

Characteristics of COSMIC RADIO RADIATION

By H. C. Ko

COSMIC radio radiation is radiation of extraterrestrial origin in the radio-frequency portion of the electromagnetic spectrum. Such radiation was discovered by Karl Jansky¹ of Bell Telephone Laboratories in 1932 on a wavelength of 14.6 m. While studying the direction of arrival of the atmospheric disturbances which interfere with the transatlantic short-wave radio communications, Jansky found that in addition to familiar atmospheric static due to local and distant thunderstorms, his directive antenna was picking up persistent strange static noise. From further observations he concluded that the static noise was coming from the general direction of the Milky Way and the maximum noise was from the Constellation of Sagittarius, the central region of the Milky Way. Jansky suggested that this cosmic radio wave might be originating either in the stars or in interstellar space.

Since most of the information about the universe had been gained by optical observations, the existence of the cosmic radio waves opened an entirely new possibility for the exploration of the universe. However, the immense significance of Jansky's discovery was not fully appreciated at that time. Apart from the pioneer work of Grote Reber² between 1940 and 1944, no serious efforts were made to pursue Jansky's work until the end of World War II. During the last decade our knowledge of the nature of the cosmic radio waves has been greatly increased through the efforts of radio astronomers. In the course of the discussion I would

like to summarize some of the principal observational facts on the cosmic radio waves. The 21-cm hydrogen line emission from the galaxy and the radio emission from the sun and the planets will be excluded, since these topics have been discussed in detail by other speakers at this meeting.

The cosmic radio radiation consists of continuous radiation extending over practically the whole radio-frequency range and a line emission restricted to a very narrow frequency near 1420 Mc (21-cm wavelength). Observations of the continuous radiation are now available from 1 Mc up to 30 000 Mc. It extends a frequency range of over 30 000 to 1 or 15 octaves. The cosmic radio waves cause a steady audible hiss from the speaker of a receiver that can hardly be distinguished from the hiss caused by radio-set noise. Because of this acoustical effect accompanying the cosmic radio waves in radio receivers, it is often called cosmic radio noise or cosmic static. The radiation appears to be randomly polarized and does not show intrinsic fluctuations in its intensity.

Two quantities are conveniently used in radio astronomy to describe the intensity of radio radiation from the sky, namely flux density and brightness. Flux density is used as a measure of the radiation from a point source or a source with very small angular extent, and is expressed in watts per square meter per cycle per second.

The unit brightness is used to specify the intensity of radiation received from an extended source such as the diffuse background radiation of the Milky Way, and is expressed in watts per square meter per cycle

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Photograph taken at Holmdel, N. J., in the early 1930's shows Karl G. Jansky of Bell Telephone Laboratories and his historic rotating antenna. With it he observed the presence of radio waves emitted from the direction of the center of the Milky Way, a discovery which gave rise to the modern science of radio astronomy.

