Radio astronomy — A sky survey at 34.5 MHz

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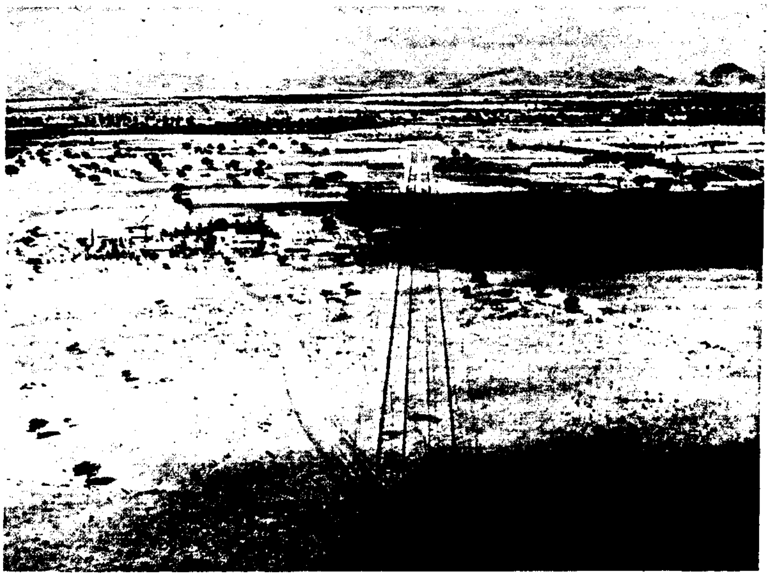
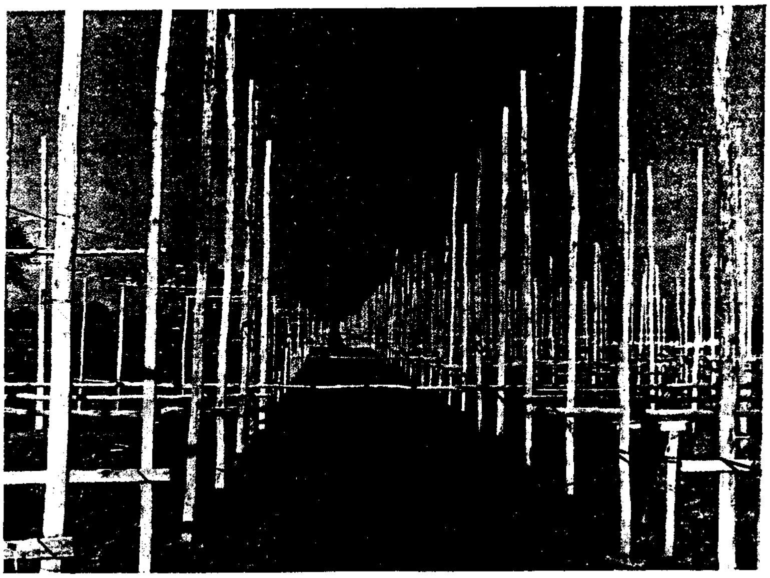
Radio astronomy began at low frequencies. It may be recalled that the historic observations of Karl Jansky (around 1932) were done at 20.5 MHz. Interestingly, the next major observations, by Grote Reber in 1940, were done at a much higher frequency of 160 MHz, and this has been the general trend ever since. The main motivation for this was, of course, the quest for higher and higher angular resolution; this was easier to achieve at higher frequencies for obvious reasons. On the other hand, the quest for higher angular resolution and higher sensitivity at lower frequencies was hindered by the fact that the construction and maintenance of large arrays proved to be difficult.

Around 1960, Martin Ryle and his associates at Cambridge, England, developed the method of *aperture synthesis*. In its most basic form, aperture synthesis may be considered as a method whereby the information-gathering capability of a large aperture is *synthesized* by measurements with an interferometer of two elemental apertures, one fixed and the other *movable* to various positions within the large aperture. (It may be recalled that in 1973 Martin Ryle was awarded the Nobel prize for physics for elucidating the principles, and the successful construction of an aperture-synthesis telescope.) Although the technique of synthesizing a large aperture was available, it was rendered less useful at low frequencies by the fact that the interference introduced by the ionosphere and terrestrial sources was highly variable over the sort of time-scales that would be required to synthesize a large aperture. Notwithstanding these formidable difficulties, there were many early attempts to observe the sky at low frequencies. For example, as early as 1961, Shain, Komesaroff and Higgins mapped a part of the Galactic plane at 19.7 MHz with 1°.4 resolution using the Mills Cross in Australia. Five years later, Williams, Kenderdine and Baldwin at Cambridge used the aperture-synthesis technique to map the northern sky at 38 MHz with a resolution of 0°.7.

