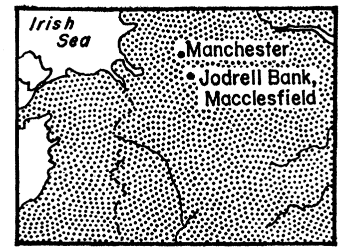


# Jodrell Bank Observatory

Since 1957 Jodrell Bank Observatory and its controversial director, Sir Bernard Lovell, have been frequently in the news. The observatory has especially good facilities for radio astronomy, including the world's largest fully steerable antenna, a 76-meter (250-foot) dish.

A famous early use of the 76-meter dish was for tracking of Russian and American satellites, starting with Sputnik I. Although the tracking and data acquisition have taken little of the telescope's time, the activity has earned money ($140 an hour from NASA) and much good will both from Americans (who have stayed at the observatory for long periods) and Russians (who have visited occasionally and who get repeated warm invitations to return for longer, cooperative studies). Lovell eagerly cultivates close association with astronomers on both sides of the iron curtain, a course which won him an interview with President Eisenhower after the tracking of Pioneer V out to 30 million kilometers and made him the channel, in 1963, for Soviet Academy of Sciences President Keldysh's view that manned lunar landings are unlikely in the near future. Lovell reported in 1963 (*New Scientist*, 25 July, p. 174) that he is trying to get an interferometry program going with the Soviet deep-space tracking array in the Crimea. So far, he is the only Westerner to have visited the installation.

So, Jodrell Bank became the focus in February and March of a series of experimental transmissions from the U.S. to Britain and from Britain to the Zimenki radio receiver near Gorki in the Soviet Union via the aluminized orbiting balloon Echo II. J. G. Davies led Jodrell Bank's participation in the work. He reported that the experiment was technically interesting but, so far, "not much of a communications link." The most successful transmissions were of highly contrasting facsimile photographs. Reflections off the moon were tried simultaneously with transmissions via Echo II.

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### Superenergetic Objects

Satellite tracking is regarded as a relatively minor sideline at Jodrell Bank, which concentrates on radio astronomy. It was collaboration between radio and optical astronomers that led to the identification, beginning in 1962, of a number of what appear to be very distant objects radiating huge quantities of energies from a small volume. These objects have aroused intense discussion and were the subject of a special international symposium in Dallas in December 1963 (*Scientific American*, Dec. 1963, p. 54).

But even before the recent discoveries, scientific prospects had already led astronomers to start building or planning a host of new instruments: a new photoelectric stellar interferometer in Australia, a 254-centimeter (100-inch) reflector in England, a 600-centimeter reflector to be built in the Soviet Union (perhaps in the Caucasus, around 1975), a 350-centimeter European reflector in Chile, the "Benelux cross" array of parabolic antennas, and an array of three 185-centimeter paraboloids at Cambridge University.

One of the major collaborators is the Jodrell Bank Observatory, which conducted a sharp-resolution survey of the diameters of radio sources before study of the puzzling superenergetic objects was begun. The Australian stellar interferometer was designed at Jodrell Bank.

The Jodrell Bank Observatory concentrates on such work as:

Studying (in collaboration with optical observers) what appear to be true flares from distant stars;

Making measurements, by interferometry, of the angular diameters of radio sources;

Using emission from neutral hydrogen to examine the distribution of matter from which new stars can be formed in this and other galaxies;

Studying neutral hydrogen emission for evidence of magnetic fields in gas clouds and polarization of radiation from other galaxies;

Using neutral hydrogen absorption in efforts to make a different measurement of the astronomical unit—the distance between the earth and the sun.

When Venus reaches the point in its orbit that is nearest the earth, as it will again in June, radar echoes are obtained for studying its rotation rate and its surface and for measuring the astronomical unit. To obtain accurate readings of their positions, radio sources are studied at the time of occultation by the moon, when the moon blocks out their signals for up to an hour. As part of an international program that is continuing into the IQSY, signals from satellites are recorded for measuring irregularities in the total electron content of the ionosphere.

In studying radio emission from "flare stars," Lovell has worked with Fred L. Whipple and Leonard H. Solomon of the Smithsonian Astrophysical Observatory (*New Scientist*, 25 Apr. 1963, p. 190). They have paid particular attention to a binary star called UV Ceti, a faint red dwarf about 8.6 light years away. Since the late 1940's, optical flares have been observed in UV Ceti, some of which have increased its brightness 6 times, some as much as 250 times. Despite a lack of agreement over the physical mechanism that might be operating, Lovell was led to think, some years ago, "that from the radio point of view the stars might be reasonably expected to radiate like the sun in one of its more violent phases."

