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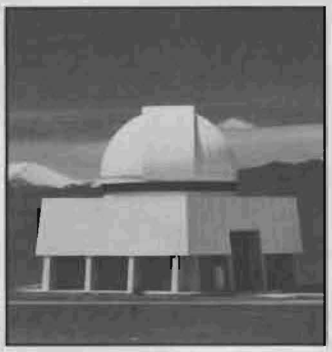

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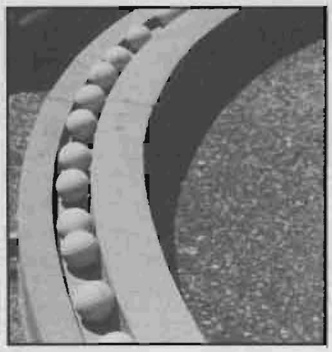

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Cover: Early this month, the twin spacecraft of the Soviet Union's Phobos project will start a seven-month voyage to Mars. The main objective is an examination of the red planet's larger satellite, culminating in a close rendezvous in April of next year. From a scant 50 meters away, the spacecraft will fire a laser beam at Phobos' surface, and on-board instruments will capture and analyze some of the vaporized material. Beginning on page 17, a Soviet scientist recounts what is known about the Martian moons and what might be learned from the international collection of instruments aboard these probes. Painting © 1988 Michael Carroll.

Such rapid motions defy a simple picture of circular orbits in the galaxy. According to this picture, all clouds toward the galactic center should move at right angles to our line of sight, regardless of their distance from the Sun. Therefore all such clouds should have zero radial velocity.

What could cause the large observed velocities? The most likely culprit is large-scale expansion of gas from the galactic center, though collapse toward the center would look the same in the velocity map. Most astronomers prefer expansion, for it is easier to concoct scenarios involving explosive events in the galaxy's nucleus than to explain why gas should be falling toward it so rapidly.

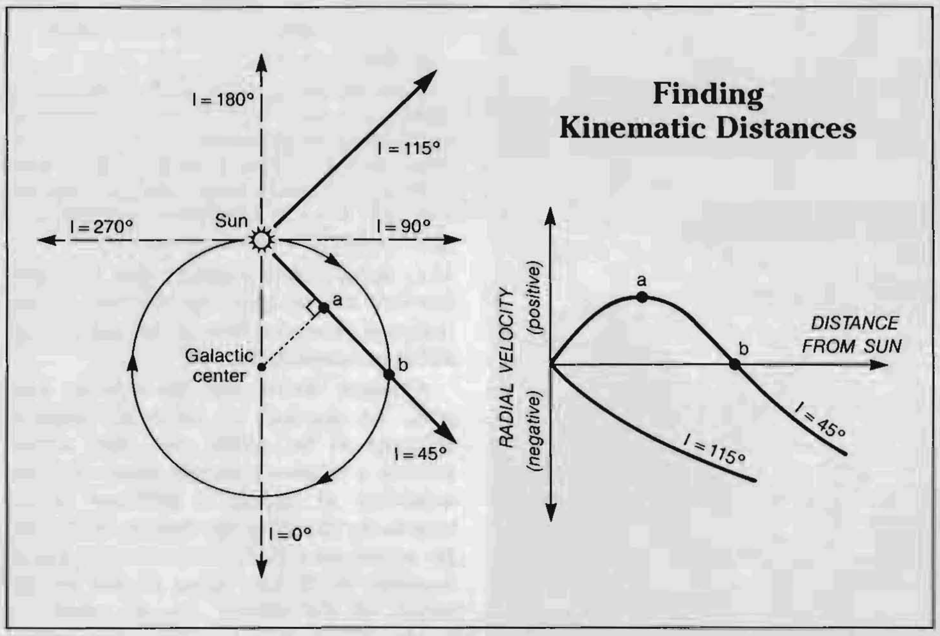
Nearly all the CO emission outside the bright inner galactic ridge (within 90° of the center) in the intensity map arises from molecular clouds that are relatively close by galactic standards, less than a few thousand light-years away. In the velocity map these "local" clouds appear near 0 km per second at all longitudes, because they orbit the galactic center at about the same speed as the Sun.