Turning now to the Indian scene, here, too, the first efforts were at relatively higher frequencies. The Ooty radio telescope was built to operate at

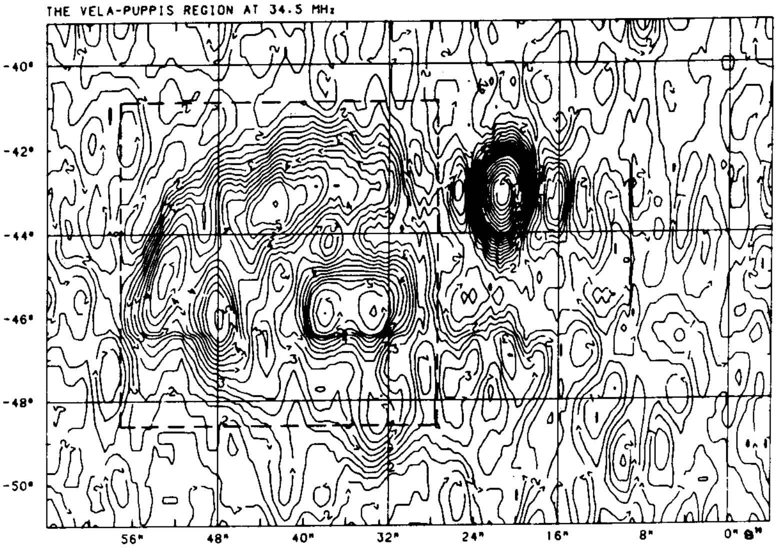


An aerial view of the Gauribidanur radio telescope from the eastern end.



A view of the west array as seen from the centre of the east–west arm.

327 MHz and the lunar occultation technique was used to make high-resolution observations of radio galaxies. In the mid-seventies a large low-frequency array was built at Gauribidanur (latitude 13° 36′ 12″ N) near Bangalore jointly by the Indian Institute of Astrophysics and the Raman Research Institute. This array is made up of 1000 dipoles oriented in the east–west direction and arranged in the form of the letter 'T' with a 1.4-km-long east–west arm and a 0.45-km-long southern arm. The angular response of the east–west array is narrow along the east–west direction but broad along the north–south direction (i.e. along the meridian). The southern array has the opposite response. Thus, by multiplying the signals from the two arrays, it is possible to produce a narrow angular response of the telescope. By *phasing* the telescope, this response can be 'steered' along the meridian. While operating at 34.5 MHz, the telescope thus used has an angular resolution of 26′ × 42′ and a collecting area of 18,000 m^2 at zenith. Thus, by steering the telescope response along the meridian and making use of the Earth's rotation, the entire observable sky from Gauribidanur can be mapped. However, if we are to cover, say, ±50° of zenith angle, then, in this way of observing we would need ∼400 days to map the sky. Given the problems due to terrestrial interference, ionosphere and solar activity that plague low-frequency observations this is not meaningful. An alternative to this is to do a *one-dimensional image synthesis*[1–3]. In this method the east–west array is combined to produce a fan beam along the meridian. The south array consists of 90 rows of dipoles, each of which has an angular response along the meridian covering the entire observable range of declinations. At each instant of time the signals from the east–west array and each of the 90 rows of the south array are brought to the laboratory separately and multiplied in a multichannel digital receiver system built for this purpose[4]. The correlations so obtained are later Fourier-transformed to produce a radio brightness distribution of the sky. In this way the entire sky can be covered in 24 sidereal hours. This novel technique, along with choosing the period of observations during the solar minimum, alleviated many of the problems.



A map of the Vela and Puppis supernova remnants. The Vela remnant is inside the 'box' drawn with dashed lines. The numbers on the contours are in units of 10^4 K.

One of the objectives of the recently completed 34.5-MHz sky survey[1,2] with the Gauribidanur radio telescope was to map the *large-scale features* of the Galaxy. The picture on the cover of this issue (produced by D. Bhattacharya and K. S. Dwarakanath of the Raman Research Institute) shows the entire sky within ±50° of zenith angle mapped in the survey, but smoothed to a resolution of 2° to highlight the large-scale features. The numbers next to the 'colour key' indicate the equivalent *brightness temperature* of the sky in units of ≈1000 K. This radiation is not radiation from a 'hot' body but is synchrotron radiation and arises owing to the cosmic-ray electrons gyrating in the magnetic field of the Galaxy. Nevertheless, astronomers describe the intensity of the observed radiation in terms of a 'temperature'; the brightness temperature is the temperature of a hypothetical black body that will emit the observed flux density in the frequency range under consideration. The shape of the Galactic plane is clearly seen, with the brightest region of the plane being in the direction of the Galactic centre. The brightness temperature varies from 200,000 K towards this direction to about 20,000 K towards the direction of the Galactic anticentre.

