RADIO ASTRONOMY RESEARCH IN THE UNITED STATES

by

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1. Brief Historical Notes. Radio astronomy had its birth in the United States in the early 1930's, when Karl G. Jansky discovered radio static reaching us from the direction of the center of our Milky Way System. Some of the basic early discovery work was done in the United States by Grote Reber (first map of the distribution of radio radiation from our galaxy) and by J. C. Southworth (radio radiation from the sun), but in the postwar period the lead was taken by Great Britain, Australia, the Netherlands and Canada. Ten years ago, only one single university -- Cornell -- devoted major attention to research in radio astronomy and the Naval Research Laboratory (NRL) had then only just entered the field.

The National Science Foundation recognized almost immediately after it had been established, a little more than four years ago, that the United States was lagging far behind other countries in this important new field of research. The Foundation began its efforts in radio astronomy by the support of the activities at Harvard (where the research effort had been sparked by the discovery of the 21-cm line of neutral hydrogen by H. I. Ewen and E. M. Purcell; March 1951) and at Ohio State. Independently the Department of Terrestrial Magnetism of the Carnegie Institution of Washington (DTM) and the National Bureau of Standards (NBS) had entered the field, so that by the summer of 1952 six American centers could be counted as being active in radio astronomy.

In January 1953, the NSF organized a Symposium to survey the future prospects for radio-astronomical research in the United States. As a result of this Symposium, the efforts at the six institutions engaged in the work was intensified, and the United States has now regained its place among the nations recognized as leaders in the field.

The early efforts by NSF have had important catylitic effects on three fronts:

1. The renewed emphasis on radio astronomy in the United States has in part provided the impetus for the establishment of several additional research centers. Research beyond the initial planning stages is now under way at the California Institute of Technology, the University of Michigan, Stanford University, Rensselaer Polytechnic Institute (RPI) and at the Harvard Solar Station near Fort Davis, Texas; in every case the initial support for these new efforts has come from sources other than NSF, notably the Office of Naval Research and the Air Force.

2. Following a suggestion originating from Harvard and MIT, the NSF and Associated Universities Incorporated (AUI) embarked upon a feasibility study for a large inter-university radio observatory -- the very observatory that we shall be discussing today.

3. With ten institutions now active in radio astronomy, serious consideration is being given at five additional universities to the possibility of their entering this young and exciting field. We may thus count on close to fifteen active centers by the time the proposed radio observatory at Greenbank, West Virginia, will be ready to operate as an inter-university center for research in radio astronomy.

Radio astronomy is being integrated rapidly into the ancient field of astronomy. It has become apparent during the past few years that radio-astronomical techniques are as basic to astronomical research as are photo-electric or spectrographic techniques. In other words, radio-astronomical techniques are one of several ways for the study of the universe. In investigations of the behavior and evolution of interstellar clouds of gas and dust, for instance, the astronomer can hardly escape using the radio techniques along with the more traditional optical techniques.

Before we examine in detail the scientific effort now under way in radio astronomy in the United States, we should note the following general points:

1. Whereas four years ago, the construction of a 50-foot paraboloid mounted in alt-azimuth fashion, or of a 30-foot dish mounted equatorily, was considered a major new engineering effort, we contemplate now with confidence the construction of a 100-foot paraboloid mounted either way. The step from a 100-foot paraboloid to a 140-foot paraboloid is a rather modest one.

2. In all but at most three of the ten institutions active in radio astronomy, men who received their Ph.D.'s in astronomy are directing or co-directing the radio-astronomical activity, and the contemplated new entries in the field are at universities with strong departments of astronomy.

3. The number of active radio astronomers in the United States has increased in the past five years from half a dozen to twenty or more. A program for graduate study is now actively under way at four universities and three more are about to enter the field. Six Ph.D.'s in radio astronomy have been awarded

in the past three years and the graduate students in the field now number between fifteen and twenty. Increasing interest in radio astronomy is being shown by American astronomers at almost all observatories.

4. The majority of the radio-astronomical centers in the Eastern and Central United States are not contemplating the construction in the near future of new large-scale equipment, because they expect to make full use of the Greenbank facilities.

5. The developments in the United States must be considered in relation to those of our northern neighbor, Canada, which has long been active in two areas, solar research (A. E. Covington; Ottawa) and meteoric research (P. M. Millman and D. W. R. McKinley; Ottawa). In addition we note that the University of Toronto (D. A. MacRae) is entering the field. With new Canadian plans in the making, much good can come from a future close collaboration between the United States and Canada, especially as this affects the Radio Observatory at Greenbank.

