David Moore · LIFE

Largest "dish" radio telescope in the world looms above the English countryside near Manchester. The 250-foot dish, mounted on towers 180 feet high, has been operating only a few months.

Science

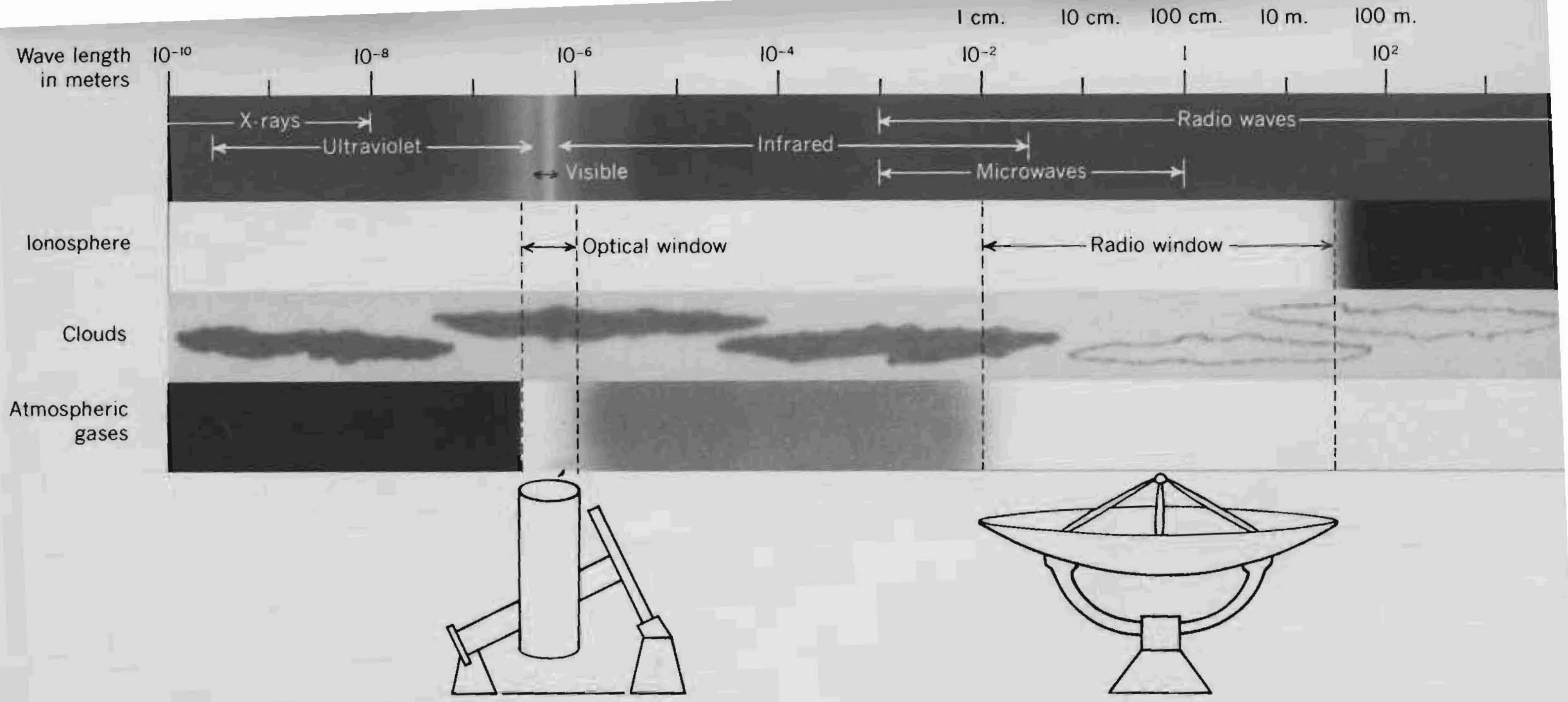
A New Window on the Universe

by Francis Bello

Far out beyond the Sputnik orbits, a world more spectacular and turbulent than astronomers ever imagined is being disclosed by radio astronomy. Soon radio telescopes may "see" to the very edge of the universe.

For the next decade or more, the important discoveries about the universe we live in will almost certainly not be made by such headline grabbers as Sputniks or even by a manned flight to the moon. Though the first space voyager will doubtless find it an exhilarating experience to sift moon dust through his gloved fingers, man can really learn very little about nature directly through his unaided senses. What he needs is instruments to make visible the things that are normally beyond the range of sight. That is precisely the kind of instrument he is now getting from the new science of radio astronomy. With the help of radio astronomy man has found a window with an exciting new view of the universe.

Radio astronomy is simply the extension of old-fashioned



Information from the outer universe reaches the earth only if it can pass through "windows" in the earth's atmosphere. This diagram shows how little man can see of the world with his eyes and with optical telescopes. Most of the entire spectrum of radiation (top of diagram) that falls on the earth's upper atmosphere is blocked either by the ionosphere or by the lower atmosphere. Conventional optic telescopes, like the human eye, must work wit the small sliver of radiation that comes throug the "optical window." The business of radi astronomy is to observe the much broade spectrum of long wave-length light that shine through the "radio window" and to make sens of the objects that emit it.

optical astronomy to the detection of wave lengths of light so long that they cannot be seen by the eye, recorded on film, or detected by ordinary photometric devices. These ultralong light waves are radio waves of the same type used in radio and television broadcasting. The telescope used in radio astronomy to detect these waves consists of an antenna of substantial size, often dish-shaped, hooked up to a radio receiver that can tune in and amplify extremely weak signals. While taking observations, radio astronomers do not listen to the receiver, even though the signals emanating from outer space are often called radio "noise" (it actually comes through like a hiss). What the telescope "sees" is usually recorded by a pen that produces an intensity graph on a strip chart.