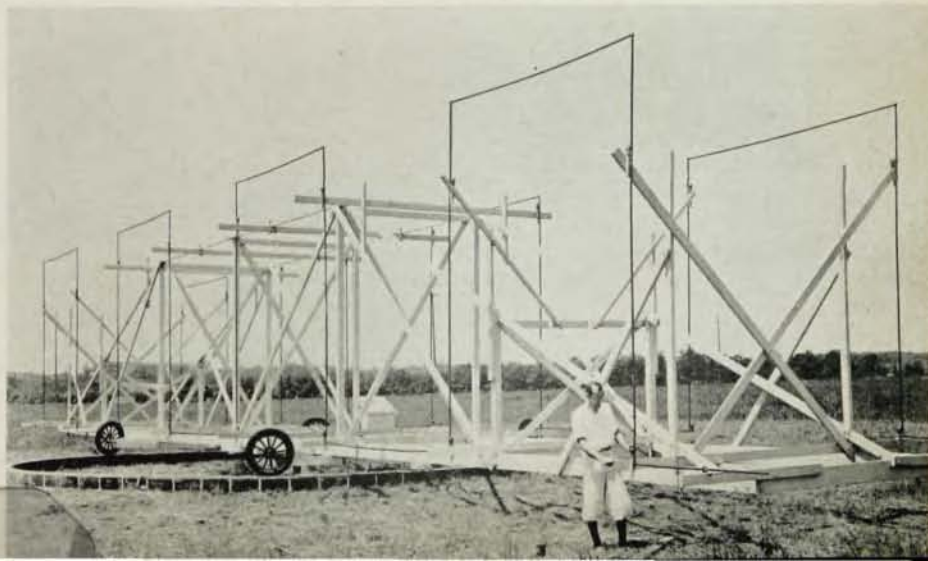


Fig. 1. Ohio State University 96-helix radio telescope antenna shown at right, has a beam approximately one degree wide in right ascension and eight degrees in declination at the frequency of 242 Mc.



per second per steradian. The brightness is more often specified by an equivalent black-body temperature. The brightness temperature of a radio source at a frequency f is defined as the temperature of a black body of the same angular size which would give the same brightness as that actually observed. The brightness B and the brightness temperature T are therefore related by the Rayleigh-Jeans law of radiation

$$B = \frac{2kf^2T}{c^2}$$

where k is Boltzmann's constant and c is the velocity of light.

The sky brightness is a function of the direction and the frequency. The determination of this brightness temperature distribution in the sky has been one of the major observational works in radio astronomy. The measured sky brightness temperature is in the range between a few $^{\circ}\text{K}$ and $500\,000^{\circ}\text{K}$. It must be emphasized that this sky brightness temperature is an *equivalent* black-body temperature, and does not imply that the mechanism of cosmic radio noise is that of black-body radiation.

The basic instrument used by radio astronomers is the radio telescope. Basically it consists of a radio antenna system and a highly sensitive radio receiving system. While a radio telescope differs to a large extent from a conventional optical telescope, its function is analogous. The antenna system collects and focuses incoming radio waves and the receiving system detects and records the signals. The radio-telescope antenna must possess sufficient angular resolution to pinpoint the direction of arrival of cosmic radio waves and have a collecting aperture area large enough to gather sufficient radio power for satisfactory detection. The exist-

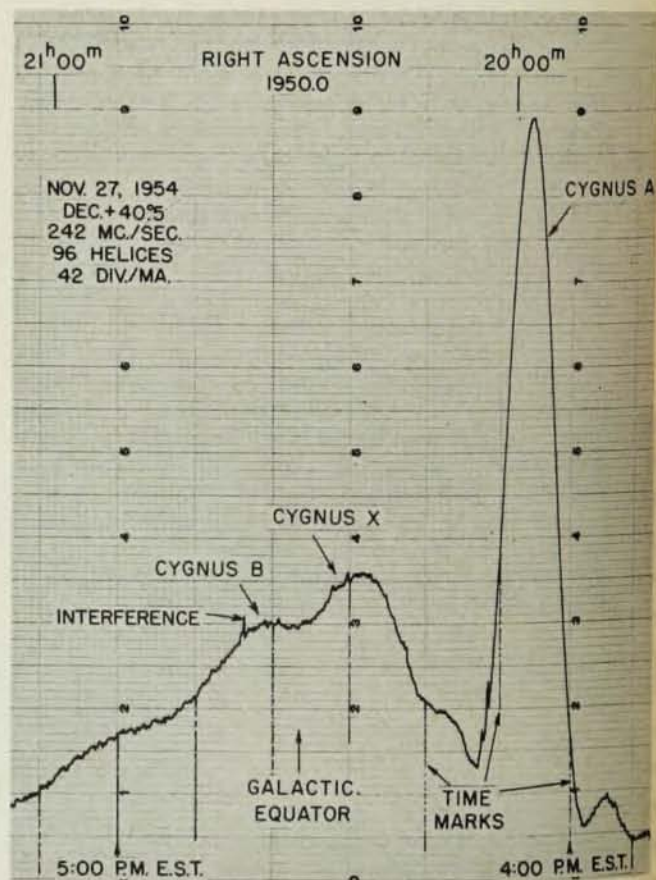


Fig. 2. Sample record taken with the 96-helix radio telescope in the Cygnus region. Deflections indicating the transit of radio stars Cygnus A, Cygnus X, and Cygnus B are shown superposed on the gradual rise caused by the general background radiation.

ing radio-telescope antennas have angular beam widths from a few tenths of a degree in arc to some tens of degrees.

