THE RADIO TELESCOPE

A New Tool of Astronomical Research

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FOR those who are acquainted with the remarkable results achieved during the past few years in radio astronomy the announcement in April that a giant radio telescope is to be constructed at Jodrell Bank, in Cheshire, came as a satisfactory indication of Britain's determination to keep in the forefront of this new science. To others, the proposal to expend over £300,000 and 2,000 tons of steel on an instrument with no obvious practical application may have caused surprise. Some misgivings might also have been felt at the news that the instrument was to be built in a district more commonly associated with cloudy conditions than with clear skies necessary for astronomical research. It may therefore be appropriate to explain why the telescope is being built, and the reason for its location in Cheshire.

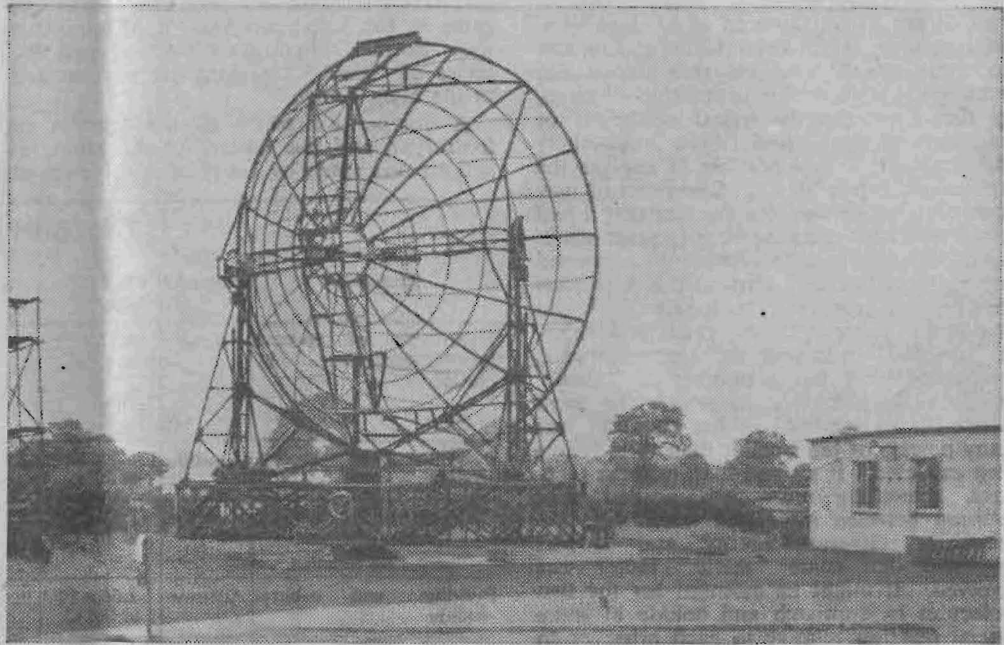
Work is now well advanced on the 500-ton concrete and steel foundation of this giant steerable radio telescope, which will have a paraboloidal steel bowl 250ft. in diameter, 60ft. deep at the centre, alone weighing 300 tons. The bowl is to be supported on steel towers 180ft. above ground, riding on a railway track 340ft. in diameter. The instrument, which has been designed so that it can be directed to any part of the sky and will be able to track a given point in the sky automatically with a precision of about 15 minutes of arc, will have a total weight above ground of well over 1,000 tons.

Great Britain's lead in observational astronomy was firmly established in the eighteenth and nineteenth centuries when the first large telescopes were built by Herschel and Rosse. The subsequent development of telescopes of ever-increasing size made possible the exploration of remoter parts of the universe. These and Eddington's "celestial multiplication table," that "100,000 million stars make one galaxy and 100,000 million galaxies make one universe" remains a trustworthy mnemonic.