As the diagram above shows, the earth's atmosphere is pierced by two "windows" through which radiation from outer space can pass. Before the development of radio astronomy, astronomers had to do all of their looking through the cramped space of the "optical window." What has been seen of the universe through the much wider "radio window" in just the last ten years reveals it to be more turbulent and more energetic than optical astronomers had ever dreamed. The universe is also seen to be more baffling, despite the fact that radio observations are turning up a host of new clues about the nature of planets, stars, galaxies, and the deepest of all mysteries, the size and origin of the universe itself.

Current theories of astrophysics hold that the universe has a definite limit beyond which man can never see, no matter what new instruments he may devise. In the radio telescope he appears to have an instrument that will reach to the very edge of that limit. And in so doing it may provide scientists with crucial information they need before they can discuss with much confidence how the universe may have begun, or whether it had any beginning at all, as beginnings are commonly understood.

They thought they knew

The science of radio astronomy was discovered by accident twenty-five years ago in the U.S., but for ten years afterward old-line astronomers everywhere pretended it didn't exist. In the country of its birth the new science was

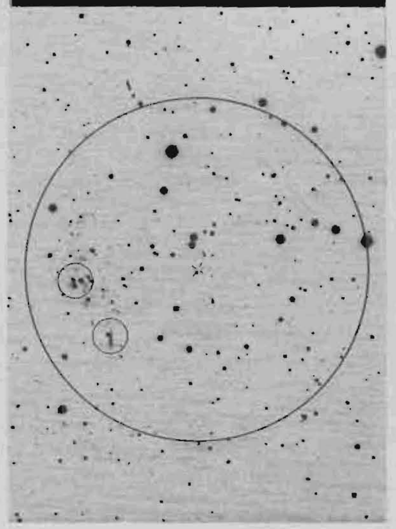
The Earth's Galaxy As Revealed by Radio

Exploration of the earth's own Galaxy seemed all but hopeless before the advent of radio astronomy, for most of the Galaxy lies hidden behind vast clouds of interstellar dust. The artist's conception, at right, showing the Galaxy in top and side views, incorporates the latest radio findings. The sun is represented by an orange cross lying some 27,000 light-years to the left of the galactic center. The Galaxy contains so many stars that near the center they seem to fuse into a solid glowing mass. Actually, they are light-years apart. In more than three centuries optical astronomers were able to chart only the small portion of the Galaxy's spiral structure indicated by the yellow lines near the sun in the top drawing. Within the last six years radio astronomers have traced the star-filled spiral arms, shown in red, nearly the whole way around the Galaxy. These new findings have finally answered John Donne's three-hundred-year-old lament, evoked by the discovery that the earth was not the center of the universe:

The Sun is lost, and th' earth, and no mans wit
Can well direct him where to looke for it.

Ten Kinds of Celestial Transmitters Detected by Radio Astronomy

Cassiopeia A



2,000,000	10^{28}
16	10,000

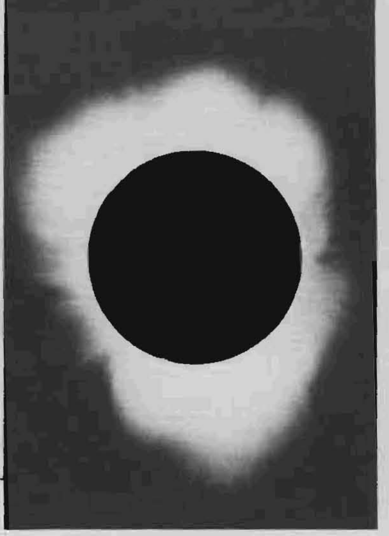
Brightest radio source in the sky, Cassiopeia A, seems to consist solely of luminous wisps of gas moving at speeds up to seven million miles an hour. Two of the wisps appear within the small circles, above; others are scattered throughout the large circle. Photograph (shown in negative print for clarity) was made with the 200-inch Palomar telescope.

Cygnus A

1,000,000	10^{36}
1	270,000,000

The most powerful radio source is Cygnus A, which comprises two colliding galaxies. Though 27,000 times more distant than Cassiopeia A, Cygnus A appears about half as bright when viewed by radio telescope. Presumably many unidentified radio sources are colliding galaxies so remote they are beyond reach of the largest optical telescopes.

