

Contributions of

OVERSEAS OBSERVATORIES

By *B. F. Burke*

BEFORE sketching the activities in radio astronomy elsewhere in the world, let me start with a brief historical survey. Radio astronomy had its beginnings in the United States, with the pioneer work of Jansky in the early 1930's, followed by Grote Reber in the late thirties and early forties. Jansky, in the course of radio atmospheric studies at the Bell Laboratories, showed that at meter wavelengths the dominating source of noise is not terrestrial but celestial, with the radio intensity at 15-m wavelength varying as a function of position in the sky. The most intense radiation came from the Milky Way in the direction of Sagittarius, which was known to be the direction of the center of our galaxy. Reber, who worked in his own back yard at Wheaton, Illinois, produced the first maps of sky brightness, at the somewhat shorter wavelength of 1.5 m and later at 70 cm. Taken together, these pioneer observations of Jansky and Reber raised puzzles which were inexplicable by existing theories and indeed are not yet settled, for the sky brightness was several orders of magnitude greater than expected. American physicists for the most part remained oblivious to this particular large-scale puzzle of nature, and it remained for physicists and astronomers abroad to make most of the advances during the decade which followed World War II. Four groups have been outstanding: the Radiophysics Laboratory of CSIRO in Sydney, Australia; the English radiophysics groups at the Cavendish Laboratory and the University of Manchester; and the astronomers of the Observatory of Leiden, Holland.

The work of Jansky and Reber had its first impact in Holland during the War, when Reber's first article was received in 1944. The Dutch astronomers were in a state of enforced inactivity at the time, and Professor Oort held a seminar based on Reber's article. During the course of discussion he remarked that continuum radiation was fine, but a discrete line in the radio region would be even better, and shortly thereafter his student Van de Hulst found that the hyperfine splitting

of the ground state of atomic hydrogen offered the most promise. This, the well-known 21-cm hydrogen line, was first observed in 1951 by Purcell and Ewen at Harvard, and within six weeks was detected by the Dutch and Australians as well. Subsequently, the Leiden astronomers under the leadership of Oort and Van de Hulst have been vigorously pursuing the study of the 21-cm radiation, which has been a powerful tool in the study of our own galaxy, particularly. Most of our galaxy is invisible to the optical astronomer, because of obscuration by interstellar dust in the plane of the Milky Way. Radio-frequency radiation is unhindered by the dust and consequently the radio astronomer can observe the most distant parts of our own galaxy. Since the natural line width is very narrow, observations of the Doppler-shifted line shape give a representation in velocity space of the hydrogen distribution in the galaxy. If one has a model of the velocity field in our galaxy it is possible to convert observed Doppler shift to distance and the first Dutch results, supplemented by the Australian observations in the southern sky, have given us our first idea concerning the large-scale structure of the Milky Way. In this model it was assumed that the hydrogen gas traveled in circular Keplerian orbits, and that the variation in velocity as a function of distance from the center of the galaxy was the same as that deduced from the observed motion of stars in our vicinity. It was immediately apparent that the neutral hydrogen was not distributed continuously, but rather was concentrated in lanes, suggesting the spiral structure observed in other galaxies similar to our own. Their diagram contains the seeds of its own destruction, however, for a close look shows that the features are decidedly anthropocentric. The northern hemisphere observations show nearly circular features on the far side of the galaxy, while the Australian observations in the southern hemisphere show arms that are much more sharply inclined. Clearly, something is not quite right in the initial assumptions.