Fig. 1 shows one of the radio telescopes operating at The Ohio State University Radio Observatory. It consists of 96 helical antennas mounted on a tiltable, flat screen measuring 160 ft by 22 ft. It has an aperture of about 300 square meters at 242 Mc. As the antenna beam sweeps across the sky because of the earth's rotation, the radiation it receives is detected and amplified by the receiver and pen-recorded on a moving paper chart. Fig. 2 presents a sample record obtained using this helical telescope antenna. It shows a strong radio source and several weak ones superimposed on a gradual rise due to diffuse background radiation. From a number of such charts, it is possible to construct a map showing the distribution of cosmic radio radiation in the sky.

What radio astronomers discovered with their radio telescopes is an entirely new view of the universe. The first radio map of the sky was made by Grote Reber in 1944 at a wavelength of 1.87 m. His work confirmed Jansky's discovery and revealed more detailed features of the distribution of cosmic radio radiation. His map showed that the radiation is concentrated along the Milky Way, with several strong maxima in the direction of the constellations of Sagittarius, Cygnus, and Cassiopeia. In 1947 Bolton and Stanley³ of Australia discovered a new type of radio source in the radio sky. They found that, in addition to radio radiation widely distributed along the Milky Way, there are several discrete intense radio sources—as if individual stars were sending out radio signals. These discrete sources have a well-defined boundary and have angular sizes of the order of few minutes of arc. The discrete radio sources are today popularly known as "radio stars", although in no known cases do they correspond to any visual stars.

Thus, the radio radiation from outer space basically consists of radiation from (1) radio stars and (2) the general background radiation which can not be resolved into radio stars.

ONE of the major works in radio astronomy has been concerned with the determination of distribution of cosmic radio waves across the sky. During the last ten years, many radio surveys of the radio stars and the general background radiation have been undertaken at various radio observatories in the world, notably in Australia, England, France, the Netherlands, and the United States. As larger antennas with better angular resolution and radio receivers of higher sensitivity were built and put into operation, more detailed features of the radio sky were revealed. The number of known radio stars has risen from six in 1948 to over 2000 in 1960, and the list is still growing.

Fig. 3 is a radio map of the sky at 242 Mc (1.2 m wavelength) which was made at The Ohio State University Radio Observatory using the 96-helix radio telescope antenna shown in Fig. 1. The antenna beam (1° by 8°) is narrow enough to reveal many details of the continuous background radiation and to detect many radio stars.

This map shows how the sky would appear if our eyes were sensitive to radio waves of 1.2 m wavelength instead of to light. The map is a Mercator projection showing celestial coordinates in a rectangular grid with the intensity of cosmic radio radiation indicated by contour lines of equal brightness. The dashed line in the map represents the galactic equator or the plane of the visual Milky Way. Inspection of the contour lines shows that the general background radiation is concentrated in the plane of the visual Milky Way and it reaches its highest intensity in the direction of the galactic center.