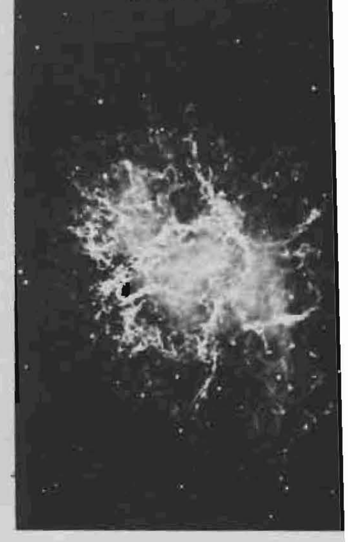
The sun



1,000,000	10^{10}
1,000,000,000,000,000,000	8.3 light-minutes

The sun is the only true "radio star" yet detected; all the other stars are too far away for existing radio telescopes to tune them in. Most of the sun's normal radio emission comes from its corona, visible in this picture of the sun in eclipse. But occasionally great explosions near the sun's surface increase its radio power from 10^{10} to 10^{15} watts or more.

Crab nebula



200,000	10^{26}
5,000	3,000

Unlike true stars, remnants supernovae, or exploding sta are energetic radio emitte The Crab nebula is the remains a supernova seen by the Chin in 1054 A.D. Luminous gases, s expanding violently, account its irregular shape. It is possi that Cassiopeia A is the remai of another supernova, one sight by the Chinese in 369 A.D.

Radio brightness (relative)	Absolute radio power (watts)
Optical brightness (relative)	Distance (light-years from earth)

In key at left "brightness" refers to observed values (whether by radio or optical telescope) on a relative scale that sets the faintest objects equal to 1. Rule for reading values of "absolute radio power" in watts: 10^X equals 1 followed by x zeros; thus 10^{25}=1 followed by 25 zeros, 5×10^{25}=5 followed by 25 zeros. (For the moon and Jupiter, no generally accepted values for radio power are available.)

neglected longer than almost anywhere else, with the result that in radio astronomy today this country lags behind Britain, Australia, the Netherlands, and probably Russia.

Astronomers failed to anticipate any part of the breathtaking magnitude of the discoveries the radio telescope would yield because they thought they could predict roughly what might be observed with a radio telescope and it seemed scarcely worth observing. They knew, of course, that any object with a temperature above absolute zero (-459.6° Fahrenheit) will emit a wide spectrum of electromagnetic radiation. Even at one degree above absolute zero this radiation ranges from very long radio waves, a hundred or more meters in length, to shorter waves, some less than a centimeter in length, called microwaves. As an object is heated further, it emits waves of shorter and shorter length until, finally, it gives off visible light. Thus, when we look at a luminous body like the sun, the light our eyes perceive is only a thin slice of the total emitted radiation. The classical astronomer pointed out, however, that most of the sun's total energy output is concentrated in and around the visible region of the spectrum; only a tiny fraction of its energy is in the form of radio waves. It seemed clear that this weak radio emission would be difficult to detect on earth (and in fact many early attempts to locate solar radio waves did fail). Since stars other than the sun are so distant, four light-years away and more, it seemed hopeless to try to detect radio emission from them (and in fa radio astronomers have not yet succeeded in doing so).

What the classical astronomers entirely overlooked w the possibility of detecting radio emission from objec other than stars. For the firmament is ablaze with rad "noise." This noise from the sky increases in intensity wi increases in wave lengths. Thus, when a good television s is tuned to Channel 2 (5.0 to 5.6 meters, the longest TV wa length), about 80 per cent of all the background noi (which appears as "snow" or granulation in the picture is radio transmission from outer space. The volume of t noise from outer space, totally unexpected by astrophysicist is the big surprise of radio astronomy. "We now have reckon," says Jesse Greenstein, one of the leading astr physicists of Mount Wilson and Palomar observatorie "with a whole new set of forces that we didn't know abou These forces are neither gravitational nor nuclear, b primarily electrical and magnetic. We are seeing things one ever suspected."

The weird radio sky

If we could "see" the sky with the "eyes" of a radio tel scope tuned to meter wave lengths, it would bear scar resemblance to the sky we are familiar with. First of a night and day, fair weather and foul, would be almost i distinguishable, since there is no radio source bright enoug

Jet in galaxy M-87

100,000	10^{33}
1,000	20,000,000

This unique astronomical object is the second most powerful radio source yet discovered. M-87, a large galaxy of the nonspiral type, has an unexplained jet of ionized gas, strongly blue in color, extending from the galactic center. The light from the jet is polarized, indicating the presence of strong magnetic fields often associated with strong radio emission.

Andromeda galaxy (M-31)

10,000	10^{30}
100,000	1,000,000

M-31 is a spiral galaxy much like our own. Despite its hundreds of billions of stars it puts out less than 100 times more radio power than wispy Cassiopeia A. Even so, M-31's output is 100 million times what would be expected if each of its stars had an average radio strength equal to that of our sun. Evidently M-31 conceals a few Cassiopeias of its own.