But Lovell knew well that the radiation of the flare stars must be greater than that if we are going to detect it. If the sun were translated to the distance of UV Ceti—544,000 astronomical units away—its radiation would be diminished by a factor of $10^{11}$, and thus even the brightest flares would be "near the limits of detection of modern equipment."

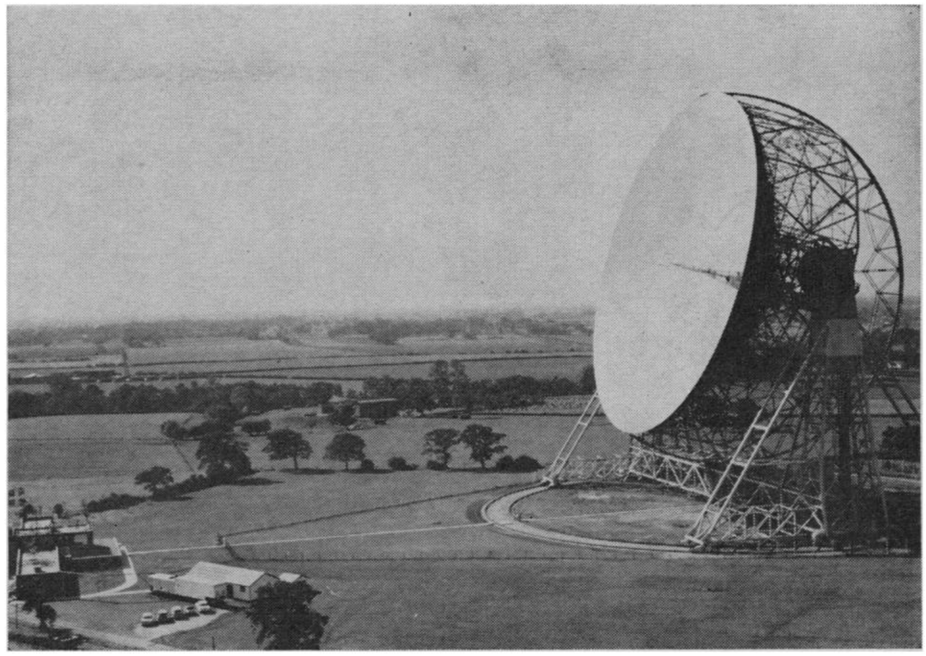
From late 1958 to 1960, Lovell had studied the radio output of UV Ceti and other flare stars and had found what he thought were 13 possible instances of true flare activity. But he could not be sure; an effort to make joint observations with an optical observatory at Cambridge had failed because of bad weather. So Lovell turned to the Smithsonian, and the joint program began. By now, it has run to thousands of hours of observations. The data from many of these observations have not yet been reduced.

A year ago, however, Lovell, Whipple, and Solomon reported the first six series of observations, scattered over a year, from September 1960 to October 1961. Besides the 76-meter dish at Jodrell Bank, five of the Smithsonian's Baker-Nunn cameras were used—in Iran, Curaçao, Argentina, Spain, and South Africa. Jodrell Bank received on a frequency of 240 megacycles (and later on 408 megacycles as well), with one receiver at the focus and the other well removed to cover portions of the sky adjacent to the star and to serve as a control. According to the experimental design, if any of the radiation were terrestrial in origin, the two receivers should record it simultaneously. Camera exposures of up to 15 seconds were made at intervals of 3 minutes, and later of 2 minutes.

The radio observations totaled 727 hours, the camera observations, 216. The period of good overlap was 166 hours, and in that time there were 23 minor optical flares on UV Ceti. The integrated radio record indicated a definite increase just before and a few minutes after the peak of the optical flare.

Lovell, Whipple, and Solomon report indications that the flares come from the fainter of the two stars in the binary. The fainter star has a diameter about 9 percent of the sun's. If the fainter star is responsible for the flares, then a 0.55 magnitude flare on it would appear, at the distance of the sun, as a disk temperature of $10^{15}$ degrees Kelvin, or 100 times the temperature observed in severe flares on the sun's surface.

The discovery of a correlation between flares and radio emission from UV Ceti led Lovell, Whipple, and Solomon to speculate that flare stars could be responsible for a small percentage of the radiation of our galaxy, which has been attributed for the past decade to the thermal ionized hydrogen radiation and the nonthermal synchrotron radiation described theoretically by Soviet scientist I. S. Shklovsky.