The velocity map helps explain why optical astronomers interested in studying galactic structure have long been drawn to the Southern Hemisphere. About half the inner galaxy, roughly the stretch from l = 270° to 0°, climbs high in the sky only for observers south of the equator. As shown by the scarcity of low-velocity emission at these longitudes, this half contains far fewer local clouds than the northern half, which runs between l = 0° and 90°.

The nearly continuous lane of CO with velocities near 10 km per second in the northern Milky Way is due to the molecular clouds of the Great Rift (see the illustration on page 22). They lie just a few hundred light-years away and badly obscure our view of the inner galaxy. In contrast, in the southern Milky Way we can see bright stars and nebulae that are thousands of light-years away, thanks to the absence of similar foreground clouds.

The intensity and velocity maps on page 25 contain a wealth of information on the distribution and properties of molecular clouds in the galaxy. Yet these maps are but two projections of a much larger three-dimensional data array. The extensive CO survey by the twin mini telescopes represents only an important first step in the study of molecular clouds and star formation in the galaxy. But it has already given us our first grand view of the molecular Milky Way, and this view will guide more detailed investigations for years to come.

Thomas Dame earned his Ph.D. in astronomy at Columbia University in 1982. He specializes in millimeter-wavelength studies of galactic structure and the interstellar medium.



Astronomers can estimate a molecular cloud's *kinematic distance* from its galactic longitude, l, and line-of-sight (radial) velocity. *Left:* Schematic view from above the north galactic pole; the galaxy rotates clockwise seen from this perspective. *Right:* Run of radial velocity with distance from the Sun in two directions. At point *a* all a cloud's velocity is along the line of sight. Note the distance ambiguity toward l = 45° for a cloud with zero radial velocity: it can be either very near the Sun or at point *b*, ahead of the Sun in the same orbit. More information is needed to tell which is correct.

50 & 25 Years Ago

The Sky
July, 1938

Astronomers have endeavored to determine the source of the energy which a star so profusely radiates. The theory of the contraction of the sun and the consequent increase in its temperature from the loss of gravitational energy does not permit the sun a lifetime as long as that of the earth. Neither can radioactivity supply sufficient energy. . . . The only present theory which seems to fit the facts is that the stars are giant converters — changing matter into radiant energy.

Charles A. Federer, Jr., wrote these words just when scientists were first uncovering the ways the stars shine. We now know that main-sequence objects such as the Sun change hydrogen to helium in their cores, converting some mass into radiant energy in the process.

Sky and Telescope
July, 1963

Early in May an Air Force rocket placed a second West Ford package in orbit, designed to spread a band of tiny copper needles around the earth for communications purposes. . . . Dr. William Liller of Harvard Observatory has been acting as coordinator for optical observations of the belt. On June 7th he issued the following statement to *Sky and Telescope:*

"The brightness of the West Ford dipole belt has been successfully measured at optical wavelengths by several observatories in the United States. . . .

"The observed brightnesses of the West Ford belt appear to agree well with predictions made earlier by Liller and by van de Hulst and Volders. On June 1st the belt was approximately two percent brighter than the night sky and fading slowly. . . ."

Radio signals were reflected off the needles to provide experimental long-distance communications at high frequencies. Scientists were worried that such dipole belts would seriously degrade astronomical observations. Fortunately, active communications satellites — those carrying receivers and transmitters — soon made the passive variety obsolete. However, proposals to orbit various bright objects are still put forward, and so astronomers must continue efforts to protect the dark night skies above their observatories.