Emission nebula (M-16)

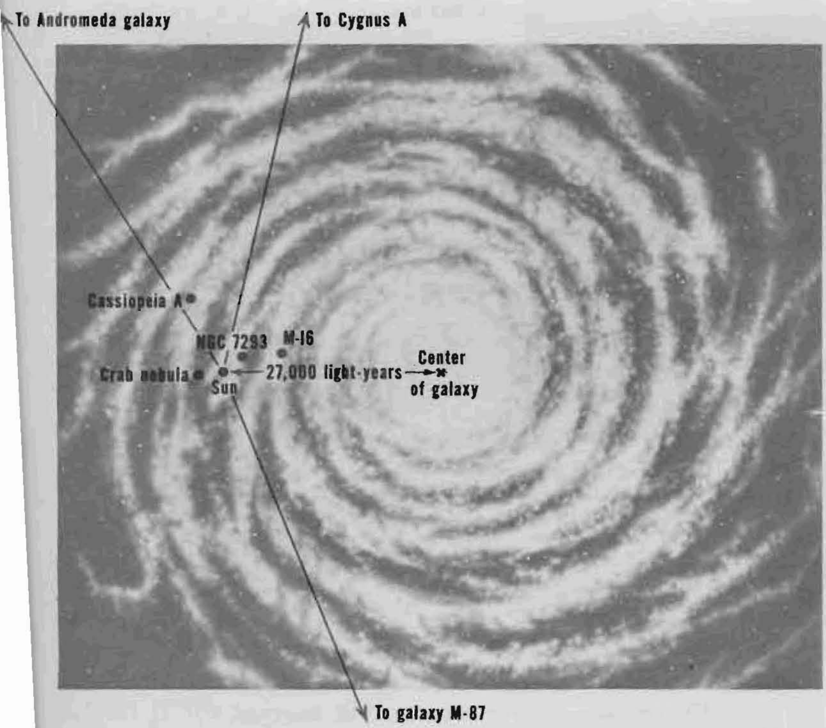
1,000	5×10^{26}
200,000	7,500

M-16 is nothing more than a huge cloud of hydrogen gas excited to high temperature (around 10,000° C.) by abnormally hot stars embedded inside. The gas emits radio waves as part of its over-all emission spectrum. About twenty-five such nebulae have been detected by radio. These include the well-known Orion nebula, which can be seen by the naked eye.

Planetary nebula (NGC 7293)

10	5×10^{24}
50,000	3,000

Planetary nebulae are among t faintest radio sources yet foun Three, including NGC 7293, we detected for the first time la year by Frank Drake, a Harvai graduate student. The nebula glowing ring consists chiefly c hot ionized hydrogen, probabl ejected from a large star, a "re giant," in the process of contract ing into a "white dwarf."



Astronomical distances make it impossible to plot on one diagram all ten objects illustrated on these two pages. This representation of our home Galaxy can show only the sun and four other radio sources. On the scale used here (1 inch=27,000 light-years) the space taken up by the dot representing the sun has about 300,000 times the diameter of the whole solar system, within which, of course, the moon and Jupiter lie. The Andromeda galaxy would lie about 3 feet away from the sun, M-87 60 feet, Cygnus A 800 feet. Whereas the world's largest optical telescope is unable to detect galaxies much more than a mile away on the same scale, radio telescopes are probably "seeing" objects two miles away, and perhaps more.

The moon

100	
1,000,000,000,000	1.3 light-seconds

Two sorts of radio waves come from the moon: waves reflected by it from the sun, and waves given off by the moon itself. The latter radiation is called "thermal," the normal radio emission of a warm body. Other so-called thermal emitters are the sun (except when disturbed by explosions near its surface), M-16, the planetary nebulae, and the planets.

Jupiter

1	
100,000,000	37 light-minutes

Jupiter, like Saturn, Mars, an the planetary nebulae, is among the faintest radio sources ye identified. In addition to simpl thermal radiation, Jupiter period ically emits powerful radio bursts possibly arising from great storm in the Jovian atmosphere. Jupi ter's weak thermal emission wa first detected in 1956 at the Nava Research Laboratory.

Radio Astronomy

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to light up the radio sky as the sun lights up the daytime sky. Most of the time the sun itself would be a pale apparition with an irregular shape corresponding to that of its corona. Sporadically, however, its radio brightness would flare up awesomely to thousands and even millions of times its normal intensity. No one knows why. Then, in seconds or hours, the flare-up would subside and to the "eyes" of the radio telescope all would be dim once more.

The moon would rank with the faintest discernible objects. So would the planets, except for Jupiter, which would emit brilliant bursts of radio "light" reminiscent of lightning.

The great starry arc known as the Milky Way has as its radio counterpart a diffuse ribbon showing clearly from the northern to the southern horizon. But unlike the familiar Milky Way, the radio Milky Way increases steadily in brightness along its length, reaching a brilliant peak in the region of Sagittarius (visible low in the southern sky in summer). This peak identifies the center of our Galaxy, 27,000 light-years away, which is shielded from human eyes and ordinary telescopes by vast clouds of interstellar dust.

Two radio jewels

Embedded in the Milky Way ribbon, far to the north of the galactic center, are the two most spectacular jewels of the radio firmament: Cassiopeia A and Cygnus A. Cassiopeia A is perhaps 10,000 light-years away in our own Galaxy. Yet within it is a radio source that is the brightest detected in outer space. In photographs taken with the 200-inch Palomar telescope, it shows only as a few wisps of glowing gas moving at tremendous velocities. Cygnus A is even more astonishing. Although 270 million light-years distant, it showers the earth with as much radio energy as the sun ordinarily does from only 8.3 light-*minutes* away. To do this, Cygnus A must pour out more than a billion billion (10^{18}) times as many watts as the sun does at its violent peaks.