The positions of intense radio stars are also shown on

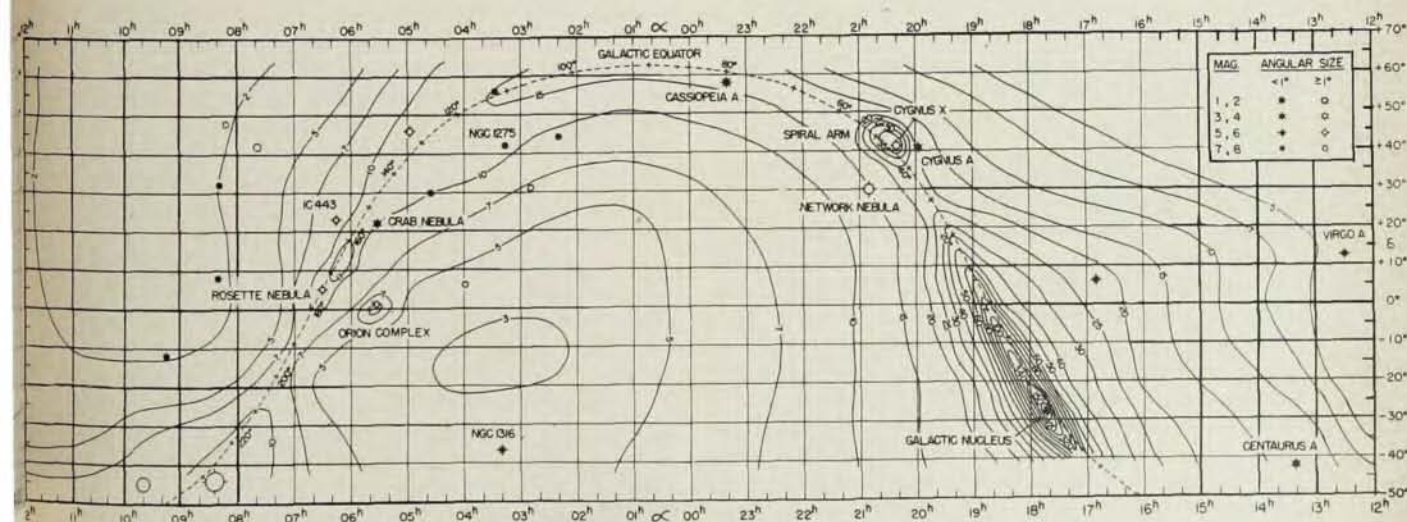


Fig. 3. Radio map of the sky in celestial coordinates made at a frequency of 242 Mc using the Ohio State University 96-helix radio telescope. Contour lines show the radio brightness of the background cosmic radio radiation while small dots and circles indicate radio stars.

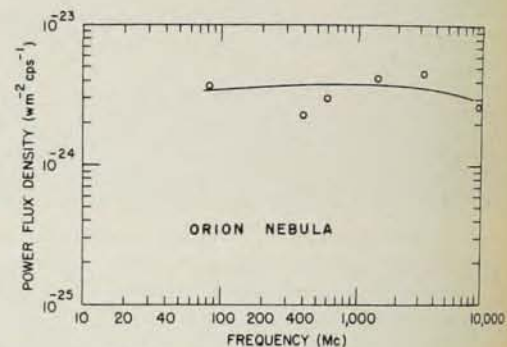
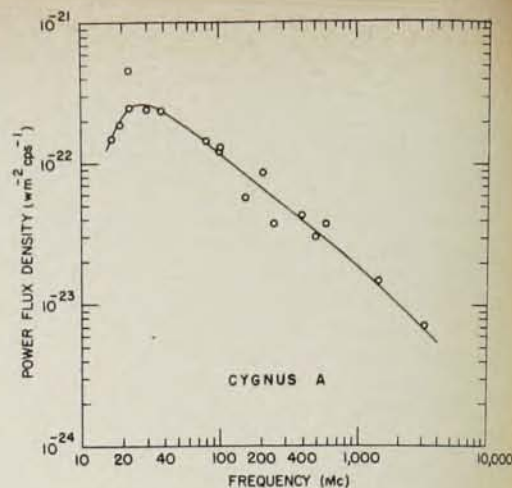
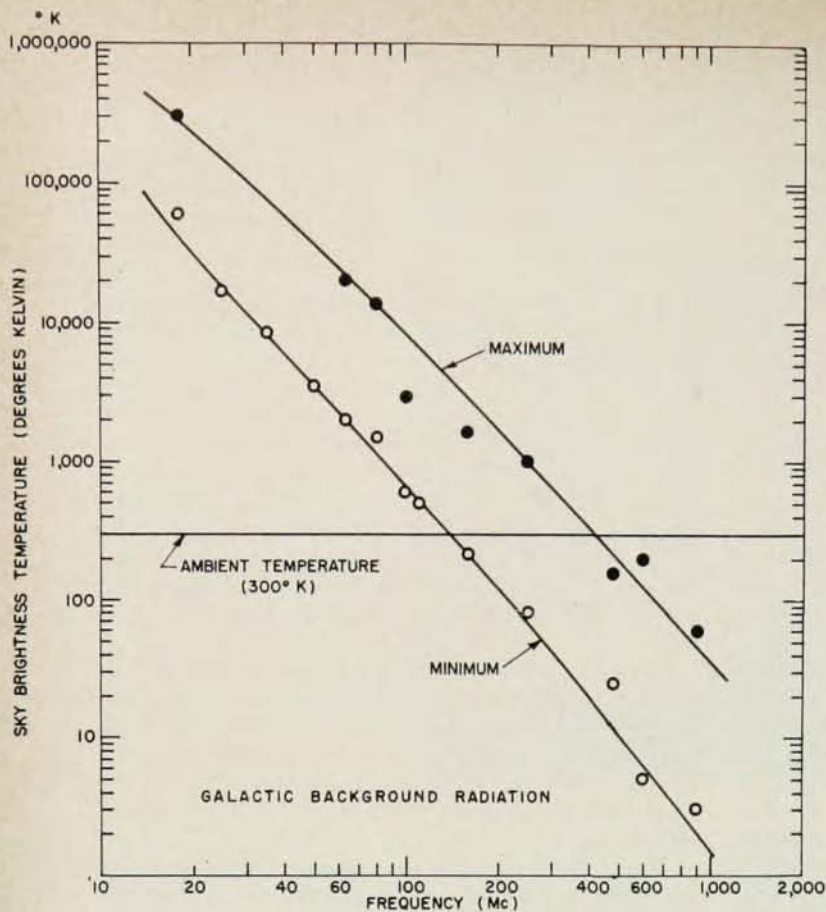


