (2) a sensitive radiometer or radio receiver. The sensitivity of a radio telescope, i.e., the ability to measure weak sources of radio emission, depends on the area and efficiency of the antenna and the sensitivity of the radio receiver used to amplify and detect the signals. For broadband continuum emission the sensitivity also depends on the bandwidth of the receiver. Because cosmic radio sources are extremely weak, radio telescopes are usually very large and only the most sensitive radio receivers are used. Moreover, weak cosmic signals can be easily masked by terrestrial radio interference, and great effort is taken to protect radio telescopes from man-made interference.

The most familiar type of radio telescope is the radio reflector consisting of a parabolic antenna, the so-called dish. In some radio telescopes the parabolic surface is equatorially mounted, with one axis parallel to the rotation axis of the Earth. Equatorial mounts are attractive because they allow the telescope to follow a position in the sky as the Earth rotates by moving the antenna about a single axis parallel to the Earth's axis of rotation. But equatorially mounted radio telescopes are difficult and expensive to build. In most modern radio telescopes a digital computer is used to drive the telescope about the azimuth and elevation axes to follow the motion of a radio source across the sky.

GMRT:

The Giant Metre wave Radio Telescope (GMRT) is currently worldôs largest radio telescope operating at Metre wave lengths. The GMRT was built and is operated by the National Centre for Radio Astrophysics of the Tata Institute of Fundamental Research (NCRA-TIFR). The GMRT is located at Khodad, about 80 km. north of Pune, offset from the Pune Nashik Highway. It consists of 30 fully steerable gigantic parabolic dishes of 45 m diameter each, spread over in a 25 km diameter circle, effectively operating like a single antenna of 25 km diameter through aperture synthesis techniques. GMRT is one of the most challenging experimental programmes in basic sciences undertaken by Indian scientists and engineers. It has six operating frequency bands around 1420 MHz, 610 MHz, 325 MHz, 235 MHz, 150 MHz and 50 MHz.

Design:

The Giant Metre-wave Radio Telescope, an aperture-synthesis array consisting of 30 fully steerable parabolic dishes of 45-m diameter each, is situated about 80 km north of Pune as a national facility for frontline research in radio astronomy in the frequency range 38 MHz to 1420 MHz. The novel design of a low-solidity dish for metre-wave operation in which a thin wire mesh (varying in size from 10 mm x 10 mm to 20 mm x 20 mm and made of 0.55 mm diameter stainless steel wire). Which constitutes the reflecting surface is stretched over a parabolic surface formed by rope trusses, has made it possible to build a large collecting area (total effective area of about 30,000 square metres over three times that of the Very Large Array in the USA) at modest cost.

It is a major new instrument designed to fill the existing worldwide gap in powerful radio telescopes operating at metre wavelengths, where there are many exciting and challenging astrophysical problems and phenomena to be investigated. Two of the primary scientific objectives of the telescope are to detect the highly redshifted 21-m line of neutral hydrogen form protoclusters or protogalaxies in the early epochs of the Universe before galaxy formation, and to detect and study a large number of millisecond pulsars in an attempt to detect the primordial background of gravitational radiation.

The more widespread prevalence of man-made radio interference at metre, compared to centimetre wavelengths in the Western world and the increasing distortions at longer wavelengths in the incoming wave fronts caused by ionospheric irregularities have also possibly been responsible for the present neglect of metre-wave radio astronomy. Fortunately, radio interference is not a serious problem in India and the harmful ionospheric effects can be largely overcome or greatly reduced through the use of powerful self-calibration techniques that have been developed over the last decade or so.

Astrophysical objectives

GMRT is designed to cover a wide region of the radio spectrum in the wavelength range of about 20 cm to 8 m. Some aspects of its design features were motivated by the important astrophysical objectives of (i) searching for the highly red-shifted line of neutral hydrogen from protoclusters or protogalaxies in an attempt to determine to epoch of galaxy formation, and (ii) searching for new short-period pulsars. However. GMRT is being a very versatile and general-purpose astronomical facility for both continuum as well as spectral line observations. Because of its high sensitivity and angular resolution, it is useful for investigations of almost every type of celestial object that emits radiation at radio wavelengths. With a view to informing potential users of the telescope, a brief account of some of the areas where GMRT have the capability of making outstanding contributions

The parabolic dish antenna

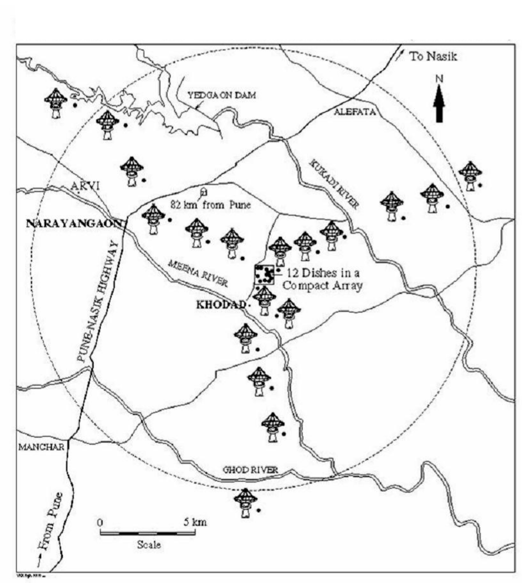
Conventional parabolic dishes have generally been built for operation only at centimetre and decimetre wavelengths (> GHz) and their high cost can in part be attributed to the need to maintain high surface accuracy in the presence of gravity deflections and large wind forces because of their solid surfaces. Even for mesh surfaces, large wind forces have to be allowed for in the event of snowfall. Although the structural specifications for GMRT antennas could be relaxed considerably because of the longer wavelengths of operation and the total absence of snowfall in the plains of India, it was hard to estimate the potential savings in cost as no large antennas specifically designed for metre-wave operation have previously been built anywhere. It was clear therefore that new and innovative designs with a much lower solidity, would have to be developed if the requirement of a total physical area of ~ 50,000 m2 with about 30 elements had to be met within the limited available budget. To meet this challenge, several different approaches were investigated in considerable detail, as described elsewhere.