The identification of Cygnus A with a visible object was one of the dramatic episodes in modern astronomy. When Cygnus A was first detected, in 1947, optical astronomers immediately began searching for it. But their telescopes found nothing more in the region of the radio noise than a typical assortment of stars and faint galaxies. There was no reason to single out any one of them as a powerful radio emitter. Since there was no evidence of obscuring dust in this part of the sky, astronomers concluded that Cygnus A was too distant or too faint to show on photographic plates.

A titanic encounter

In 1951, Walter Baade, one of the most distinguished observers at Mount Wilson and Palomar, began a fresh search, using a new radio fix supplied by B. Y. Mills of Australia and F. G. Smith of Great Britain. Baade finally discerned a curious smudge, little larger than the head of a pin, on one of his photographs. After close study of the smudge, Baade rendered an astonishing interpretation: it represented two giant galaxies, each perhaps as large as our own, in titanic collision.

At first, Baade's colleagues scoffed. But Rudolph Minkowski, a senior observer on the Mount Wilson–Palomar staff, made a spectrographic analysis of the light coming from the smudge-like object. This proved that the thinly spread interstellar gas within the galaxies was excited to temperatures up to 10,000° C. In ordinary galaxies this gas (chiefly hydrogen) is far below 0° C. The high temperatures confirmed that a collision must be taking place between the dust, gas, and magnetic fields spread throughout the two galaxies.

In the whole radio sky there are several thousand objects that can be detected with the radio telescopes now in use. Experts do not agree on the exact number because many radio sources seem to overlap. To add to the difficulty, radio emission from space is hard to distinguish from the electronic noise generated within the radio telescope itself. The positions of only about a hundred are reasonably well confirmed by different observers. No one doubts, however, that bigger and more sensitive instruments will discover more and more sources, running ultimately into the millions.

Only about sixty of the hundred or so well-confirmed radio sources have been matched with objects visible through optical telescopes. The radio sources beyond our solar system that have been thus identified can be grouped in seven categories: wisps of high-velocity gas, colliding galaxies, galaxies with special characteristics (such as M-87, which contains a huge gaseous jet), ordinary galaxies like the earth's, remnants of supernovae, so-called "emission nebulae" (huge gas clouds heated to incandescence by hot

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stars), and planetary nebulae (in which a ring of gas is heated by a single star).*

What sort of objects might the still-unidentified sources be? While a few may be objects within our Galaxy whose visible light is concealed from us by intervening dust, it is reasonably certain that most are extragalactic objects, predominantly galaxies in collision.

The occurrence of colliding galaxies in outer space is the factor that gives radio telescopes such an advantage over the optical kind in the race to "see" to the edge of the universe. Colliding galaxies have stupendous radio power and hence are detectable by radio telescopes far beyond the range even of our biggest optical instruments. Cygnus A, for example, is such a powerful transmitter that it could be detected by present radio telescopes even if it were six to eight billion light-years away. This is three or four times more distant than the Palomar telescope's range of 2 billion light-years, within which may lie some 500 million galaxies.

Where is the horizon?

There are, however, impressive reasons for believing that if Cygnus A were actually six to eight billion light-years away, it would be beyond the horizon of the observable universe. This horizon may lie at a distance of about five billion light-years, according to present measuring scales. This limit is deduced from the phenomenon known as the "red shift" in the light coming from distant galaxies. This red shift, or reddening, may be likened to the seeming fall in pitch of the whistle on a train that is rushing away from an observer. Astronomers have found that the more distant the galaxy, the more its light is shifted toward the red end of the spectrum and hence the faster it appears to be receding from our own Galaxy.

The most distant galaxies for which a red shift can be measured are about one billion light-years away and are receding from us at a speed of 38,000 miles per second, or about one-fifth the velocity of light. If the recession speed continues to increase proportionately with distance, the limit of observation works out to about five billion light-years. If there are any galaxies farther away, their light can never reach the earth, for the distance is increasing faster than light can bridge the gap.

The red shift has another implication, which also may set the "edge" of the universe at roughly five billion light-years. According to a hypothesis first proposed in 1931 by Abbé Georges Lemaître of Belgium, the universe began with the explosion of a gigantic "primeval atom" that contained all the matter now scattered throughout space. On the basis of the apparent expansion of the universe, the date of the hypothetical explosion may be placed at some five or six billion years ago, a figure that conforms reasonably well with other estimates of the age of the universe. Lemaître's hypothesis implies, of course, that astronomers will find no galaxies more than five or six billion light-years away, for there were none in existence more than five or six billion years ago to start light on its way toward us.

The first reports from the "edge" of the universe may be brought in by the great 250-foot radio telescope at Jodrell Bank, England. This may also be the first instrument to measure recession velocities greater than the 38,000 miles per second recorded at Palomar.

Continuous creation?

Cosmologists—the theoreticians concerned with the structure, origin, and destiny of the universe—will be watching such results closely to see which of several "models" of the universe they may back up. In addition to Lemaître's "big bang" model, there is a somewhat similar model that dispenses with the bang, and suggests that the universe is alternatively expanding and contracting.

There is also a new and highly controversial model which supposes that the universe is continuously being created afresh. According to this hypothesis, the universe has always looked—and always will look—exactly as it does now. As galaxies hurtle beyond the observable horizon, more are born to take their place.