In the last several years, the Dutch have been concentrating on the central portion of the galaxy. Here,

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A re-enactment at the Leiden Observatory of one of the great moments of modern astronomy when H. van de Hulst (right) presented his prediction that the hydrogen gas of interstellar space would produce a discrete line at a wavelength of 21 cm. J. H. Oort, director of the Leiden Observatory, is seated in front row, far right.



the observations run counter to expectation in a more striking manner. The evidence is very strong that the motions are decidedly noncircular. In fact, a tentative model deduced from observations is shown in Fig. 1. At the very center there appears to be a disk about 300 parsecs in radius, rotating rapidly. Outside is a ring of radius 600 pc or so, also rotating with a high circular

velocity of 265 km/sec. These imply a great concentration of mass in the center. Outside of this region the first spiral arms are observed, but instead of simple rotation the observations can only be fitted by superimposing an expansion of 50 km/sec upon the Keplerian rotation of the gas. In addition, throughout the entire central regions, hydrogen appears to be streaming out with radial motion up to 200 km/sec. A total outward flux of about one solar mass per year of atomic hydrogen is apparently involved. This would exhaust the gas in the central region within 10^8 years, and clearly some source must be found. It is evident that ideas on the nature of this peculiar cosmic engine are in rapid state of flux as a result of these Dutch observations. In addition, the Leiden astronomers have been using their 84-foot dish to study the radio continuum.

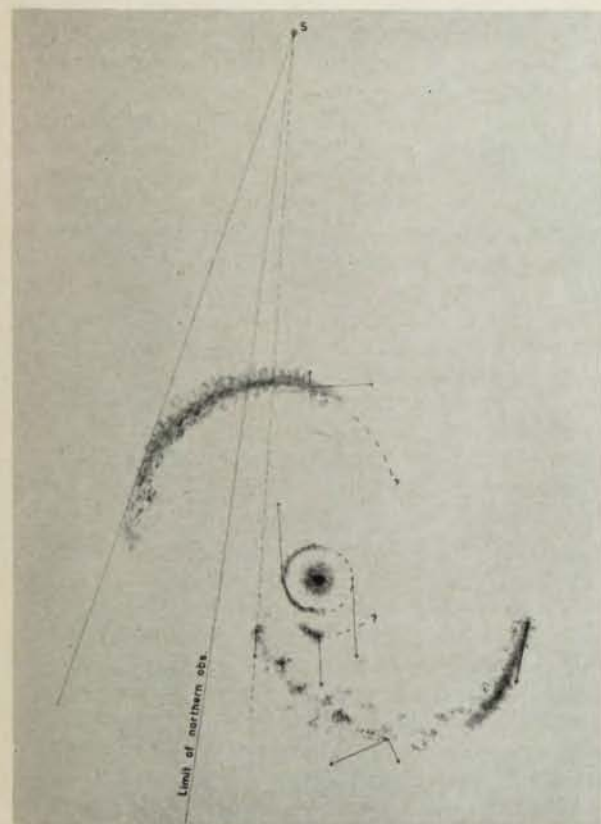


Fig. 1. Schematic representation of hydrogen gas in central portions of the galaxy with relative position of sun shown at S. (Rougou and Oort)

LET us turn now from radio spectroscopy to the study of the radio continuum. Here, it is difficult to separate the activities of the Cambridge and Sydney groups, who have been active competitors ever since the late forties. It is important to realize that we are dealing with several kinds of radio noise: the smooth general background, associated with our own galaxy; the galactic sources, which are localized sources of radio emission in our own galaxy, many of them apparently remnants of old supernovae; and the extragalactic discrete sources, which are immensely powerful emitters of radio radiation, associated with various sorts of peculiar galaxies, some of which are at enormous distances. Most of the Cambridge and Sydney measurements have been at meter wavelengths, where high resolving power is extremely difficult to achieve. It is well known that high resolving power requires apertures of many wavelengths, and so to achieve the resolving power of the unaided human eye at a 3-m wavelength would require an aperture some 10 km across. Evidently one must resort to trickery to circumvent this fundamental limitation.

At both Cambridge and Sydney it was realized very early that it is not the power-gathering capabilities of

a large aperture that was needed, but rather the Fourier information. We may regard the sky brightness as a two-dimensional Fourier integral whose amplitude at various spatial frequencies must be measured. A completely filled aperture gives redundant information, far more than is required, and so the approach used was to design systems which made as complete a set of measurements as possible on the amplitude of the Fourier transform of the brightness distribution. The first steps at both Sydney and Cambridge involved use of simple interferometers to measure the amplitude of one spatial frequency only and then various spacings and orientations were used to sketch the rough properties of the discrete sources. In this way the positions and rough angular sizes of the brightest sources were obtained and the first identifications of radio and optical objects made possible. In recent years the most thorough example of this technique has come from Manchester, where brightness distributions of the two brightest radio sources have been measured, using several different interferometer techniques. The reconstructed brightness of the Cygnus A radio source, a faint but extremely peculiar galaxy several hundred million light years distant, shows that it is in reality a double source, much larger than the optical object. Interferometer spacings up to 10 km were needed to construct their model.