In the face of this penetration to the remote depths of space it seemed hardly possible a few years ago that the remaining tasks of observational astronomy could be other than the detailed study of the individual stars and nebulae as seen in the conventional telescopes. Even if many of the details remained obscure, at least the general content of the universe and the various classes of objects contained in it seemed to be established. But by a strange twist of fate the Second World War was to place a new and enormously powerful tool in the hands of astronomers for the exploration of space, and the discoveries of the last few years have rivalled in excitement the more conventional developments on the American mountains.

Almost all astronomical research has been carried out with telescopes and other instruments receiving light waves emitted by the stars in the visual part of the electromagnetic spectrum. Various auxiliary instruments such as photoelectric cells have been used to extend the studies a little beyond the visual limits into the infra-red and ultra-violet regions, but appreciable extension is prohibited by the absorption caused by water vapour and fine dust in the earth's atmosphere. Thus our knowledge of the universe has arisen almost entirely from the study of stellar emissions in this narrow visual and near-visual region of the spectrum. This restricted band of wavelengths in which the universe could be studied caused no concern, since the prominent features in the universe

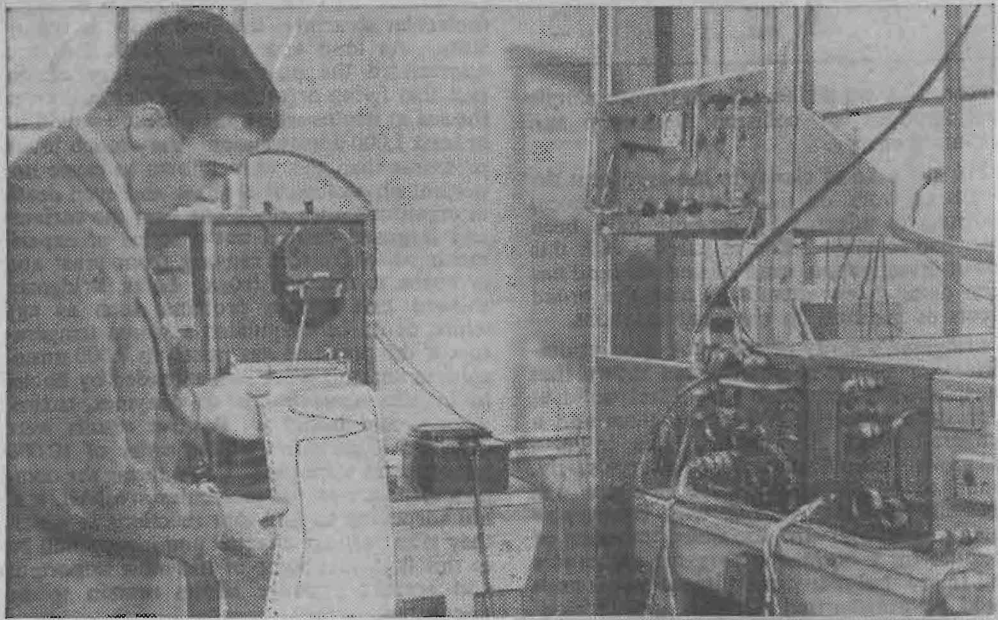
what surprising when an American engineer, Jansky, discovered at the end of 1931 that radio waves, apparently emanating from regions beyond the solar system, were reaching the earth. Jansky's discovery was published in a radio engineering journal and it seems doubtful whether many astronomers knew of his work. Certainly it seems to have caused little interest, and the only important additions to his results before the Second World War were obtained by Grote Reber, an amateur investigator who built apparatus of advanced design in the garden of his home in Illinois. In fact Reber constructed the first radio telescope of the type with which we are familiar to-day. It was 30ft. in diameter and received radio waves on a wavelength of about two metres. This instrument could readily be pointed to different parts of the sky. With it Reber confirmed Jansky's discovery that radio waves were reaching the earth from outer space, and he made the first



Small steerable radio telescope at Jodrell Bank. It has a 30ft. aperture, and is tuned by aerial rods at the focus to receive radiation on a wavelength of three metres.