This so-called "steady-state" universe was proposed shortly after World War II by three British scientists, H. Bondi, Thomas Gold (now at Harvard), and Fred Hoyle (who divides his time between Cambridge and Cal Tech). They figured that the amount of freshly created matter needed to maintain a steady-state universe is one new hydrogen atom every century for a volume of

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**The radio output of the last two categories appears to be simply the normal emission of gases heated to ultrasolar temperatures. The vastly greater radio power of the other five seems to call for a different explanation. The currently favored theory is "synchrotron radiation"—the radio waves emitted when very high-speed electrons are forced to describe tight orbits around magnetic lines of force.*

space equal to that of the Empire State Building. (For the universe as a whole, this comes to 10^{32} tons of fresh hydrogen per second.) Such infinitesimal traces of newly created hydrogen cannot be detected, but the steady-state hypothesis is open to a variety of other tests.

The hypothesis would be strengthened, for example, if astronomers could find convincing evidence that galaxies differ significantly in age. So far the evidence on age, from optical astronomy, is ambiguous. Perhaps radio astronomy can find age differences. On the other hand, the new radio telescopes may reveal that galaxies three to five billion light-years away, and hence three to five billion years old, show a greater incidence of collisions than do nearer ones and therefore must be bunched together more closely. Such a finding would refute the "steady-state" hypothesis and support the view that the universe was once in a denser state than at present. Whatever the case, it should be possible within the next five to ten years to rule out one hypothesis or the other.

Jansky's practical problem

The new science to which cosmologists are appealing for help on their deepest questions grew out of research on a thoroughly practical problem. The year was 1928. The Bell System wanted to find out why its newly introduced transatlantic radiotelephone service was plagued by static and miscellaneous noises that often made conversation impossible. To make a systematic study of radio noise, Bell Laboratories called on a twenty-three-year-old physicist, Karl Jansky.

Jansky designed and built a large rotatable antenna and a sensitive radio receiver, which was erected at Holmdel, New Jersey. He began by measuring radio static, noting how it varied in intensity and in point of origin. In April, 1932, he presented to the International Scientific Radio Union a paper in which he described three types of static: the first from local thunderstorms, the second from distant storms, and the third "composed of a very steady hiss the the origin of which is not known."

In a follow-up study a year later Jansky described ". . . the existence of electromagnetic waves in the earth's atmosphere which apparently come from a direction that is fixed in space." Karl Jansky's radio telescope—though he did not call it that—had picked up the intense radio noise pouring out from the center of our Galaxy.

Thereafter Karl Jansky made only a few more radio astronomical observations, confining himself to work for Bell on terrestrial noise sources. He died in 1950, at forty-four.

The first person to take a serious interest in Jansky's work was a gifted and highly individualistic young electronics engineer named Grote Reber. By day Reber worked for a radio manufacturer in Chicago; by night he scanned the skies with a homemade radio telescope, about 30 feet in diameter, that foreshadowed the design of present-day instruments. Reber picked up his first radio waves from space in 1938. He soon confirmed Jansky's general observations and went on to locate a number of radio "hot spots" outside the galactic center. Noting that the "hot spots" did not seem to coincide with the locations of particularly bright stars, Reber drew an important inference: radio astronomy seemed to deal with a set of features entirely different from those that dominated the visible heavens.

In 1940 the *Astrophysical Journal* accepted for publication a paper by Reber on his findings. Reber's article reached astronomers at the University of Leiden Observatory in occupied Holland. They were impressed enough to work out a program for postwar investigation of radio astronomy. It is that program which has helped define the structure of earth's Galaxy in the last six years.

The crippled radar

Even without the pioneering research of Jansky and Reber, it is probable that radio astronomy would have been discovered as an offshoot of British and U.S. work on radar, which began in deep secrecy in the late Thirties. Early radar operated at frequencies of 40 to 100 megacycles, where the radio noise from space is particularly strong. By the end of World War II the British were thoroughly familiar with galactic noise, and they had made two significant findings. They discovered that the trails left by meteors produce radar echoes, and they finally detected radio noise from the sun.

In late February, 1942, the British early-warning radar was crippled by an intense outburst of static unlike anything ever detected before. British experts immediately feared the Germans had perfected a new radar-jamming device to knock the British defenses out of action, prior to launching a great bomber attack. The intense static continued

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may be opposite to each other. When the electron flips over from one position to the other, a tiny pulse of radio energy is emitted at a wave length that Van de Hulst calculated should be about 21 centimeters, corresponding to a frequency of 1,420 megacycles.

The total amount of 21-centimeter radiation reaching the earth from all the interstellar hydrogen in the universe is fantastically small —no more than two or three watts. The first record of this faint emission from space was obtained at Harvard in 1951 by a young graduate student, Harold I. Ewen, and his professor, Edward M. Purcell. Confirmation of the discovery came from Leiden and Australia.

Going or coming?

The ability to detect cold rarefied hydrogen wherever it may occur in the universe has been a tremendous advance. Since the cold-hydrogen radiation is always emitted at a constant frequency, 1,420 megacycles, radio astronomers can tell whether substantial masses of it are in relative motion with respect to the earth. If moving toward us, the hydrogen's *observed* frequency is *higher than 1,420 megacycles*; if moving away, its observed frequency is shifted lower. The velocity is proportional to the magnitude of the shift.