The next step, of course, has been to measure many Fourier components at once, and here the paths of Sydney and Cambridge diverge. At Sydney, Mills constructed the first example of what has come to be known as the Mills Cross. Rather than fill up an entire aperture with small elements, two linear arrays of dipoles are used. The outputs of the two arrays are multiplied instead of added, the resulting antenna pattern being equivalent in information-gathering capability to the solid aperture shown in Fig. 2. Since the number of elements increases linearly rather than as the square of the aperture diameter, a great saving in complexity is gained. Mills' antenna is about 1600 ft each way, the wavelength 3.5 m, and the resulting pencil beam 50 min of arc to half-power points. With this, a map of the galactic background and the discrete sources over a wide strip of sky has been produced.

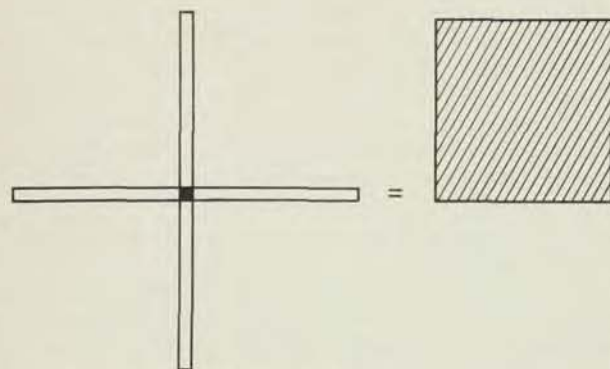


Fig. 2. Mills Cross and equivalent completely filled aperture.

At the Cavendish Laboratory a different philosophy has been followed. Initially, a compound interferometer was used, with the belief that the small discrete sources can be picked out readily with an interferometer by their large Fourier amplitude, while the slowly varying background is suppressed. The individual antennas were large cylindrical paraboloids 300 ft by 40 ft, and were used individually for studying large-scale features. The instruments at Cambridge and Sydney have been used at nearly the same time, the results being in one instance in gratifying agreement, and in the other case in radical disagreement. Let me first discuss the agreement.

From its symmetry, it has been clear that the smoothly varying radio background was in large part associated with our galaxy. From both the Sydney and Cambridge observations, it has been shown that our galaxy is imbedded in a more or less spherical, uniformly emitting sphere which has been called the galactic corona. So far, the corona can only be deduced from the radio observations, and it has been suggested that the source of radio emission arises from the magnetic bremsstrahlung of relativistic electrons circulating in a weak magnetic field of perhaps 10^{-6} gauss. If this is so, a large amount of energy in our galaxy is contained in this corona.

With respect to the discrete sources, the agreement has been less striking. For a while, it looked like the northern and southern skies had completely different character, a geocentric effect which seemed suspicious. In recent years, the disagreement has diminished, and for the stronger sources reasonable concordance exists.

A central purpose of both surveys was aimed at a very large problem indeed. Many of you have heard of Olber's paradox, which in its more modern form can be expressed by saying that if the universe consisted of galaxies scattered at random throughout a static Euclidean space, the sky should appear uniformly bright. This prediction is easily disproved by a quick look outdoors on any clear night. The optical case has been taken care of by modern cosmology, but there are rival systems of very different character between which we cannot decide on the basis of optical observations alone, because the more distant galaxies are so faint. The extragalactic radio sources are known, in some cases, to be so intense that extremely distant objects, well beyond optical limits, should be easily detectable. Consequently, when one counts the number of radio sources observed as a function of intensity, there is a hope that observation will support one or another of the existing cosmological models. In fact, the two sets of observations seem to disagree. Naïvely, one would expect to find that the total number of sources above a given intensity, I , should vary as $I^{-3/2}$. In actual fact, the Sydney observations have a slope of -1.7 , while Cambridge sees a slope of -2.2 . There are reasons to believe, however, that neither result bears directly on cosmological problems.