In the brief summary to follow, we shall survey the present status of research in radio astronomy grouped under four headings. Ionospheric and meteoric research are not included in the present survey.

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2. Solar Research. Much of the early activity at Cornell and at NRL was in the field of solar research and both institutions continue to be among the leaders in the field. DTM has been active in solar radio astronomy for many years and several of the newcomers to radio astronomy, Michigan, Stanford, Harvard (Fort Davis) and RPI are concentrating their efforts upon studies of the radio sun.

The NRL group has been concerned primarily with studies of the sun at 8 mm, 3 cm, and 10 cm, during and outside total eclipses of the sun. Some of the most important basic information about the brightness distribution at various frequencies has resulted from the NRL studies.

At Cornell there is continuing emphasis on a solar patrol, first begun in 1948, and now at a frequency of 201.5 mc/sec. A 50 wavelengths E-W interferometer is used for several hours around noon each day, and with its aid the position of active radio spots on the sun can be found within a 3' slice. The total flux is also recorded. Wide distribution is being given to the daily results and duplicates of all records are sent regularly to the McMath-Hulbert Observatory for correlation with other radio and optical data. Now under construction is equipment for the measurement of the polarization characteristics at 200 mc/sec. Once this equipment is operating properly, it will be enlarged to permit the measurement of polarization as a function of frequency. Also under construction is an L-shaped N-S and E-W lobe-switching interferometer, with a spacing of 50 wavelengths at 53 mc/sec, which will, however, initially be employed mostly for ionospheric studies.

Interferometric studies of the solar radiation have been the principal area for solar research at DTM. Studies have been made to derive the brightness distribution over the quiet sun at 200 mc/sec and this equipment is now being used for positional and polarization measures on the active sun. A Christiansen array for 300 mc/sec, which will have a resolution of 3', is now under construction.

A regular patrol of solar radio radiation on 167 and 460 mc/sec is being maintained by the NBS at Boulder, Colorado. Median levels are reported for three hour intervals as a part of a survey that operates daily from sunrise to sunset throughout the year. Automatic calibration is provided.

The RPI radio astronomy observatory is located 16 miles east of Troy, N.Y. in the township of Grafton. The initial program consists of a study of the motions of sources of solar outbursts at a frequency of 500 mc/sec. The basic interferometer equipment consists of two 10-foot reflectors separated by 250 meters. The lobe-pattern of the interferometer is swept in angle by varying the relative phase-delay between the antennas and the common receiver. The changing phase angle of maximum signal indicates the apparent motion, relative to the sun, of sources smaller than a single lobe.

The major new effort in solar radio research in the United States is presently the study of the radio frequency spectrum of bursts and outbursts on the sun, following the sweep-frequency techniques developed by J. P. Wild at Sydney.

The Harvard program at Fort Davis, Texas, employs a 28-foot paraboloid reflector with three primary arrays and associated receivers, covering successively the ranges 90 to 180, 160 to 320 and 300 to 550 mc/sec. The purpose of the research is to obtain a dynamic record of solar radio activity over a large frequency band, 90 to 550 mc/sec as contrasted to the range 40 to 250 mc/sec employed at Sydney. The large aperture of the antenna and the high sensitivity of the receivers will assist in yielding high sensitivity for small-scale phenomena in the solar atmosphere. The research at Fort Davis will be closely coordinated with that at the nearby High Altitude Observatory (optical) on Sacremento Peak in New Mexico.

The Michigan program has its base near the University's Portage Lake Observatory. The principal initial radio telescope will be a 28-foot paraboloid with recording equipment capable of scanning mechanically from 100 to 600 mc/sec, ten times every second. Simultaneous measurements will be made of the state of polarization of the solar bursts. The work will be coordinated closely with the optical observations carried out at the McMath-Hulbert Observatory.

Future plans include extension of the work to a paraboloid antenna with an aperture of 60 feet and the use of travelling-wave tube receivers for solar bursts observations in the range 5,000 to 10,000 mc/sec. With an array of four small horns at the focus of the 60-foot reflector, it should be possible to locate isolated bursts to within a fraction of beam width; at 3-cm wavelength the precision should be of the order of a fraction of a minute of arc. Burst positions and dynamic spectra should thus be obtainable with the aid of one single large paraboloid antenna.

