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SECTION III

SYMPOSIUM ON "RADIO ASTRONOMY"

Low-Frequency Radio Astronomy

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RECENT years have seen a great increase in the effort devoted to radio astronomy. At most observatories there has been a trend towards the use of higher and higher frequencies to obtain greater resolving power. For an aerial of a given size, the beam width is proportional to wavelength, and therefore at high frequencies adequate resolving power may be obtained with structures of moderate size. Although the emission from most astronomical radio sources falls rapidly at higher frequencies, sufficient sensitivity can now be obtained with masers or parametric amplifiers.

One result of these developments has been the almost complete neglect, in the northern hemisphere at least, of important measurements at the low-frequency end of the radio spectrum. Such measurements require very large aerials to achieve the desired resolution. The observations are frequently interrupted or modified by man-made interference or ionospheric effects. In spite of the difficulties involved, there are good reasons for obtaining observations at low frequencies. The complex structure of the continuum emission from the galactic plane and halo and from the north galactic spur may best be studied at low frequencies where the intensities are very high. Such features as the absorption of the galactic continuum by ionized hydrogen and the impulsive radiation from the planet Jupiter may be observed only at the longer wavelengths. In addition, accurate intensity measurements at low frequencies are required to extend determinations of the radio spectra of all sources of radio emission. A knowledge of the radio spectra will often help to differentiate between various possible emission mechanisms. This may be particularly important for a new class of radio source, the quasi-stellar objects or "quasars," some of which have spectra that are curved downward at low frequencies (1).

The chart in Figure 1 shows the region of the electromagnetic spectrum available to radio astronomy. The term *low frequency* when applied to radio astronomy generally means frequencies from about 40 Mc/s to 2.5 Mc/s. In only a few instances have astronomical observations been attempted below 2.5 Mc/s (2).

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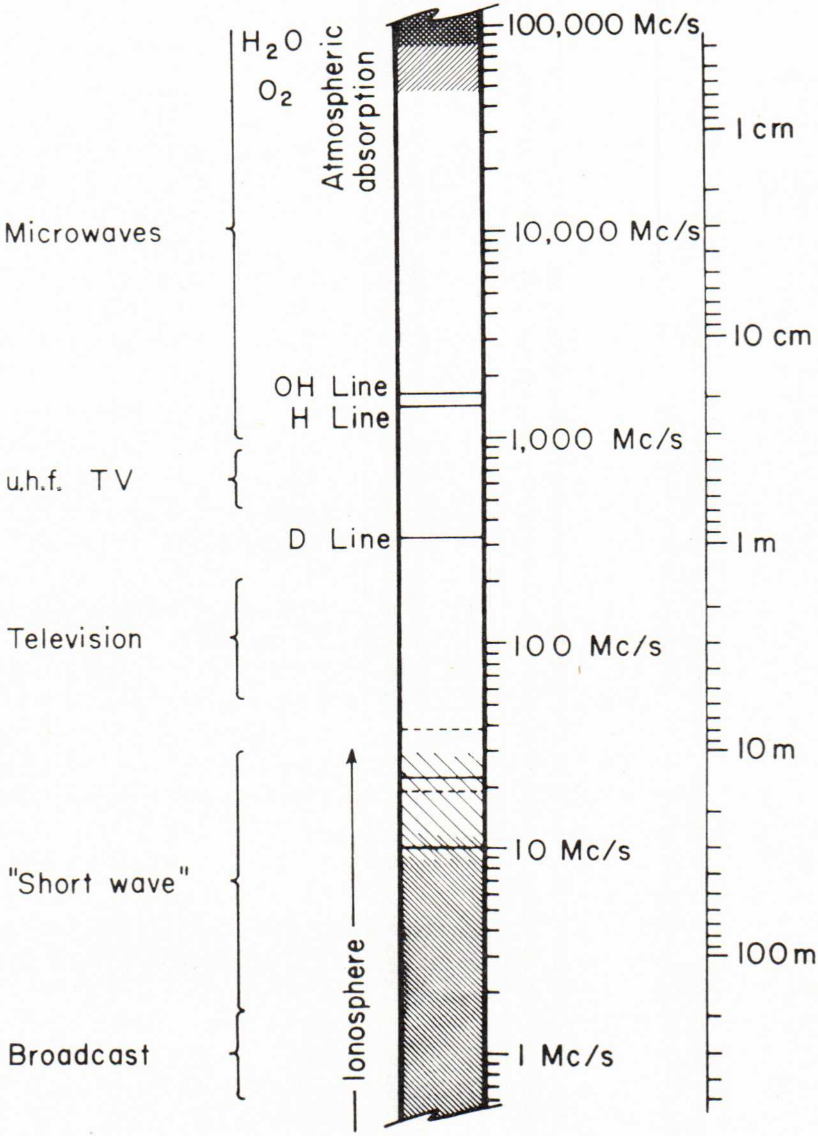