Another approach is now being pursued at Cambridge. The method is referred to as "aperture synthesis" and has a family resemblance to the Mills Cross. If we have

The Manchester University 250-ft steerable paraboloid radio telescope at Jodrell Bank, Cheshire, England, as conceived by an artist in 1952, before it was built.



a single array, as shown in Fig. 3, together with a small array, as shown, and the outputs are multiplied, the resulting Fourier information is equivalent to that shown in the shaded area. If one now takes a series of measurements, moving the small antenna north and south by increments of its own width, one has all the information given by the equivalent Mills Cross. The Fourier recomposition can be done with ease by modern computers.

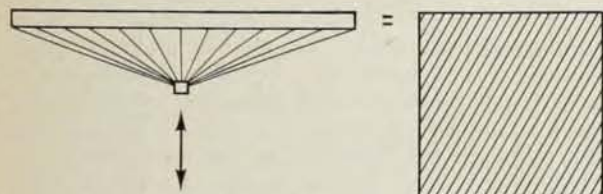


Fig. 3. Aperture synthesis with linear array and single element.

Three instruments of this sort have been built, one small one by Blythe to test the method, and two are now in use—one at 1.7 m wavelength, consisting of a cylindrical paraboloid 1450×65 ft, with a 190×65 ft traversing element, and another 3300 ft long, having 1700 ft traverse, for a wavelength of 7.9 m. The results are being awaited with interest.

At Manchester there is an instrument which all of you, I am sure, have heard about—the 250-ft steerable paraboloid. Much of its time is taken up with satellite tracking, but other activities are also being pursued. A very nice map of the Andromeda nebula has been made, showing that it has a galactic corona much like our own. In addition, a large number of other normal galaxies are being studied. One very interesting program is being carried out, involving use of the large paraboloid as an interferometer together with smaller antennas at varying spacings. The principal purpose is to measure the rough angular sizes of a large number of radio sources, for it appears that this parameter is much more sensitive to cosmological models than the apparent intensity is.

ANOTHER field of great activity abroad has been the study of our own sun at radio wavelengths. This is an extensive branch of radio astronomy, representing perhaps half the total activity around the world, but I shall only describe briefly one recent achievement, from Sydney, which has been for fifteen years a world leader in solar studies. The outbursts of extraordinarily intense radiation from the active sun have been shown to have complicated spectra, both in frequency and time. A particularly interesting class of radio bursts was discovered by Wild, at Sydney, to be concentrated in a narrow band, with the center frequency drifting in time from high to low frequency. He interpreted this as implying excitation of plasma oscillations by a disturbance moving outward through the solar corona, the plasma frequency decreasing as the electron density decreased. Two classes of burst were found, one moving apparently at 300 to 1000 km/sec, exhibiting a harmonic structure, the other type moving much more rapidly, at $1/3$ to $1/2$ the speed of light. The former seemed to suggest the streams responsible for magnetic storms and aurora, while the latter strongly suggested solar-produced cosmic rays. Over the last two years, it has been shown at Sydney that the change in angular position of the emitting centers was indeed consistent with such velocities, the fast-moving bursts exhibiting rapid changes in position when they started near the solar limb.

In closing, I should also mention the active French group at Meudon, who have discovered another class of solar radio emissions, coming from restricted regions high in the solar corona. The observations strongly suggest that the emission arises from synchrotron radiation by relativistic electrons trapped in a magnetic bottle in the corona of the sun. Their observations are particularly interesting because the phenomenon appears to be particularly well defined, and may represent an especially simple event. Perhaps it is on our own sun, in the end, that we will find the solution to the puzzle of how such large quantities of radio noise can be produced by such a variety of objects in the universe.