Another aspect of the survey concerns the nature of the *thermal gas* in the Galaxy. Since the temperature of this gas (∼5000 K) is much smaller than the brightness temperature of the Galactic background radiation, it is seen in *absorption* against the bright background at low frequencies. Several such absorption features are clearly seen in the maps, predominantly in the Galactic plane. Studies relating to their electron density, temperature and location in the Galaxy are in progress. Some of the most important results obtained by the Infrared Astronomical Satellite (IRAS) pertain to the distribution of this thermal gas. A comparative study of the properties of this thermal gas as deduced from the Gauribidanur low-frequency observation with the IRAS observations is expected to throw some light on the nature of the thermal gas in the Galaxy.

One of the most spectacular discoveries in recent times is that of the millisecond pulsars. These are neutron stars spinning at up to 600 times a second. Interestingly, low-frequency astronomy played an important role in the discovery of the very first millisecond pulsar. Observations done with the Clark Lake Telescope revealed a very-steep-spectrum point source (i.e. a source whose intensity rises unusually rapidly at low frequencies). A concerted effort to understand the nature of this source finally showed that it was an ultra-rapidly spinning pulsar. Since then several more of these pulsars have been found. Various theoretical attempts to understand the origin and evolution of these millisecond pulsars predict a substantial number of them in the Galaxy; indeed, their population may exceed a hundred thousand. Therefore, a crucial test of these theoretical scenarios would be to find many more of these pulsars, and establish their true distribution in the Galaxy. However, these are very faint objects and hence extremely difficult to detect even with the largest telescopes. Thus it would help a great deal if millisecond-pulsar 'suspects' or 'candidates' could be identified. With this in mind, a careful analysis is being made of the low-frequency maps obtained in the Gauribidanur survey to identify steep-spectrum point sources.

In recent times there has been renewed interest in the source counts, as well as in the large-scale distribution, of extragalactic radio sources. In all these discussions, the main observational input has been the results of surveys done at relatively high frequencies. It may be of some interest to do a similar analysis based on the observations of extragalactic sources at a much lower frequency. There could in principle be differences in the source counts, as well as in their angular distribution. For example, some of the sources seen at low frequencies may not form a part of the population seen at higher frequencies; this can happen if they have a very steep spectrum. The Gauribidanur survey, with its wide coverage and uniform sensitivity, is of particular interest in this context.

The low-angular-resolution colour picture (cover) is intended only to highlight the large-scale features. To make detailed studies of individual objects, or a small region of the sky, one has to make contour maps of the brightness with the full angular resolution possible with the telescope. As an illustration, the contour map of the VELA supernova remnant is shown. A supernova remnant is the expanding ejecta of explosions of massive stars (Supernovae). Initially the ejecta expand at very high velocities of ~10,000 kilometres per second; later on they slow down owing to their interaction with the gas between the stars. Owing to this interaction they also become very powerful radio sources. According to the standard model of supernovae (originally due to Baade and Zwicky, 1934), the explosive deaths of massive stars are the result of the formation of neutron stars at their centres. [Neutron stars are extremely compact objects (radius ~10 km) with average density of $\sim 10^{14}\ \mathrm{g\,cm^{-3}}$.] Soon after these exotic stars were discovered (by Jocelyn Bell in 1967) it was found that the Vela supernova remnant harbours a central pulsar. This seemed to confirm spectacularly the association of neutron stars with the supernova phenomenon. Although this hypothesis is now extremely well established, ironically, the very first association between a pulsar and a supernova remnant (namely the Vela pulsar in the Vela supernova remnant) is now being questioned! It has been recently suggested that this may be a chance superposition in the sky. A detailed analysis of this question by Dwarakanath seems to suggest that the Gauribidanur observations of this remnant may substantially help answer the question.

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1. Dwarakanath, K. S., 'A synthesis study of the radio sky at decametre wavelengths' Ph D thesis, Indian Institute of Science, Bangalore, 1989.
2. Dwarakanath, K. S. and Udaya Shankar, N., *J. Astrophys. Astron.*, 1990, **11**, 323.
3. Dwarakanath, K. S., Deshpande, A. A. and Udaya Shankar, N., *J. Astrophys. Astron.*, 1990, **11**, 311.
4. Udaya Shankar, N. and Ravi Shankar, T. S., *J. Astrophys. Astron.*, 1990, **11**, 297.

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