Figure 1. Artist's sketch of the 45-m diameter parabolic dish antenna based on the SMART design.

The design finally adopted as one meeting both technical and budgetary requirements is a 45-m-diameter dish based on a novel concept that was nicknamed SMART, for stretched mesh attached to rope trusses. Basically, very low weight and solidity are achieved in this concept by replacing the conventional back-up structure in a dish by a series of rope trusses (made of thin stainless steel wire ropes) stretched between radial parabolic frames and suitably tensioned to form a parabolic surface. A very-low solidity wire mesh (made of thin stainless-steel wire) stretched over the rope trusses forms the reflecting surface of the dish. An artistôs sketch of one of the 45-m dishes based on this concept is shown in the above Figure.

The total tonnage of the back-up structure of the dish, the quadripod which supports the feed system at the focus of the dish, the elevation bull-gear structure, the yoke and the azimuth bearing support (excluding counterweight of 34 tonnes) is only about 82 tonnes. In contrast, the tonnage of a typical 25-m dish for use at centimetre wavelengths is about 250 tonnes (excluding counterweight). For a front wind speed of 1.33 kph at a 10-m height (increasing to 155 kph at 45-m height), the total force on the dish is only about 50 tonnes. For the elevation axis the maximum torque gets applied near the zenith position of the dish and is estimated to be 189,000 kg at 1.33 kph wind speed; for the azimuth axis, the same occurs near the horizon position of the dish and is about 206,000 kg. The overall wind forces and rotational moments of the 45-m dish based on the SMART concept are thus similar to those of only a 22-m conventional dish resulting in considerable economy.

Array configuration:



After investigating a variety of possible-configurations from the point of view of coverage, sideline levels and logistics of access road and cabling work, the configuration finally selected is shown in Figure 5. Six antennas are distributed along each of the three arms of a rough Y and the remaining 12 antennas are more or less randomly placed in a compact cluster near the centre of the, with a maximum baseline of about 1.1 km. The maximum baseline length among the distant antennas is about 25 km. Note that, because the optimizing function is fairly insensitive to small variations in the antenna positions, the final antenna locations do not all lie on a regular Y and were chosen to be located reasonably close to existing village roads or in non-agricultural lands and so on.

The hybrid configuration gives reasonably good sensitivity for both compact and extended sources (of the order of 20 arc sec and 5 arc min respectively at 150 MHz). The shortest spatial frequency that can be measured corresponds to baselines of about 100 m. Figure 6 shows the Fourier components that would be measured instantaneously by GMRT .All the Fourier components, up to baselines of 25 km and 1 km respectively, that can be measured by tracking a source for the full range of observable hour angles. As can be seen very good coverage of spatial frequencies corresponding to antenna separations of 100 m to 25 km is achieved.

Contribution through GMRT

The provision of high time resolution capability (40 msec, about an order of magnitude higher than available with VIA) allowing GMRT to be effectively used for studying a variety of solar and planetary radio bursts, including those from Saturn discovered by the Voyager spacecraft. It also become possible to probe the ionospheres and magnetospheres of some planets other than Earth by observing scintillations of radio sources passing close to the planet.

Galactic plane surreys: With its multifrequency coverage at metre wavelengths, continuum surveys of the Milky and detailed imaging of interesting sources with GMRT showing the way to deeper insights into the physics and evolution of H II regions, planetary nebulae, supernova remnants, voids, spurs and other phenomena in our galaxy. Of particular value will be a search for young supernova remnants or plerions (Crab-Nebula type).

Pulsars: With its large collecting area and extensive sky coverage, GMRT is one of the most powerful telescopes for the study of pulsars, associated with rotating neutron stars. Accurate timing measurements of millisecond pulsars have also been used to place limits on the presence of gravitational background relation of primordial origin thought to have arisen during the early inflationary phase of the Universe GMRT will have the potential of greatly improving the present limits on the long wavelengths gravitational radiation

Variability of radio sources of metre wavelengths GMRT would be a powerful tool for investigating the origin of low frequency variability of extragalactic sources and to monitor transient sources in the galactic plane and supernovae in external galaxies. Accurate timing measurements of millisecond pulsars have also been used to place limits on the presence of gravitational background relation of primordial origin thought to have arisen during the early inflationary phase of the Universe GMRT have the potential of greatly improving the present limits on the long wavelengths gravitational radiation (equivalent to about 10 of the closure density of the Universe) because of its ability to find and monitor many new pulsars well distributed over the sky.

In the area of observational cosmology, deep radio surveys using GMRT able to extend the number-flux density counts of radio sources at metre wavelengths to flux levels about 10 times fainter than at present and the angular size-flux density relation to even 100 times fainter levels than at present. Together with deep optical identifications and spectroscopy, this data would be very valuable in constraining models of cosmic evolution in the properties of radio sources over a wide range of radio luminosity.