The First True Radio Telescope

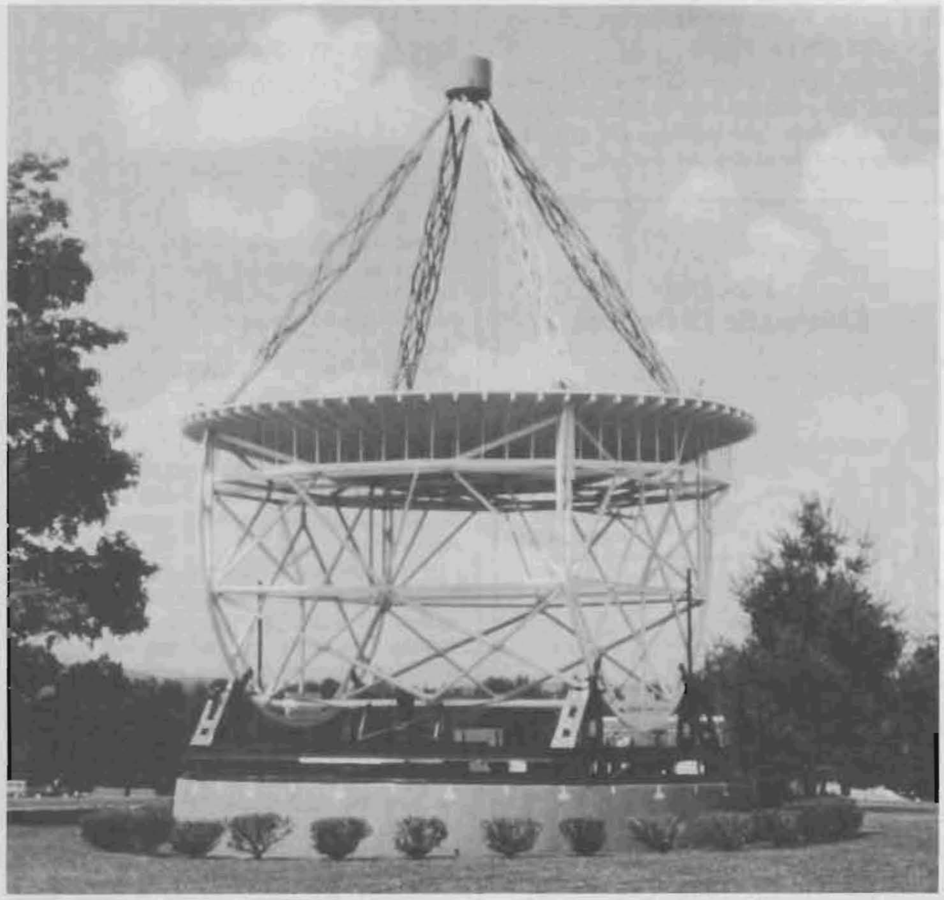
Joseph L. Spradley, Wheaton College, Illinois

THE BEGINNING of deliberate radio astronomy came 50 years ago, just 50 years after Heinrich Hertz first produced radio waves, and just 5 years after Karl G. Jansky reported his accidental discovery of natural radio waves from space. The opening of this new window on the universe eventually led to such epochal discoveries as quasars, pulsars, and the cosmic background radiation.

In 1930 Jansky was asked to study the atmospheric static that interferes with radio communications. To do so he built a rotating dipole-array antenna sensitive to radiation with a wavelength of about 15 meters. In addition to the usual terrestrial noise, he found a weak, steady hiss of unknown origin. Since this interference appeared four minutes earlier each day (corresponding to the 23-hour 56-minute period of the stars), it was evident that its origin lay outside the solar system.

Jansky established that the most intense emission came from near the center of our galaxy, with weaker signals from other places along the Milky Way. He concluded that the source of the cosmic static was from interstellar material.

Starting in 1932 Jansky's work was published in a series of scientific papers. His results made the front page of the *New York Times,* and 10 seconds of "radio hiss from the depths of space" were broadcast on a national radio network. Yet, despite this publicity, no professional scientist followed up Jansky's investigations. This job was left to Grote Reber, a 25-year-old radio engineer who pursued research at his own expense and in his spare time. In 1937 he built a parabolic antenna in his side yard at Wheaton, Illinois. It was the only existing radio telescope until after World War II.