With this basic discovery radio astronomers have made the following major findings:

▶ Astronomers at the University of Leiden used it to determine the structure of our Galaxy. The determination is possible because the arms of the Galaxy contain up to 100 atoms of hydrogen per cubic centimeter, compared to the overall density in the Galaxy of less than one atom per cc. Since the Galaxy is also revolving—much like cream swirling in a cup of coffee that has been stirred—the arms show different relative velocities with respect to the earth.

▶ Harvard investigators have used 21-centimeter radiation to substantiate the hypothesis that clusters of new stars are being continuously formed from vast concentrations of hydrogen and dust.

▶ At the Naval Research Laboratory, A. E. Lilley (now at Yale) and E. F. McClain were the first to use the shift in the hydrogen line to confirm the high recessional velocities of distant galaxies. They observed the equivalent of a "red shift" in the radio emission from the colliding galaxies in Cygnus A.

At Cygnus A's distance of 270 million light-years, the radiation directly emitted by interstellar hydrogen is too weak to be detected. But Lilley and McClain figured that the intense radio waves generated by the collision would probably have to pass through a large volume of interstellar hydrogen located within the two galaxies before beginning their long journey to earth. This cold hydrogen would have the ability to absorb radio waves of the frequency it would normally emit—i.e., waves of 1,420 megacycles. The radio waves originating in Cygnus A should therefore be deficient in waves of 1,420 megacycles. This is precisely what Lilley and McClain found—except that the "nick" in the Cygnus A spectrum occurred not at 1,420 megacycles but 81 megacycles lower in frequency, indicating that Cygnus A is receding from the earth at a velocity of some 10,000 miles per second. This conforms closely with the velocity calculated from the red shift in the visible spectrum.

▶ At Harvard, David S. Heeschen (now at the National Radio Astronomy Observatory) was subsequently able to find hydrogen-line "red shifts" directly, rather than by evidence of absorption. The greatest "red shift" he recorded was from the Corona Borealis cluster of galaxies, 30 per cent more distant than Cygnus A. His measurements show that the cluster, consisting of some 400 galaxies in close association, is flying away from earth at a speed of about 13,000 miles per second.

How big a dish?

Most of the easy advances in radio astronomy appear to have been made. The next major advances will require radio telescopes bigger and more costly than any yet operating. The 250-footer at Jodrell Bank is the first of the new breed. Australia has plans for a similar instrument, and Russia has one or two large instruments of a different style. In the U.S., Harvard's 60-footer was the biggest until the recent completion of an 84-footer by the Naval Research Laboratory.

The Office of Naval Research has been supporting work at the Naval Research Laboratory under Edward McClain, at the University of Michigan under Fred T. Haddock Jr., and at Cal Tech under John Bolton. The National Science Foundation, which is supporting radio astronomy at Harvard, Ohio State, and the University of Florida, has appropriated $5 million to build

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for two days, but the attack never came. J. S. Hey, a physicist assigned to investigate what had happened, concluded that the static had been caused by a violent sunspot storm that had snarled worldwide radio communications at the same time.

Independently, and almost simultaneously, G. C. Southworth of Bell Labs searched for and found the much weaker radio waves emitted by the sun under normal conditions.

War-made astronomers

The worldwide flowering of radio astronomy in the last dozen years is one of the beneficent byproducts of World War II. Refinements in electronics made it possible to build sensitive radio telescopes, and there was a cadre of top-notch young physicists and engineers familiar with the new electronics and itching to do something exciting. They were not astronomers but they were soon exploring the heavens with great verve and diligence.

The first big postwar finding came in 1946 from J. S. Hey, S. J. Parsons, and J. W. Phillips. The English group noted that a "hot spot" in the constellation of Cygnus seemed to fluctuate erratically in much the same way as they had observed the sun's radio brightness to fluctuate. This fluctuation clearly refuted a leading hypothesis of the day, which suggested that extraterrestrial radio waves might originate in extended masses of interstellar gas. Hey and his associates concluded that the radiation they had found "could originate only from a few discrete sources of comparatively small dimensions."

They could not say more because their instrument, like all radio telescopes of the time, had a relatively low resolving power; i.e., it could not produce a sharp image.

Radio telescopes will never have the resolving power of optical telescopes for a very fundamental reason: high resolving power requires that the aperture of the instrument be large compared to the wave length of the radiation being observed. Thus the pupil of the human eye has a diameter several thousand times the wave length of ordinary light. In big optical telescopes the ratio of aperture to wave length is many millions to one. Since radio wave lengths begin at less than an inch and extend to many yards, it would be a formidable task to build antennas or collecting dishes having diameters a thousand times greater than the wave lengths.

There is a way, however, to obtain reasonable resolving power without building huge dishes, and that is to employ interferometry. In this technique, radio waves are detected by two dishes, or other aerial systems, placed several hundred feet apart. By measuring, in effect, the difference in time of arrival of radio waves at the two aerials, it is possible to locate the sources with considerable accuracy.