Fig. 4. Radio spectra of the galactic background radiation (left), the radio star Cygnus A (upper right), and the Orion nebula (lower right).

the map. Solid dots represent radio stars of angular extent smaller than one degree and open circles represent those of larger angular extent.

This map is a radio view of the sky at only one frequency, 242 Mc. This is equivalent to a visual view of the sky through a color filter. Through the work of radio astronomers at various observatories, radio maps of the sky are now available at many frequencies ranging from 20 Mc to 1400 Mc.^{4, 5} Radio maps at different frequencies have a general similarity to that at 242 Mc shown in Fig. 3, but differ considerably in structural detail. Differences are due to variations of intensity of radio stars with frequency.

Fig. 4 shows typical frequency spectra of radio stars and background radiation. Broadly speaking, there are two distinct types of frequency spectrum, the nonthermal type and the thermal type. The nonthermal type has a spectrum in which the intensity decreases as the frequency increases, while the thermal type has a spectrum in which the intensity is independent of the frequency or increases with the frequency. The frequency spectrum of the general background radiation can also be classified into the above two types. Obviously the different spectra arise from different physical processes of radio radiation. As a result, the radio sky appears different at widely separated frequencies. Background brightness temperature varies from 500 000°K at low frequencies to a few Kelvin degrees at high frequencies, as is shown in Fig. 4.

It is generally accepted by radio astronomers that the mechanism of the continuous radiation consists of at least two distinct processes,⁵ one of which is the well-known thermal process involving free-free transitions in the ionized interstellar hydrogen gas, the other being the nonthermal process involving the synchrotron radiation from relativistic electrons moving in the galactic magnetic field. Over nearly all the sky the observed radiation at frequencies below 300 Mc is mainly dominated by the nonthermal component. At much higher frequency the thermal component begins to dominate the rapidly decreasing nonthermal component.

A study of the available radio map and lists of the radio stars leads to important conclusions concerning the distribution of continuous background radiation, and also the distribution of the radio stars. As to the continuous background radiation, there appear to be three subsystems:^{4, 5, 6} (1) the plane component, which is a narrow bright belt of radiation about 3° wide lying along the galactic equator and concentrated towards the galactic center; (2) a rather broad band of radiation concentrated within about 30° from the galactic equator; and (3) the "halo" component which is a roughly isotropic component of radiation distributed over the whole sky. The radiation from the galactic plane has both thermal and nonthermal components, while the others are of nonthermal origin.

As to the angular distribution of radio stars in space, the present evidence shows that there appear to be two

classes of radio stars.^{7, 8} Class I sources consist of radio stars of large angular diameter and strong intensity and are concentrated in the galactic plane. Class I radio stars are therefore objects within the Milky Way. Class II sources consist of radio stars of small angular diameter and appear to be quite uniformly distributed over the sky. It is generally believed that a number of the Class II sources are probably extragalactic objects. The total radio power output of radio stars is estimated as being in the range 10^{26} w to 10^{36} w.