Grote Reber's radio telescope as it appeared in 1985 at Green Bank, West Virginia, on the grounds of the National Radio Astronomy Observatory. The antenna is mounted on a circular track and thus is no longer a simple meridian transit instrument. Courtesy NRAO and Associated Universities, Inc.

A PIONEERING PROJECT

Reber was a member of one of the early families to settle in Wheaton, a small town about 25 miles west of Chicago. Coincidentally, he graduated from the same high school as Edwin P. Hubble, famous for the measurement of the distances to galaxies and the concept of an expanding universe. Hubble's 7th- and 8th-grade teacher was Harriet Grote, eventually Reber's mother, who later interested her son in astronomy by giving him a book by the well-known scientist.

At age 15 Reber built a transceiver and began to communicate with radio amateurs around the world. In 1933 he completed a B.S. degree in electrical engineering at what is now the Illinois Institute of Technology. Later, while working for the Stewart-Warner Co., he read Jansky's papers and was inspired to try listening beyond the range of normal ham radios.

In Reber's words,

> It was obvious that K. G. Jansky had made a fundamental and very important discovery. Furthermore, he had exploited it to the limit of his equipment facilities. If greater progress were to be made, it would be necessary to construct new and different equipment especially designed to measure the cosmic static.

Thus Reber began planning how he could measure the detailed distribution of the radiation intensity throughout the sky at different wavelengths.

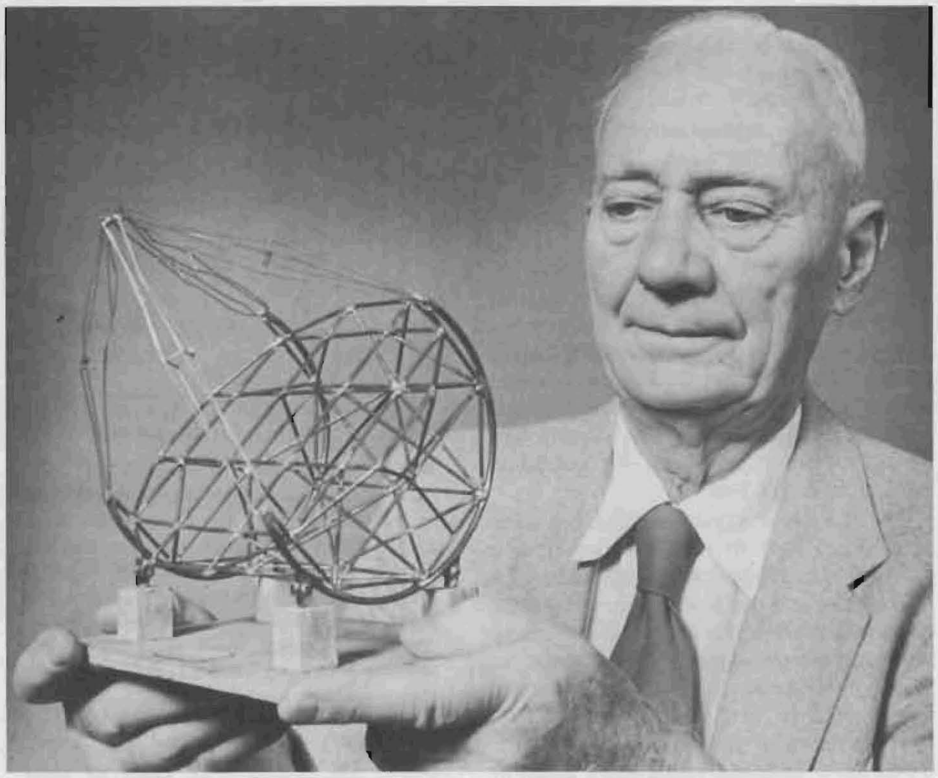
Although Reber had no outside support, he decided to build as large a reflector as he could, one that would provide a relatively narrow beam and the capability of tuning to different wavelengths by changing the feed at the focus. He settled on a 20-foot focal length and a diameter of 31 feet, being limited by the length of the longest 2-by-4's available locally. From June to September, 1937, Reber built his radio telescope at a cost of $1,300. For 10 years the instrument remained in his side yard at 212 West Seminary Avenue. This property is now owned by the Illinois Bell Telephone Co. and is used as a parking lot.