Radio telescope at Jodrell Bank. [British Official Photograph]

More recently, the three noticed a different sort of flare from UV Ceti, one in which the radio peak came a few minutes after the optical peak. They said this flare seems to resemble the "drift type" of radio bursts from the sun. The radio peak from a type II solar flare comes 5 to 20 minutes after the visual peak, whereas the radio peaks from UV Ceti on frequencies of 240 and 408 megacycles came within the first 4 minutes after the visual peak.

Next to an accurate position, which may permit identification with a visible object, perhaps the most vital piece of information about a radio source is its diameter and the variation of radiation across it, which may yield information about the source's fine structure.

It was the finding that certain extremely bright "stars" had radio structures less than a second of arc across that started the hunt for the superenergetic objects, which many astronomers feel are the most important discovery to emerge from astronomy since Edwin Hubble's finding of "red shift." The surveys which revealed the small objects were conducted at California Institute of Technology as well as at Jodrell Bank.

A number of the most interesting radio objects—radio galaxies or something smaller—divide into two invisible components, one on each side of an optical star-assembly. One of the puzzling superenergetic objects—3C 273, studied by lunar occultation at Parkes, Australia, at Jodrell Bank, and at Cambridge, and studied optically at Palomar—seems to divide into two components, and the one that is almost invisible apparently provides 90 percent of the radio energy.

The most distant identified object, 3C 295—whose red shift indicates it is receding at nearly half the speed of light—is divided into two components less than 4 seconds of arc apart; it resembles Cygnus A, which is much closer and is one of the most powerful of the radio sources. Both these objects appear to be radio galaxies, not super-energetic objects.

To get these data, radio astronomers normally use interferometers with elements widely separated (up to 115 kilometers in the Jodrell Bank system), in order to approach the resolutions available to optical astronomers working at wavelengths shorter by 5 to 7 orders of magnitude. Another method is to use occultation by the moon, whose motions are known to within very small margins of error.

**Radio-Source Diameters**

The most recent survey of radio-source diameters at Jodrell Bank was completed in 1961 [*Monthly Notices* *of the Royal Astronomical Society,* **124**, 477 (1962)] under the leadership of H. P. Palmer. The 76-meter dish was used, and a remote cylindrical paraboloid antenna linked by microwave and operated at 158 megacycles, or wavelength of 1.89 meters. Using two nearby sites first, the interferometry group then moved to a seaside site, in North Wales, 60 kilometers away, but got only 3 weeks' good observations. The remote antenna was finally removed to Lincolnshire, 115 kilometers away; by this time only five sources remained unresolved. To study these sources of very small diameter, the interferometry equipment has been converted to operate at 408 megacycles, or wavelength of 75 centimeters. An easily transported 8.3-meter wire-mesh dish has been placed at a site called Bishop Wilton Wold in Yorkshire, 135 kilometers to the northeast. As before, the remote dish is linked to Jodrell Bank by microwave. Instruments recording from the remote dish are monitored by a television camera.

The first observations with the 75-centimeter system were made last fall, but Palmer said at Jodrell Bank recently, "We don't quite understand yet what we're getting."

Starting in 1965, if all goes well, Palmer's group should also have partial use of a much larger and more sensitive remote instrument: an elliptical wire-mesh telescope, known at Jodrell Bank as Mark III. It will receive at frequencies up to 1000 megacycles, operating first in a rented field about 25 kilometers away. The 38- by 25-meter Mark III, which is to cost about $280,000, is designed to be taken down, moved, and reinstalled in a new site in about 6 months. Reginald Lascelles, the observatory's administrative officer, says it is hoped that contracts for the device will be let this month.

It is expected that the 75-centimeter survey will take up about a quarter of the 76-meter Mark I telescope's time over the next 3 to 4 years.

A pioneer in this interferometry work was R. Hanbury Brown, who is still attached to Jodrell Bank, although he now holds a professorship in astronomy at the University of Sydney. Hanbury Brown and R. Q. Twiss worked out one of the radio interferometry systems which permitted the use of long baselines.

The first device, at Jodrell Bank, was constructed out of two searchlights. Since "the correlation between the fluctuations in the outputs of two photoelectric detectors illuminated by a source of finite size depends on the angular distribution of brightness over the source," Hanbury Brown and Twiss were able to obtain, in 1956, an angular diameter, 0.0071 second of arc, for Sirius.