FIGURE 1. The region of the electromagnetic spectrum of interest to ground-based radio astronomy. The dotted horizontal lines indicate the frequencies of 19.7 Mc/s (4) and 38 Mc/s (5), which have been used in previous surveys. The unmarked solid horizontal lines represent the frequencies discussed in the present paper.

It was in this frequency range that radio astronomy began. In 1932, Karl Jansky (3), while conducting a systematic search for the origins of radio "static," discovered emissions from the sky with a period of $23^h\ 56^m$. This sidereal period indicated that the emissions originated outside the solar system. The radiation came, in fact, from our own galaxy.

A large cross-type telescope operating at 19.7 Mc/s was built in 1956 by Shain (4) in Australia. Until recently, the largest low-frequency array in the northern hemisphere was the 38 Mc/s "Moving-T" aerial at the Mullard Radio Astronomy Observatory, Cambridge (5). A 26 Mc/s compound grating at the Clark Lake, California, site of the University of Maryland is being used for observations of point sources (6).

During the years 1962 to 1965, a new aerial system operating at a frequency of 22.25 Mc/s was built at the Dominion Radio Astrophysical Observatory. When this frequency was chosen it was believed to be about the lowest frequency at which extensive measurements could be made without excessive ionospheric absorption or scintillation. It was intended that the bulk of the observations be undertaken during the present minimum in sun-spot activity in order to reduce ionospheric effects. Preliminary results at 22 Mc/s were encouraging, and the discovery of the "quasars" emphasized the increased importance of extending spectral measurements to still lower frequencies. It was therefore decided, late in 1963, to build a second aerial array at a frequency of 10.02 Mc/s. The 10 Mc/s radio telescope was undertaken as a joint project with Cambridge University.

To achieve high sensitivity a radio telescope must have a large collecting area; for high resolving power great linear size is required. However, for low-frequency work, it is possible to obtain sufficient sensitivity without using all the receiving elements present in a conventional uniform aperture. We have used a system first developed by Mills (7) in which two long, thin, orthogonal arrays are combined to produce a narrow "pencil beam." Signals from the "fan beams" of each arm of the array are multiplied together so that only the region of overlap produces a detectable output. The earth's rotation provides a convenient means of scanning the sky in the east–west direction. In the north–south direction this is accomplished by introducing phase delays between the various parts of the array. Aerial systems of this type are general-purpose instruments in that they may be used for observations of the broad, extended features of the galaxy as well as for intensity measurements of the sources of small angular diameter.

The 22.25 Mc/s Radio Telescope

The 22 Mc/s aerial is a T-shaped array of 624 full-wave dipoles. The dipoles accept east–west polarization. They are suspended $\lambda/8$ above a wire reflecting screen and the whole assembly is supported on 1698 wooden poles. A photograph of the array taken from the east is shown in Figure 2, and Figure 3 gives the dimensions.

The power collected by the dipoles is fed to receivers by a branching network of coaxial transmission lines. In the region where the east–west and north–south arms of the "T" overlap, the power is shared between the two arms. In the north–south arm, lengths of phasing cable appropriate to the declination being observed are inserted in the feeder system. This is

Figure 2. The 22 Mc/s aerial array as seen from the east. The 25.6 m paraboloid can also be seen.