A clever variation of this technique was employed in 1947 by John G. Bolton and G. J. Stanley, in Australia. They erected a single antenna on a high cliff in Sydney, overlooking the Pacific Ocean to the east. The antenna picked up radio waves directly from the sky, as well as reflected waves from the surface of the sea, thus achieving the dual reception needed for interferometry. The big drawback of a cliff interferometer is that atmospheric distortions are especially acute close to the horizon, so that hundreds of readings must be checked against each other.

By the end of 1947, Bolton and Stanley had pinned down Cygnus A, plus five other discrete sources of radio emission. One of the five was a source Bolton and Stanley were never able to find again. Apparently it was not produced by an aberration in their instruments. Perhaps the readings were caused by a brief storm on a nearby star. Probably no one will ever know. During the last ten years, three such objects have flared transiently on radio telescopes, from an hour to a year, never to be seen again.

By hydrogen's cold "light"

Perhaps the most significant discovery made in radio astronomy since World War II was that the cold hydrogen atoms spread thinly through interstellar space give off a detectable radio signal. The idea of looking for this radiation was put forward in 1944 by H. C. van de Hulst, then a twenty-five-year-old astronomy student at Leiden.

While interstellar space is a far more perfect vacuum than any ever created on earth, it still contains gas clouds with a density of about one hydrogen atom per cubic centimeter. (This is true inside galaxies; the space between galaxies apparently contains little or no hydrogen.) At interstellar gas temperatures, which are mostly below −280° Fahrenheit, the electron orbiting around the nucleus of the hydrogen atom can assume only one of two positions: the electron's spin and that of the proton (or nucleus) may coincide in direction, or they

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the National Radio Astronomy Observatory at Green Bank, West Virginia. The Green Bank site, in a secluded valley in the eastern part of the state, was selected for its exceptional freedom from man-made radio interference. The observatory will be operated by Associated Universities, Inc., the organization of eastern universities that operates Brookhaven National Laboratory for the AEC.

Something really spectacular

By midyear the National Radio Observatory should have an 85-foot radio telescope in operation, to be followed in 1960 by an instrument 140 feet in diameter, which will cost at least $3 million. The N.S.F. predicts that the latter will be the most precise radio telescope of its size in the world.

The National Science Foundation is now discussing proposals for an instrument substantially larger than that at Jodrell Bank. There is growing sentiment among U.S. radio astronomers for N.S.F. to finance something really spectacular: an instrument (not necessarily a dish) having an effective aperture of perhaps 1,500 feet or more. With present technology, it might be possible to build a telescope with a movable (or "steerable") dish as large as 3,000 feet in diameter—but it might cost close to half a billion dollars.

There are, undoubtedly, less costly alternatives. The advantage of a dish-shaped or parabolic antenna, of course, is that it brings to a focus the radiation of virtually all wave lengths falling on it. Radio astronomers could, however, collect radiation of selected wave lengths simply by covering the ground with hundreds of television-like antennas. Focusing would then have to be accomplished electronically, since radio waves would reach the scattered antennas at slightly different times.

Actually U.S. radio astronomers are less concerned, at the moment, with building larger telescopes than with designing more sensitive radio receivers to hook up to the telescopes they will soon have. More sensitive receivers can cut the "exposure" time and, in effect, make fainter objects observable.

Every radio receiver seethes with internal "noise" caused by the random motion of electrons in the circuitry. The basic problem in radio astronomy is to disentangle the faint whispers of outer-space noise from the electronic roar within the receiver. The receiver noise is often 1,000 to 5,000 times louder than that collected by the radio antenna, and, in extreme cases, may approach 500,000 to one.

With a new amplifying device called a "maser," it may be possible to cut the receiver noise to a hundredth of present values, permitting radio astronomers to detect objects roughly one hundred times fainter than any yet observed. Several laboratories are trying to develop the "maser" to a practical stage, among them those of Columbia University, Harvard, M.I.T., Bell Labs, and Ewen Knight Corp. (headed by Harold Ewen, co-discoverer of the hydrogen line).

According to Hoyle

How can we explain the stupendous amount of energy that radio astronomy has already disclosed in the universe? Some astrophysicists believe the energy detected can be satisfactorily accounted for by nuclear reactions (chiefly fusion) within stars, and by the kinetic energy released by colliding galaxies. But others are not so sure. The British theoreticians, Fred Hoyle and G. R. Burbidge, suspect that fusion and collisions are not enough to balance the universe's energy budget, and that a still more fundamental energy source remains to be found.

Hoyle and Burbidge suggest that this source may reside in "annihilation" reactions between matter and antimatter—i.e., between protons and antiprotons. (Physicists have recently shown, for example, that elementary particles such as protons and antiprotons annihilate each other on contact, releasing large amounts of energy.) The two British scientists have proposed that in the "steady-state" universe not just hydrogen but all the elementary particles and antiparticles—some thirty in all—may be in continuous creation. The two types could be kept from instantly annihilating each other, suggests Hoyle, if they appeared in widely separated parts of the universe. This implies that half the galaxies may be formed from matter and the other half from antimatter. A collision between a matter and an antimatter galaxy would be a shattering event. Perhaps this is what we are seeing happen in Cygnus A.

This hypothesis is an example of the flights of speculation, based on elaborate scientific observations, that may be required before man can say he "understands" his universe. To speed his torturously slow way on the road to this understanding, he has found a powerful instrument in the radio telescope. END