To achieve stability at minimum expense, Reber chose a meridian-transit mounting. Pointing in declination was accomplished with a differential gear from a Ford Model T truck, while scanning in right ascension was provided by the Earth's rotation. The reflector surface was made from 45 pieces of galvanized sheet metal screwed to 72 radial wooden rafters cut to parabolic shape. An overall tolerance of about 0.5 centimeter was achieved, and the whole telescope weighed less than two tons.

According to Reber,

> The mirror usually emitted snapping, popping, and banging sounds every morning and evening. The rising and setting sun caused unequal expansion in the [reflector] skin. . . . When parked in a vertical position, great volumes of water poured through the center hole during a rain storm. This caused rumors among the local inhabitants that the machine was for collecting water and for controlling the weather.

On one occasion, when a small airplane suffered engine trouble after flying over the dish, some townspeople said the instrument was invented to disable enemy aircraft in case of war! Such was the prevailing atmosphere in 1938.



Reber pictured on the occasion of his induction in 1986 into the DuPage Heritage Gallery (Illinois). He holds the original 1936 model used in planning the construction of his radio telescope. Courtesy H. Richard Bamman, *Wheaton Daily Journal*.

Reber obtained custom-made vacuum tubes from glass-blowing experts at the University of Chicago and other radio components from his employer. He initially chose an operating wavelength of 9 cm, which was the shortest that was practical. It provided good angular resolution. Also, if Planck's blackbody radiation law applied to the cosmic static, this wavelength would also reveal more intense thermal emission than Jansky had detected.

But Reber's initial observations failed to detect anything, so he began to doubt that the Planck law applied to celestial radiation. By the summer of 1938, he had changed to a wavelength of 33 cm and had upgraded his receiver. However, even with improved sensitivity, nothing of celestial origin turned up, so Reber decided to try a still longer wavelength. He had Alcoa fabricate a cylindrical cavity from a 6-by-12-foot sheet of aluminum, which set a new operating wavelength of 1.87 meters. With a dipole antenna in the cavity resonator at the dish's focus, two years of persevering work finally began to pay off. He began to get positive results by the spring of 1939.

SIGNALS AT LAST!

Due to interference from automobile ignitions Reber did most of his work from midnight to dawn. After working all day in Chicago, he would sleep after supper until observing began. By April the plane of the Milky Way crossed the meridian late at night, and it became apparent that our galaxy produced radio emission at a wavelength of 1.87 meters. Reber determined the intensity of the cosmic radiation by reading a microammeter at one-minute intervals. He also monitored the audio signal to detect and remove periods of interference.

In February, 1940, his initial results were published in the *Proceedings* of the Institute of Radio Engineers. Noting that the estimated intensity was far below what Jansky had measured at a wavelength of 15 meters, Reber recognized that the source was some new phenomenon other than thermal emission. He showed that his radio data could be explained as "free-free" radiation from electrons interacting with positive ions.

Through Reber's work the attention of astronomers was at last attracted to radio. He published a paper in the June, 1940, *Astrophysical Journal*, which also contained a theoretical discussion by Louis G. Henyey and Philip C. Keenan on the amount of radio emission to be expected from interstellar gas. Their results agreed with Reber's measurements and showed that at wavelengths less than about 5 meters Planck's blackbody law would not apply to an ionized gas.

With this initial success to whet his appetite, Reber prepared to conduct a complete sky survey. He purchased an automatic recorder and built new regulated power supplies to improve his system's sensitivity. Beginning his survey in 1941, he published preliminary results a year later and a more complete account in the November, 1944, *Astrophysical Journal*. The product of this effort (shown on the bottom of the next page) was the first radio map of our galaxy.