Out of this success was born the stellar intensity interferometer now nearly completed at Narrabri, 480 kilometers north of Sydney. Two 6½-meter mirrors, each composed of about 250 small six-sided mirrors, are mounted on a circle of railway track whose diameter is about 185 meters. The device is designed to measure stellar diameters down to 0.0005 second of arc. Recently, Hanbury Brown and several of his Australian colleagues reported success, last July and August, in getting a value of 0.0037 second of arc for the star Vega, or Alpha Lyrae, a star with about the effective temperature of Sirius (9400°K) and of about three times the diameter of the sun. The diameter of Vega is about a tenth the minimum value obtained by Michelson when he used the Mount Wilson telescope 40 years ago to measure the diameter of Betelgeuse (*New Scientist,* 19 Mar. 1964, p. 730).

### Neutral Hydrogen Absorption

Another Jodrell Bank investigator with strong ties to Australia is R. D. Davies, leader of the group making observations on the neutral hydrogen frequency, at wavelength of 21 centimeters. He returned in January from a year of work with the 64-meter telescope at Parkes, Australia, where he collaborated with F. F. Gardner in a survey of the polarization of 150 radio sources. Davies and Gardner have already published observations of a three-component radio source, which appears to have a high degree of order in its magnetic field.

Davies is now preparing for continued studies of neutral hydrogen absorption at 1420 megacycles, from such sources as the Crab Nebula (Taurus A in radio terminology) and Cassiopeia A. The absorption spectra are very narrow, being only 10 to 20 kilocycles wide. By measuring the frequency of the absorption features of these sources twice a year, when the earth is moving fastest toward and fastest away from them, a measure of the radius of the earth's orbit around the sun can be obtained. It is hoped that the difference between the optical and the radar measurements of the radius of the earth's orbit will be resolved.

R. D. Davies is also working on the details of a survey of the distribution of neutral hydrogen in the nearby spiral galaxy, the nebula in Andromeda. The hydrogen extends much farther than the visible stars. Near the center of the galaxy, where theories predict exhaustion of the neutral hydrogen by absorption into stars, there is a marked gap in the 21-centimeter radiation.

Several years ago, studies of the absorption of radio emission from the source Cygnus A (3C 403) failed to show any absorption at a frequency 30 megacycles below 1420 megacycles (where observers reported having found absorption), apparently refuting the hope that there might be radio "red shift" comparable to the optical red shift, and thus an independent measure of distance.

Davies and his associates have also failed to detect any magnetic fields in the interstellar medium which are sufficiently large to hold together such structures as the spiral arms of our galaxy. The strongest galactic magnetic field indicated by Zeeman splitting of neutral hydrogen has been $1.5 \times 10^{-5}$ gauss in a single feature of the Crab Nebula absorption spectrum. Absorption features in Cassiopeia A have an upper limit of $4 \times 10^{-6}$ gauss.

But the linear polarization studies at Jodrell Bank, at Sydney, and in the United States may lead the way to new methods for classifying radio sources. In some cases radio sources may possess high polarization (around 10 percent). Correlation with other parameters of the radio sources, such as the spectrum or brightness temperature, may divide the sources into classes. But the correlations are complex and are being investigated for a large group of sources. So far, the polarization seems unrelated to red shift (and thus to the distance of the stars), indicating that there is little, if any, magnetic field between even very distant sources and the earth.

### Meteors

J. G. Davies has pioneered Jodrell Bank's study of meteors. Since 1960 he has been observing a dense but thin stream of meteors called the Giacobinids, which, calculations at Jodrell Bank have shown, were ejected from the comet Giacobini-Zinner in 1894. The earth intersects this stream occasionally, and meteor counts of 10,000 an hour were noticed in 1933 and 1946, while the count was only 100 an hour in 1952. The comet has a period of 6.5 years on its orbit, which reaches out near Jupiter and suffers considerable perturbation from the influence of Jupiter's gravity.

**The Observatory**

The telescope which does this immensely varied work stands in farm fields southwest of Manchester, just to one side of a suburban railway line, not far from a superhighway and a number of dense little villages.

By friendly agreement with the local planning authorities, every project within a 6-mile radius is cleared with the observatory. This arrangement is important, because Manchester is crowded, and local landholders could make a lot of money selling farmland for housing developments. Local communities are generally allied with the observatory, since carefully planned and restricted development prevents the building of a lot of houses where there are no municipal facilities like sewers, water lines, and power lines.