centration of work on radio and radar for military purposes resulted in technical advances in the space of a few years which might otherwise have occupied a generation of research workers. Equally important was the cooperation in this development of young research workers who rapidly became expert in radio techniques and returned to peace in 1945 with a new insight into the possibilities of these techniques when applied to fundamental research. Even if no particularly startling results were anticipated the strange radio emissions from space provided a clear opportunity for an approach with modern techniques and apparatus, and research groups arose quickly in the radiophysics division of the Commonwealth Scientific and Industrial

...if their potentialities are to be realized,



and the great telescopes of the twentieth century have been built in America on Mt. Wilson and Palomar. The 100in. telescope on Mt. Wilson came into operation just after the First World War and in the hands of a brilliant team of American astronomers quickly revealed a universe of quite unforeseen immensity. Hitherto the assemblage of stars was believed to be contained in a relatively small volume some few thousand light years in extent, with the sun and planets near the centre. The many nebulae to be seen in the telescopes were thought to be diffuse objects lying within this system. The third decade of this century witnessed an astonishing transition in these views. The Milky Way system, or local galaxy, was revealed as disk-like in structure, extending for 100,000 light-years across its plane and containing about 10,000 million stars. Moreover, Hubble's investigations with this telescope soon convinced his colleagues that many of the nebulae were external to this system, and that the nearest one in Andromeda must be separated from the local star system by nearly a million light-years, and must also contain a vast number of stars. Other nebulae were shown to be similar star systems at even greater distances,

... region open to view. It was, therefore, some-

... signals were strongest from directions near the centre of the local galaxy and along the plane of the Milky Way—in fact, that the radio signals were roughly proportional in strength to the concentration of stars in the direction in which the radio telescope was pointing. On the other hand, Reber failed completely to detect any signals from the bright stars or from other prominent features visible in telescopes. This apparent paradox led him to the view that the radio signals were being generated in the very rarefied hydrogen gas which fills interstellar space.

This represented the extent of our knowledge of these radio waves from space in 1945; but the six years lost to fundamental research were soon to appear as a rich investment for astronomical research. The con-

A recent photograph showing part of the 220ft. aperture fixed radio telescope which has a paraboloidal surface formed by a series of wires supported around the perimeter by posts 24ft. high. The aerial at the focus is carried on a 120ft. mast, which is tilted to displace the beam from the zenith. Above: Recording apparatus used with the telscope; the chart shows that the radio star in Cygnus has just passed through the beam of the aerial system.

Operational Research Group in Surrey, the Cavendish Laboratory in Cambridge, and the University of Manchester. The spectacular nature of the results obtained soon attracted workers in other countries and the study of radio astronomy is now pursued in many parts of the world.

The first post-war measurements of the radio waves from space confirmed Reber's results, and there seemed to be no direct connexion between the radio signals and the astronomical objects such as stars and nebulae which comprise the universe familiar to the human senses. Reber's idea that the emissions occurred in the interstellar gas remained, for some time, the only realistic suggestion, although there were many theoretical difficulties in this interpretation. Then, in 1948, came the first of a sequence of discoveries which stimulated the interest of astronomers throughout the world. Bolton and Stanley, in Sydney, followed immediately by Ryle and Smith in Cambridge, announced that at least some of the radio waves were coming from discrete, or localized, sources in space—subsequently called radio stars. The Sydney workers found a powerful source in the constellation of Cygnus, and the Cambridge workers an even stronger one in Cassiopeia. Now if these sources had coincided with any prominent visual objects the discovery would not, perhaps, have occasioned much surprise, but although both the radio sources lay in densely populated stellar regions there were no particular visual objects to which the radio emissions could be attributed. Subsequently many other less intense radio stars were discovered. With one exception none of these coincided with any particular class of star known to astronomers; neither did any of the common stars appear to emit radio waves which could be detected on the earth. The belief arose that we were dealing with a new type of body in the heavens, dark or only faintly luminous, but with the facility of emitting powerful radio waves; moreover, a type which appeared to be of frequent occurrence and distributed throughout the galaxy in a manner similar to that of common stars.