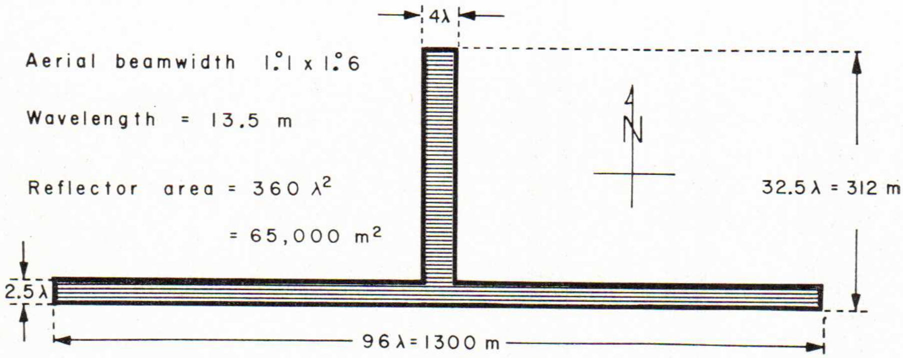

FIGURE 3. Dimensions of the 22 Mc/s radio telescope.

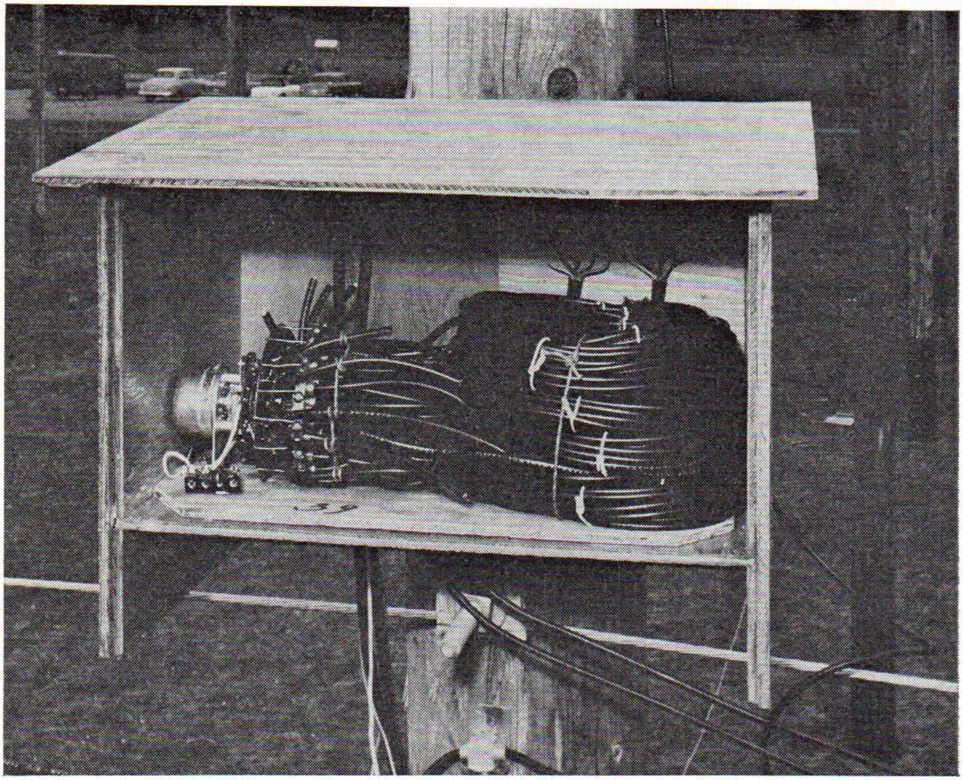

FIGURE 4. One of the phasing switches of the 22 Mc/s aerial.

accomplished by means of a set of 64 remotely controlled phasing switches like the one shown in Figure 4. For survey operations, a rapid-scanning system is employed in which the observing time is shared among five adjacent declinations.