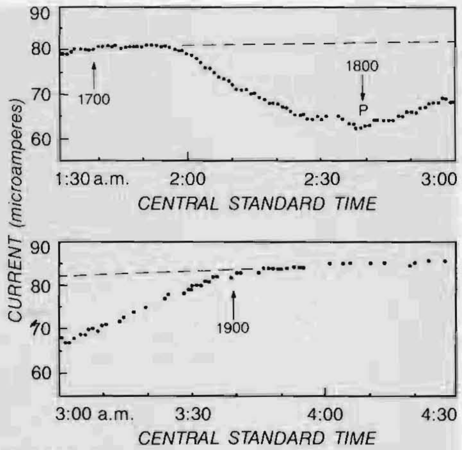
At 1.87 meters, Reber's radio telescope had a beamwidth of about 12°, making it possible to resolve structure in our galaxy's radio emission. Several chart recordings were made at each declination setting of the antenna. The pen would slowly rise and fall on the paper as the Milky Way passed through the antenna beam. After collecting about 200 chart recordings, he plotted the results as lines of constant intensity on the two hemispheres of the sky.

The radio maps of the Milky Way revealed some interesting details. The main intensity peak appeared at the center of the galaxy in Sagittarius. Also, secondary maxima were clearly evident in Cygnus and Cassiopeia, which were later resolved as discrete sources. More important was his recognition that radio waves could penetrate the interstellar dust that obscures most of the Milky Way and could possibly reveal our galaxy's spiral structure. Eventually this feat was accomplished at the 21-cm wavelength emitted by neutral atomic hydrogen.

Reber tried unsuccessfully to detect planets, stars, and nebulae. In September, 1943, he finally turned his telescope toward the Sun. On the very first meridian transit the recording pen was driven to full scale, even though it was a time of low sunspot activity. Reber reported this "discovery" of the solar background continuum in a 1944 paper. Transient surges of solar radio waves had been detected accidentally in 1942 as noise that jammed British radars. However, this finding had been kept secret and was not published until after World War II.

The last observations in Wheaton were made from 1945 to 1947 at a wavelength of 62.5 cm. Reber easily detected the Milky Way and the Sun, but now our star was much more active and produced many intense transient signals. These were the same phenomena discovered at meter wavelengths in England. With the narrower beamwidth provided by the shorter wavelength, he found much more detail in the Milky Way, as illustrated at right below.

The Cygnus region was now revealed to contain two noise peaks, later identified as the Cygnus A radio galaxy and the Cygnus X source associated with a spiral arm in the Milky Way. Later, a maximum in Taurus was matched to the Crab nebula, while one in Cassiopeia was the remnant of a 17th-century supernova.



Reber's earliest data confirmed the existence of radio noise from the Milky Way at a wavelength of 1.87 meters. In these graphs meter readings in microamperes are plotted against Central standard time. A cosmic signal is indicated by dots that lie below the dashed line, which represents no radiation. During these observations the antenna was fixed in place and pointed at the meridian toward declination −20°, and the Earth's rotation swept a band of sky through the telescope's beam. The arrows are labeled with hours of right ascension, and *P* denotes when the plane of the Milky Way crossed the meridian. Each dot is a separate visual meter reading by Reber — he did not use a chart recorder. From Reber's 1940 article in the *Proceedings* of the Institute of Radio Engineers.