The apparent paradox of the existence of these radio stars has still to be resolved. Only one coincides with a striking celestial object —the third most intense in the heavens, which was among those originally discovered by Bolton and Stanley, undoubtedly originates in the Crab Nebula—the hot expanding

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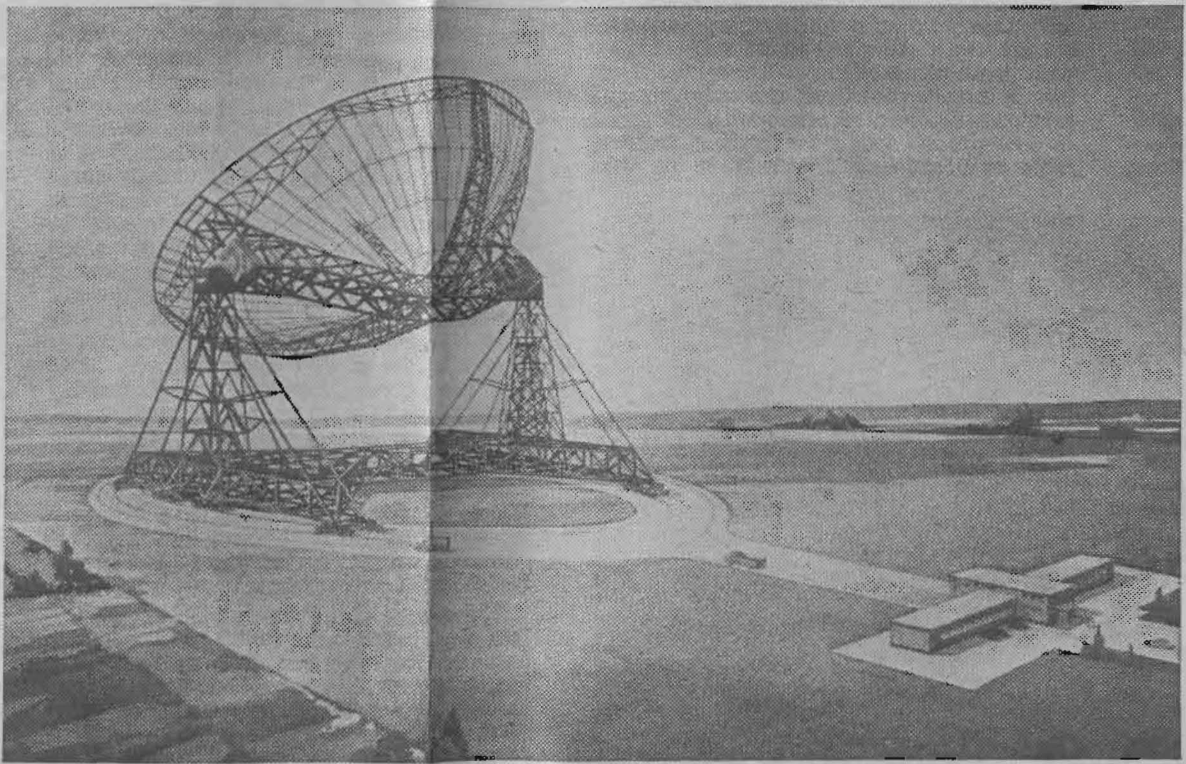
gaseous shell of a supernova, or stellar explosion, witnessed by the Chinese astronomers in A.D. 1054. But supernovae are of rare occurrence; three only are recorded in history, the other two having been witnessed by Tycho Brahe in 1572 and Kepler in 1604. Kepler's object is unfortunately outside the field of view of the large radio telescopes at present available. There are no visible remnants of Tycho Brahe's supernova, but recently a radio star in its position has been discovered by Hanbury Brown and Hazard at the University of Manchester research station at Jodrell Bank. Hence, although it can be presumed that supernovae generate intense radio waves, these objects cannot be responsible for the generality of radio stars. At present it is possible to offer only one other piece of evidence. During the last few months the astronomers on Mt. Palomar have made a careful search for faint objects with the 200-inch telescope in the neighbourhood of the strongest radio star in Cassiopeia. In the correct position they find a peculiarly diffuse gaseous structure which is now confidently believed to be responsible for the Cassiopeia radio star. The place of this gaseous object in the stellar sequence is unknown, neither is it possible to assess whether similar gaseous objects are likely to be found coincident with the position of other radio stars when the search with the 200-inch telescope is made.