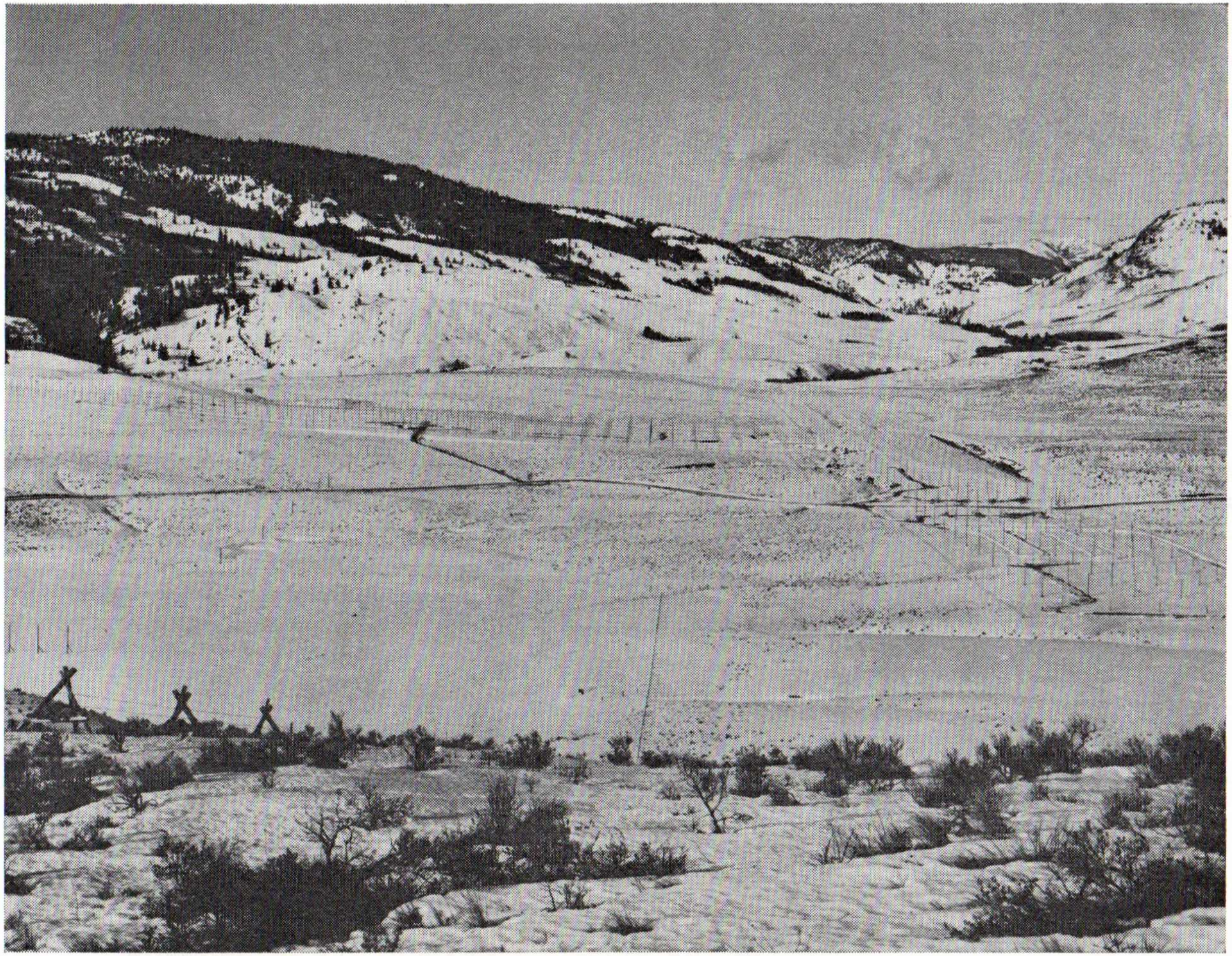

FIGURE 5. The 10 Mc/s aerial array as seen from the east. The calibration dipole can be seen in the lower left corner.

At the zenith the 22 Mc/s aerial has a beam width of 1.1° × 1.6°. The area of the reflecting screen is approximately 65,000 m². The performance of the system is roughly equivalent to that obtainable at this frequency with a convential paraboloid 650 m in diameter.

The 10.02 Mc/s Radio Telescope

The 10 Mc/s aerial is similar to the 22 Mc/s array. It consists of 400 half-wave folded dipoles supported λ/8 above a reflecting screen on 590 wooden poles. The dipoles accept north–south polarization. Figure 5 shows a photograph of the array and Figure 6 gives the dimensions. A calibration dipole placed above a shallow lake can be seen in the lower left corner of Figure 5. This is used to determine the absolute gain of the system.