The distribution of the radio stars in depth is of great interest because of its possible contribution to the study of cosmology. The Cambridge observations⁹ suggest that there are more faint radio stars than would be expected for a perfectly isotropic distribution. On the other hand, the Australian observations¹⁰ show that the distribution is not significantly different from that expected with a constant space density of radio stars. The discrepancy between the two observations is principally due to instrumental effects. More observations, especially using different types of antennas, are needed to settle this problem.

FINALLY, let us compare our view of the radio sky with that of the visual sky. There is a slight resemblance between the two views in that the Milky Way is a common feature of both. However, the Milky Way is much more dominant in the radio sky, where it stretches like a brilliant band across the sky and blazes with the maximum brightness in the direction of the center of the galaxy. On the other hand, in the visual sky, the region of the galactic center is darkened by great clouds of interstellar dust and gas. Because of their long wavelength, radio waves can easily penetrate the clouds that are opaque to light.

Here the resemblance ends, since no visual stars appear on the radio sky. In fact our familiar constellations of the visual sky disappear completely in the radio sky. Instead hundreds of radio stars dot the radio sky, forming totally new patterns.

Among more than 2000 known radio stars, less than 5 percent have been identified satisfactorily with visual objects. These objects are mostly very faint optical objects of unusual kinds and may be conveniently grouped under five classes:⁸

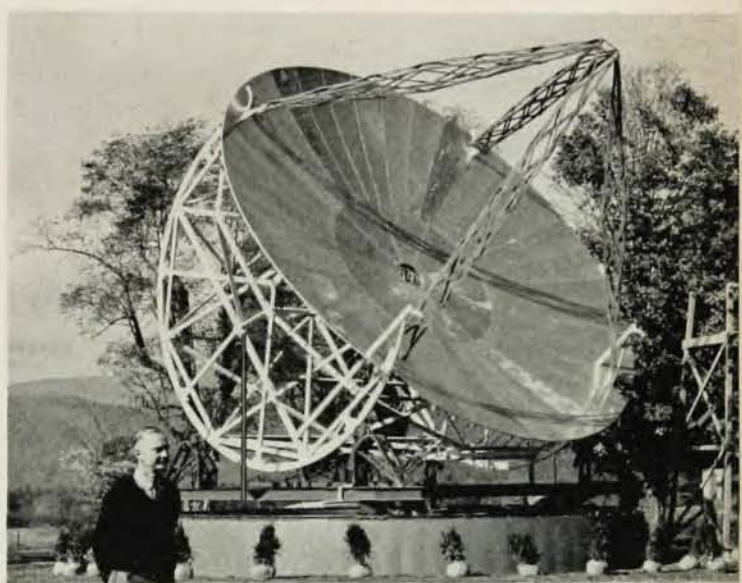
- (1) The remnants of supernovae (Crab nebula, Kepler's nova, etc.)
- (2) Peculiar galactic nebulosities (IC443, 04N4A, etc.)
- (3) Ionized hydrogen regions (Rosette nebula, Orion nebula, North American nebula, Omega nebula, etc.)
- (4) Normal galaxies (Andromeda nebula, Magellanic clouds, etc.)
- (5) Abnormal galaxies (Cygnus A, Centaurus A, Virgo A, etc.)

The first three are objects within the Milky Way while the last two are outside the Milky Way.

It was only 28 years ago that the first faint radio waves from outer space were detected. The brief his-



Above, Green Bank's 120-ft calibration horn antenna, used for accurate measurement of the intensity of radio radiation from Cassiopeia.



In this contemporary photograph, taken at Green Bank, Grote Reber stands near a reconstructed version of his 1939 radio telescope.

tory of radio astronomy is one of rapidly accumulating observations. Within the last ten years radio astronomy has greatly enlarged man's conception of the Universe. However, our present knowledge of the cosmic radio waves is still inadequate to decide most of the major questions about the origin of the radiation. We hope that these questions may be answered with the aid of larger radio telescopes now under construction at many observatories.

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