The excitement created by these new probings of the universe was heightened in 1950, when Hanbury Brown and Hazard used the large radio telescope at Jodrell Bank to explore the extragalactic nebulae. In a memorable series of experiments they were able to show that the spiral nebula in Andromeda emitted radio waves in a manner similar to the local galaxy, and subsequently that many other more remote nebulae also behaved in this way. Thus radio stars, whatever their nature, must be found throughout the entire universe.

Most of these studies have been carried out with radio waves of a few metres wave-



An artist's drawing of the great steerable radio telescope now being constructed at Jodrell Bank. This instrument, which is being provided by the Department of Scientific and Industrial Research and the Nuffield Foundation, will help to keep Britain in the forefront of the new science of radio astronomy.

and Sydney. It was with systems of this type that the original discovery of radio stars was made.

In an alternative approach the physical size of the aerial system is increased. There are now several steerable radio telescopes of 30ft. diameter in existence. The largest fixed radio telescope is believed to be the 220ft. aperture instrument at Jodrell Bank, but with this only a small part of the heavens can be explored. Experience with this instrument soon demonstrated that a completely steerable radio telescope of this order of size was a prerequisite for the further exploration of space by the radio method. The engineering difficulties and expense of such an undertaking were formidable; nevertheless the results to

had gained in radio astronomy. The scheme for the steerable radio telescope was placed before this committee in February, 1950. After a thorough investigation the committee decided, at a meeting held in Edinburgh on February 27, 1950, attended by the Astronomer Royal, the Astronomer Royal for Scotland, Sir Edward Appleton, and other distinguished scientists, to press for the construction of the radio telescope. Shortly afterwards the council of the Royal Astronomical Society issued a recommendation strongly endorsing the proposals—" for the erection in the United Kingdom of a steerable radio telescope of 250ft. diameter . . . the council considers that by the erection of this apparatus the prestige of science in Britain would be considerably enhanced . . . the council is

Industrial Research readily agreed to provide £3,000 for this preliminary work to be carried through. This labour was completed in February, 1951, and in the spring the D.S.I.R. was again approached, but this time the cost had risen to £242,000. In spite of the strong recommendation of the astronomers, and of the advice of eminent scientists of diverse interests, the financial crisis in the country made it impossible for the D.S.I.R. to commit itself readily to an expenditure of this magnitude. Throughout the remainder of 1951 the matter was in abeyance and at the turn of the year, when further rises in costs of materials had increased the amount required to £335,000, it seemed that the whole project might have to be abandoned. Fortunately the interest of the Nuffield Foundation had been attracted, and by this felicitous circumstance " the Foundation, convinced of the immense scientific importance of these new methods of astronomical research, indicated its wish to enable the work of construction to go ahead without delay. This offer was accepted by the Lord President of the Council, and the total cost of the steerable radio telescope will be provided equally by the D.S.I.R. and the Foundation. . . ."