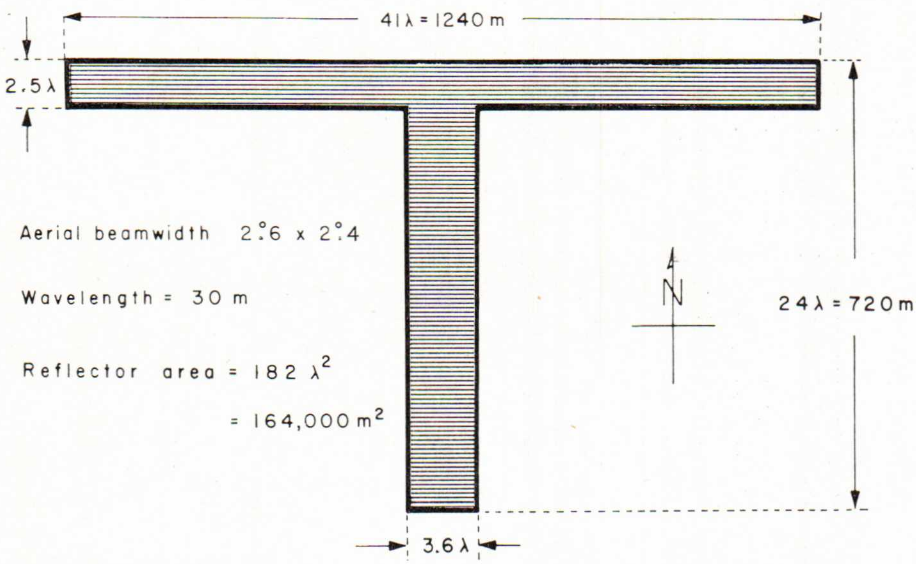

FIGURE 6. Dimensions of the 10 Mc/s radio telescope.

The power from each line of dipoles in the north–south arm is brought through equal lengths of coaxial cable to the receiver room at the centre of the arm. A network of hybrid transformers and coaxial cables provides simultaneously all possible north–south phasing arrangements of the array. Five receivers observing different declinations are normally used.

At 10 Mc/s, measurements of point sources are frequently disturbed by ionospheric scintillations. The observations of the radio source, Cygnus A, shown in Figure 7 illustrate how severe the scintillations can become.

The 10 Mc/s aerial has a beam width of 2.6° by 2.4° at the zenith. The area of the reflecting screen is approximately 164,000 m².