As administrator Lascelles puts it, the observatory can hardly object to a farmer's installing a better transformer to power his equipment. But what would kill the telescope's usefulness is the large number of unshielded electrical systems in cars that would be attracted by dense housing development. These, and the projected increase of a large 220,000-volt power line to 400,000 volts are the biggest worries. The nearby Manchester jetport and the superhighway are far less bothersome, because their traffic intercepts the telescope beam for very short periods.

Hence, the observatory objects to nearly every proposed development project within 2 miles, and to any construction within 6 miles to the south, the direction of the center of the galaxy.

Part of the land was taken over by the University of Manchester in the 1930's for botanical experiments. Other plots were added later, after Lovell moved out to the site in 1946 and set up, in 1948, a 66-meter array that soon identified a radio source that proved to be the nebula in Andromeda. When he started, all Lovell had wanted was a quiet place to study cosmic rays. But the new usefulness of the fixed array made Lovell, a veteran of World War II radar development, think of a fully steerable dish of the same size as the array.

It was planned, and its cost was fixed at around $1.1 million, to be met, in roughly equal amounts, by the British Government's Department of Scientific and Industrial Research (DSIR) and the Nuffield Foundation. Then the Korean war skyrocketed the price of steel. Lovell also decided, after the important first results with 21-centimeter radiation were observed at Harvard and followed up in Holland, that the instrument should be stiffened for this band.

DSIR went along for another $364,000, but when the bill was finally added up, the university was still $392,000 short. When no more money was forthcoming from the government, a public appeal was launched. Industrialists, NASA payments, and $140,000 from Lord Nuffield and his foundation put the drive over.

Meanwhile, there was angry inquiry in Parliament over the boosted costs, ultimately silenced by the prestige and scientific success of the instrument and the university's firm backing of Lovell. Nonetheless, the building of two large new telescopes, Mark II, at a cost of $850,000, and of Mark III, are firmly under the control of a committee and the Ministry of Public Building and works.

The university's postmortem on the affair was that "one of the errors that was made was that we treated this very large structure as a piece of departmental equipment rather than as a building project." The case seems to be regarded as closed all round.

The Mark II, now under construction a few hundred yards from Mark I, is a 38- by 25-meter ellipse of steel plates; it will receive at frequencies up to 10,000 megacycles (or wavelength of 3 cm).

The reason for building the new telescope is put this way in an observatory statement: "Although the Mark I telescope is the largest instrument in the world capable of work on the important hydrogen line wavelength . . . this is near the limit of its performance. The possibility of carrying out some of the current hydrogen line studies on the Mark II instrument will help to release the Mark I for new programmes . . . at lower frequencies. In another important programme, the Mark I and Mark II telescopes will be used simultaneously for the measurement of positions of radio stars by the lunar occultation technique developed at this observatory."

Another important reason for building the telescope emerges from a recent collaborative study of the intensities of radio sources, conducted by Jodrell Bank, the Mullard Radio-Astronomy Observatory of the University of Cambridge, and the California Institute of Technology [*Monthly Notices of the Royal Astronomical Society*, **125**, 261 (1963)]. If one plots the intensity of the radiation against the frequency on a logarithmic chart, many of the curves fall into a simple straight line, obeying a "simple power law." But a number of radio sources, among them some of the most powerful and most interesting, produce curves that tend sharply downward at wavelengths above 21 centimeters.

Thus, radio astronomers show great interest in frequencies between 5000 and 10,000 megacycles, and the new Mark II telescope is expected to be capable of observation at these frequencies by early summer. Up to now, the number of sensitive observations at these frequencies has been small, but the development of masers and parametric amplifiers makes these measurements possible as well as scientifically interesting.

The movements of the new telescope will be controlled by computer. It will be equipped with air-cooled and liquid-nitrogen-cooled parametric amplifiers. The amplifiers will be installed in a 3- by 3- by 3-meter laboratory at the focus, allowing indoor work on the amplifiers in all weather. The focus laboratory of the older telescope is much smaller and more cramped.

The observatory staff numbers about 85, cafeteria help included. The senior research staff numbers 11. In administration there are six, and the engineering staff of fitters, electricians, controllers, and others totals 30 to 40. Most of the 20 to 25 graduate students are aiming for a doctorate in physics.

Over them all presides the gigantic Mark I dish, doubtless much more impressive to a visitor than to a staff member. Planned just a little over a decade ago, when radio astronomy was hardly more than a hope, it is already at the limits of its accuracy.

—VICTOR K. MCELHENY