The chosen site for this enterprise lies in a sparsely populated region of Cheshire. A few miles to the north of the village of Holmes Chapel there is a shallow valley in which was the home of the Jauderel family, an ancestor of whom, William Jauderel, distinguished himself among a company of archers serving under the Black Prince in the Battle of Poitiers. Nearly six centuries later, on the eve of another war on French soil, the University of Manchester purchased a few acres of farmland for horticultural research on the bank which once belonged to Jauderel. In the course of centuries the Jauderels became Jodrells, and their land on the banks of the stream became Jodrell Bank. It was here that, in December, 1945, three ex-army trailers brought radar equipment after conditions of severe electrical interference had frustrated attempts to use it in the University precincts. From this lonely beginning there arose, in a little over a year, a small group of young people for whom road building and concrete scopes. Such waves are unaffected by cloud, fog, or daylight, and in this respect the radio astronomer has a marked advantage over the traditional methods of astronomical investigation. On the other hand, the disadvantage of the long wavelength lies in the very great difficulty of achieving resolution. The beam width, or angle of the cone in which the radiation is received, depends on the ratio of the wavelength to diameter of the telescope. Thus to achieve the same resolution as a very small optical telescope the aerials of a radio telescope would have to extend for thousands of miles—obviously an impossibility. Even so, the need for the maximum possible resolution in the radio work has been a dominant feature of the technical developments. A great deal has been achieved by special devices in which two similar aerial systems, spaced by several hundred yards, are connected to a common recording equipment. This type of radio telescope, known as an interferometer, has been intensively developed in Cambridge

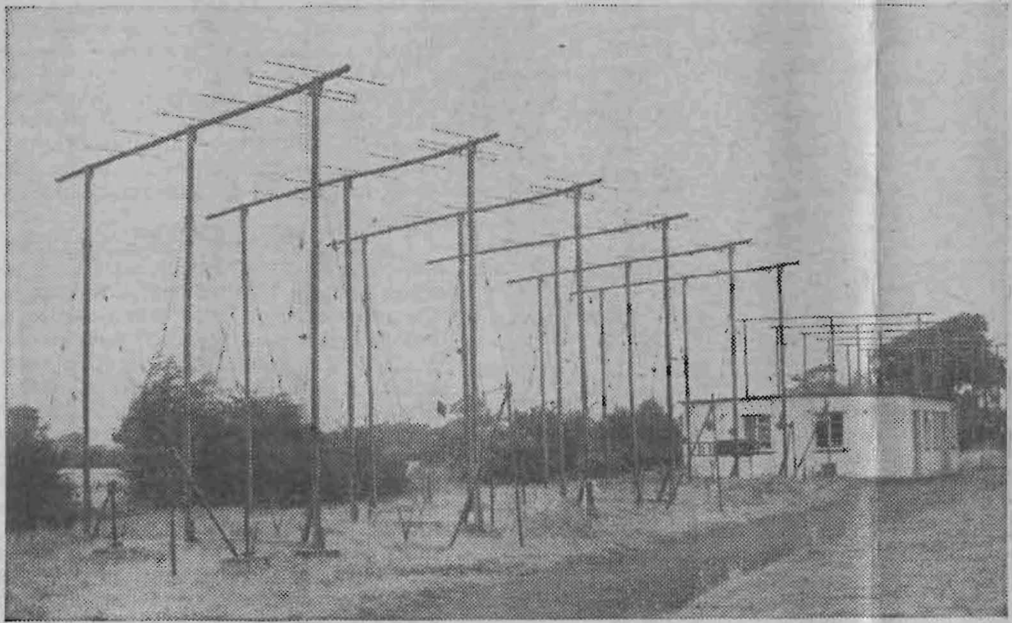
was at hand for exploring those vast regions of the universe hitherto obscured from the view of the optical telescopes by the great dust clouds in interstellar space. This dark obscuring matter obliterates over 90 per cent. of the starlight in the Milky Way, but would present no obstacle to the radio waves. With a steerable radio telescope of sufficient resolving power it would be possible to unravel some of the mysteries of the central regions of the galaxy hitherto concealed, even from the giant optical telescopes. Such considerations, and the many other uses for the instrument in all aspects of radio astronomy, created an unequivocal case for its construction if the necessary support could be obtained.