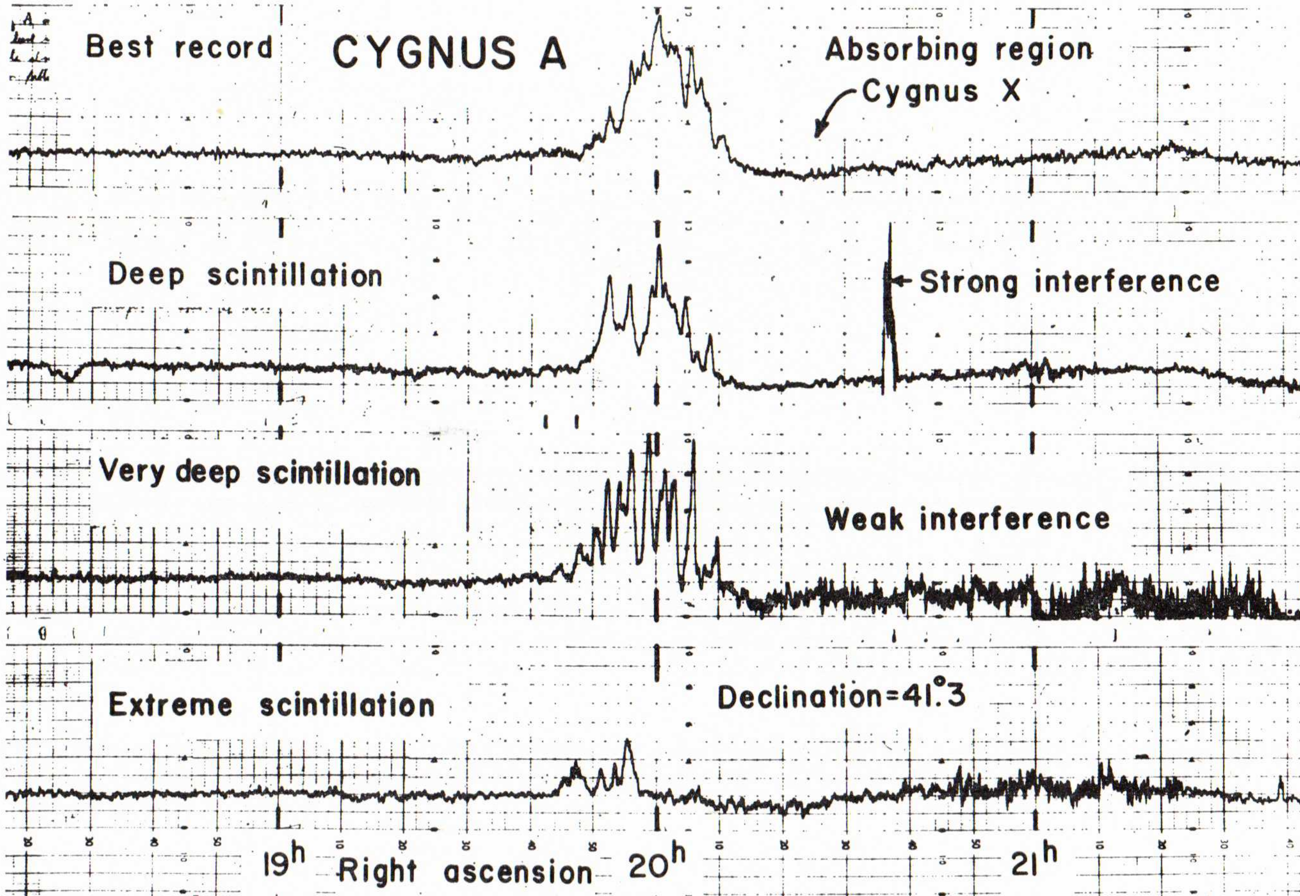

FIGURE 7. Records of the radio source Cygnus A taken on different dates in April 1965 showing the effects of ionspheric scintillation.