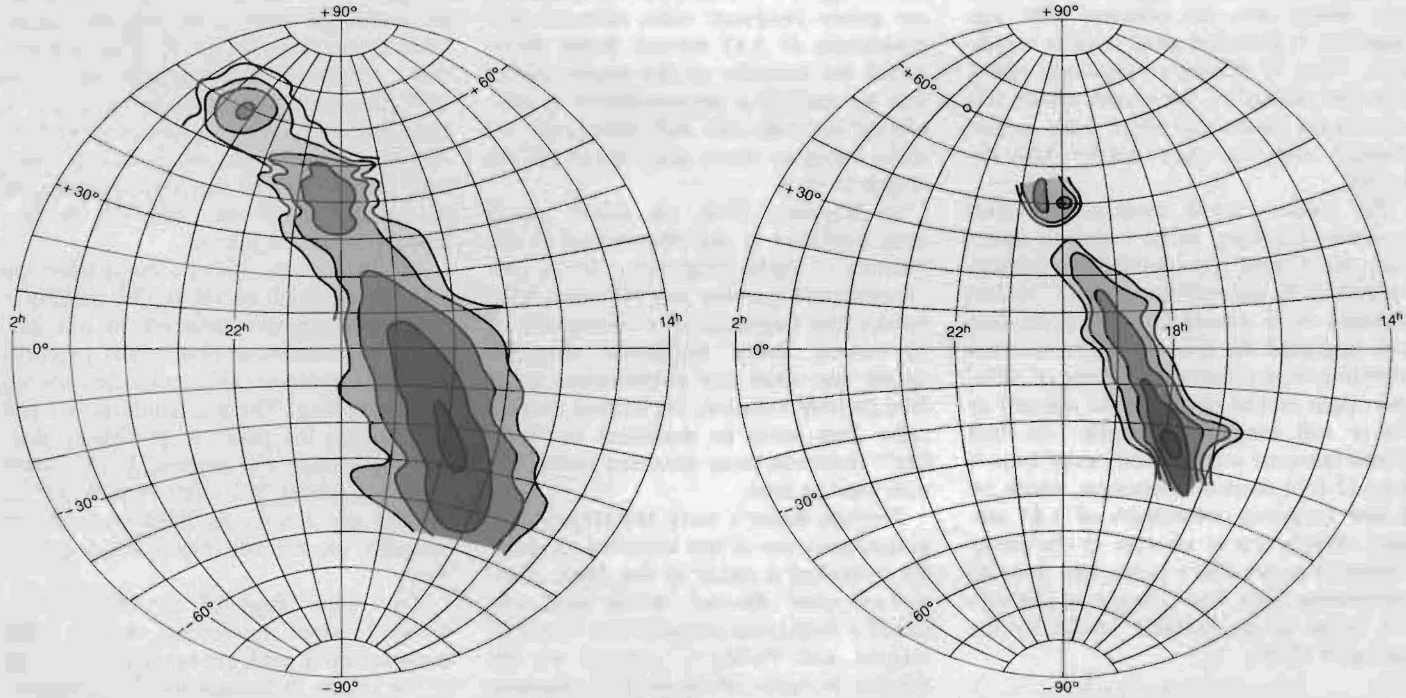
AFTER WHEATON

Operations at Wheaton ceased in 1947, and the radio telescope was moved to the U. S. Bureau of Standards. In 1960 the instrument was relocated at the National Radio Astronomy Observatory at Green Bank, West Virginia, and it remains there on public view.

In 1954 Reber moved to Tasmania, where he constructed a large wire-antenna instrument to measure radiation at a wavelength of 150 meters. He has since worked on projects ranging from Tasmanian archaeology to developing an electric car to torturing bean vines by twisting them in reverse direction.

Reber recently came to the attention of the Wheaton city fathers, and in 1986 he was inducted into the DuPage (county) Heritage Gallery, where he joins such notables as football star Harold "Red" Grange and Rev. Billy Graham.

Joseph L. Spradley is a professor of physics and teaches courses in the history of science and astronomy. He earned a Ph.D. in engineering physics by studying microwave antenna arrays.



Left: **The first radio map of the Milky Way resulted from some 200 traces made at a wavelength of 1.87 meters with an effective beamwidth of about 12°. Contours of equal intensity reveal the center of our galaxy at declination −25°, as well as peaks in Cygnus (+40°) and Cassiopeia (+60°). Adapted from Reber's November, 1944, article in the *Astrophysical Journal.* *Right:* This radio map has greater resolution because it was made at a wavelength of only 62.5 centimeters, resulting in a beamwidth of about 4°. Note that two peaks are now resolved in Cygnus at declination +40°. The small circle in Cassiopeia (+60°) is a supernova remnant. Adapted from an article by Reber in the October, 1948, *Proceedings* of the Institute of Radio Engineers.**