Fortunately the council of the Royal Astronomical Society was, from the beginning, much interested in the new subject of radio astronomy, and towards the end of 1949 convened a radio astronomy committee to decide what research projects would best serve to maintain the lead which the country

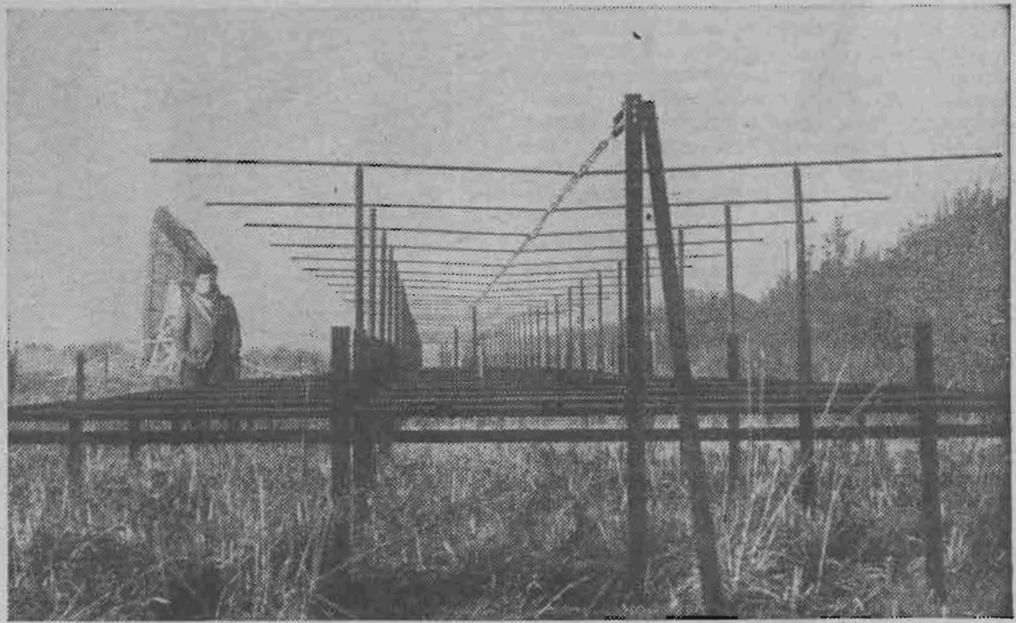
would permit the continuation in the United Kingdom of new methods of astronomical research which have been so greatly developed by the skill of scientists in the United Kingdom and which are independent of climatic conditions."

Throughout 1949 attempts were made to interest various engineering firms in the idea, but no really satisfactory contact was established until the autumn, when Mr. H. C. Husband, the head of a firm of consulting engineers, became interested in the project. His spontaneous reaction was favourable; money and steel would be required, the instrument might be an engineering wonder, but no insuperable mechanical obstacles could be foreseen. In a structure of such complexity the early estimates of its cost were necessarily vague, but a figure in the region of £100,000 was frequently mentioned in discussion. Detailed designs were required in order to obtain a more exact figure, and in the summer of 1950 the Department of Scientific and

the astonishing phenomena of the great daytime streams of shooting stars. This unpremeditated work on meteors first established the significance of the activities in the crop of caravans and trailers, full of the devices of war, now beaten to ploughshares. By this time the University found itself with an avaricious and insatiable child, but with the wisdom worthy of its traditions of foresight replaced the trailers with permanent laboratories. Financial help was readily given by the Department of Scientific and Industrial Research to support an ever-growing programme which used the methods of radio to explore the astronomy and physics of meteors, the aurora borealis, the moon, and the radio waves from the sun, as well as those from the depths of space. Now, in the autumn of 1952, the station reverberates as £50,000 of steel and concrete are driven deep into the ground to support the towering structure of steel which will give Britain its unique instrument for the exploration of the Universe.



The aerial system used for the continuous survey of meteors by the radio echo technique. In the small building is the apparatus which has now been working for several years and has provided information about meteoric activity uninterrupted by cloud or daylight.



One of the interferometer aerials used by Ryle at Cambridge in the work leading to the discovery of radio stars. Two series of rods—or broadside arrays—separated by several hundred yards on the ground are an alternative to the paraboloidal type of radio telescope.