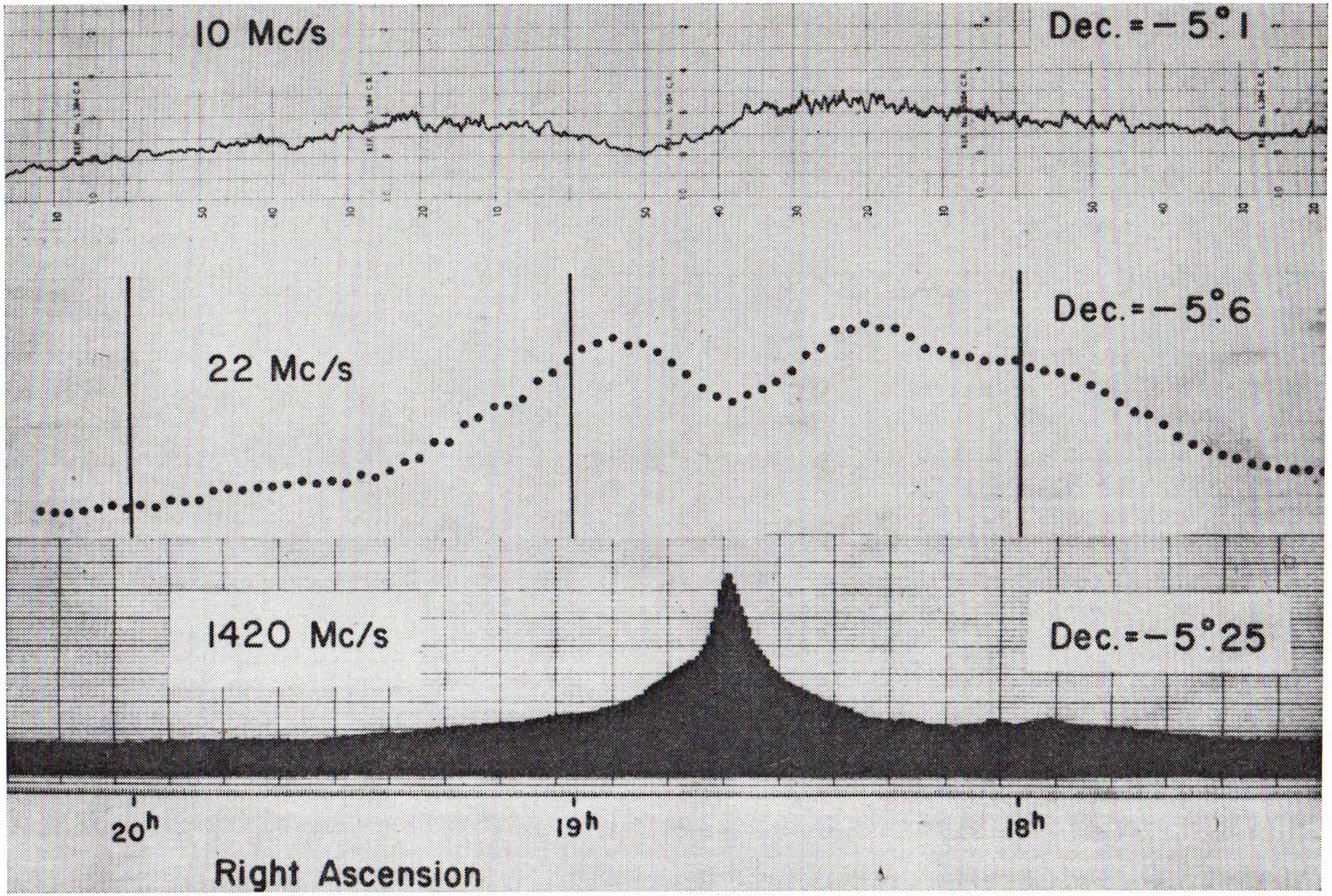

Figure 8. Comparison of the appearance of the galactic plane at three frequencies. The beam width is 2.6° at 10 Mc/s, 3.0° at 22 Mc/s, and 0.6° at 1420 Mc/s.

The Observations

The nature and distribution of the clouds of ionized hydrogen in the galaxy are of considerable interest. These regions usually have a kinetic temperature of the order of 10,000 °K. At high frequencies they are optically thin and appear in emission. At low frequencies, they are often optically thick and appear in absorption against the much more intense galactic background. Observations at high and low frequencies can therefore be used to make an unambiguous identification of an ionized hydrogen region.

A 25.6 m paraboloid, operating at a frequency near 1420 Mc/s, is being used in conjunction with the low-frequency telescopes for studies of this type. Figure 8 shows the passage of the galactic plane through the beams of the three telescopes at a declination of approximately —5°. At 1420 Mc/s, the plane appears as a bright ridge of emission composed of about equal parts of thermal and synchrotron radiation. At 22 Mc/s, there is partial absorption of the background radiation along the galactic plane and at 10 Mc/s almost complete absorption.

A full-sky survey has been carried out using the interior portions of the 22 Mc/s array. The beam width for these observations was 3.0° by 3.4°. A preliminary map of the regions $\alpha = 16^h$ to 21^h, $\delta = -20°$ to $+20°$, is shown in Figure 9. The region of strongest absorption along the galactic plane is shaded. The contour interval is 10,000 °K and the brightness temperatures range from 30,000 °K to approximately 300,000 °K near the plane.

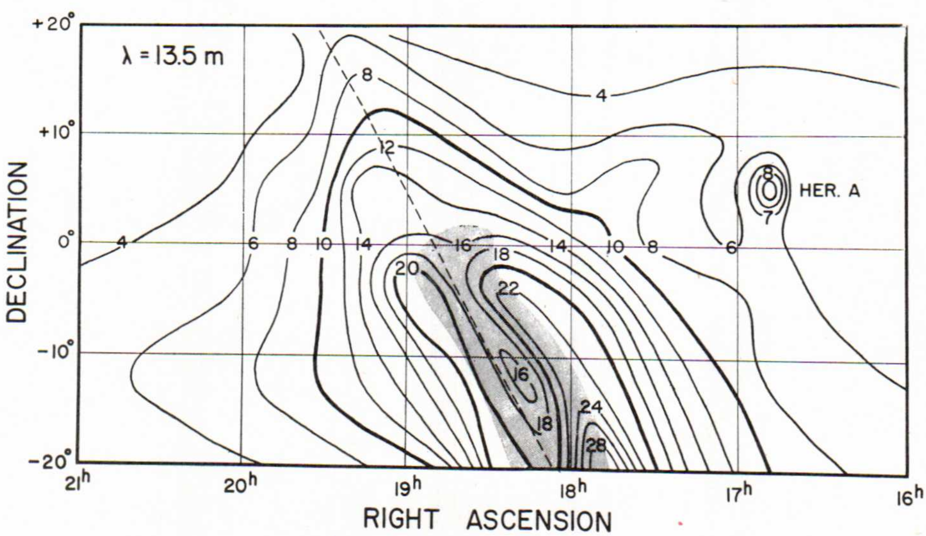

Figure 9. Preliminary map in the region of the galactic plane at 22 Mc/s. The dashed line is the plane of the galaxy. Contour interval is 10,000 °K. The north galactic spur can be seen just to the left of the radio galaxy Hercules A. (Epoch 1965.)

Observations of isolated H II regions, such as the scan across 3C400 shown in Figure 10, can yield valuable information. If the size and distance of the source are known, the absorption of the background radiation permits a determination of the average emissivity of the region of the galaxy between the source and the earth.

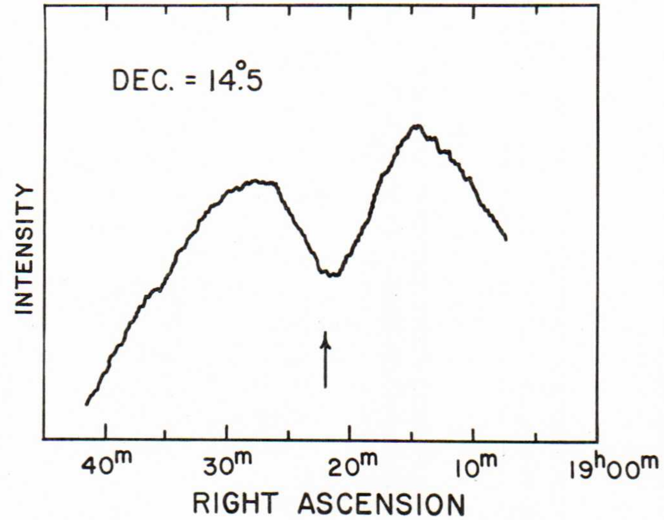

FIGURE 10. A scan across the thermal source, 3C400, taken at 22 Mc/s with a beam width of 1.1°. The arrow shows the position of the source.

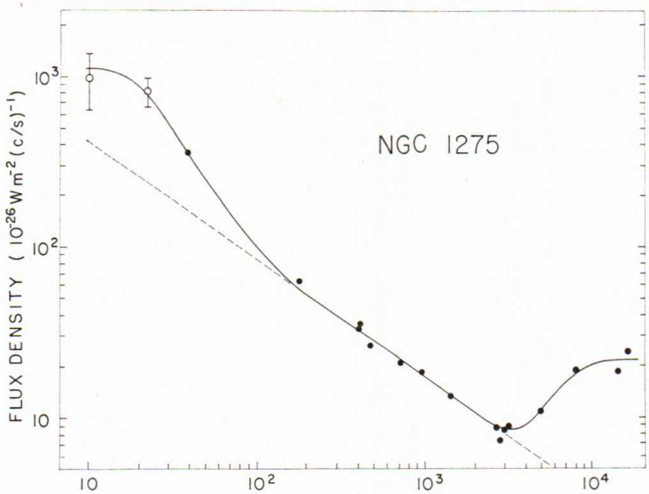

FIGURE 11. The radio spectrum of 3C84 (NGC 1275). [*Note added in proof*. New measurements indicate that the point for 10 Mc/s should be at 2×10^3 flux units with the error bars the same as those shown in the figure. The curve should be altered accordingly.]

The radio spectrum of the source, 3C84, is shown in Figure 11. The 10 Mc/s and 22 Mc/s points were obtained with the telescopes described here, and indicate a substantial increase in the flux density at low frequencies. This unusual radio source is an external galaxy of the Seyfert type (NGC 1275) and has been discussed elsewhere (8, 9).

Summary

A brief discussion is given of the need for low-frequency radio astronomical studies of galactic and extragalactic objects. Some of the observational limitations imposed by the ionosphere are less severe during the minima of solar activity. Two large radio telescopes, operating at 22 Mc/s and 10 Mc/s, have recently been constructed at the Dominion Radio Astrophysical Observatory. The aerials provide "pencil-beam" responses of $1.1° \times 1.6°$ and $2.6° \times 2.4°$ at 22 Mc/s and 10 Mc/s respectively. Both systems are described and some preliminary scans across the galactic plane are presented. A map is presented showing a portion of the galactic plane at 22 Mc/s in the region $\alpha = 16^h$ to 21^h, $\delta = -20°$ to $+20°$. The unusual radio spectrum of the source, 3C84, is shown.

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