At Stanford a very high resolution apparatus for solar radio research is now under construction; it will be operated at a wavelength of 9 cm. The instrument consists of two mutually perpendicular Christiansen arrays of 10-foot paraboloids, each 375 feet long, and so coupled electronically that their fan beams are multiplied together, following the principle first applied by Mills at Sydney. E-W scanning will depend on the rotation of the earth and N-S scanning will be done electrically. The equipment is expected to have an angular resolution of the order of 3'. For the quiet sun, the instrument should give valuable information on the brightness distribution over the sun and limb brightening. Detailed study will be possible of chromospheric phenomena associated with solar activity.

3. Studies of the Planets. The discovery by B. F. Burke and K. L. Franklin at DTM of radio noise from Jupiter has opened up an entirely new field of astronomical research. They have detected at 13.5 meters wavelength variable radio noise of high intensity emanating from the planet Jupiter. Further study has revealed that, on occasion, these bursts show strong circular polarization. The principal active region has the same period and longitude as Jupiter's Red Spot. Quite recently studies of Jupiter noise at 11 meters wavelength have been made by the Ohio State group.

At NRL recent work at 3.15 cm wavelength has led to the detection of radio radiation from Venus. The observed flux level indicates that we are dealing here with temperature radiation from the outer parts of the planet. At Ohio State intense and rather spectacular signals have been received from Venus at a wavelength of 11 meters. These signals must have a very different origin from those received at NRL.

4. Continuous Radiation. Ohio State has for several years been the leading American institution for the study of the continuous background radiation from our galaxy and beyond. J. D. Kraus and H. C. Ko have built and operated successfully a large helical array, designed for use at 250 mc/sec frequency and consisting of 96 helical beam antennas mounted on a tiltable ground plane 160 feet long by 22 feet wide. With this equipment the observations have been made that have yielded the Ohio State Radio Map of the Sky.

Ohio State is pioneering in the development and construction of radio telescopes of largest possible aperture at minimum cost. Experiments are now under way with a model consisting of a fixed section of a paraboloid with a tiltable flat-sheet reflector. The scale model designed to operate at 1.25 cm wavelength has worked out so well that it is now in use for solar and lunar observations. The first half of a unit measuring 700 feet in length by 70 feet in height will be constructed shortly on a site provided by Ohio Wesleyan University near Delaware, Ohio.

Whereas in the past there has been some emphasis at NRL upon flux measures in the meter range, the NRL work on the continuum has in recent years been concerned primarily with measures in the range of frequencies 1,000 to 10,000 mc/sec. Following the discovery at NRL of many discrete radio sources emanating radiation in all likelihood of thermal origin, detailed studies have been made and are continuing for several of the more prominent sources. The future study of brightness distribution in the continuous background in the decimeter, centimeter and millimeter range continues to be of primary importance. Once the 60-foot paraboloid at Michigan is in operation, its program will be concentrated heavily upon studies similar to those described in this paragraph. The Michigan studies at centimeter wavelengths will involve principally measurements of intensity, position, approximate size and spectral intensity distribution in the continuum of thermal and non-thermal sources.

At DTM there are two principal areas of research relating to the continuum. A new array of 64 dipoles has been completed and tested in conjunction with the Mills Cross at 22 mc/sec. It will be used as an interferometer to check on apparent sources observed with the Cross alone and, in addition, it will be used to survey the galactic background. A second area of activity relates to observations of the continuum in the 15 to 30 mc/sec frequency range, where several of the known discrete sources seem to have an energy maximum. The four brightest sources seem to fit the recent predictions by F. T. Haddock and N. G. Roman.

5. 21-Centimeter Research. Four American radio observatories, NRL, DTM, Harvard and Cal. Tech. are at present active in 21-cm research and a fifth, Michigan, may be added to the list in the near future.

21-centimeter research continues to be the central program in radio astronomy at NRL. The discovery and study of the absorption spectrum of the Cassiopeia source ranks as one of the big events of the past few years, and the recent discovery and study of an absorption feature in the remote Cygnus source has far-reaching consequences for research on the expansion of the universe of galaxies. The search for absorption or emission features other than the 21-cm line is being pressed at NRL and earlier this year much effort was spent on an exhaustive but alas unsuccessful search for OH radiation (near 1667 mc/sec). The 21-cm radiation studies of the region of the galactic center and surroundings continue to be an important feature of the research program at NRL and, to supplement the observational work, careful theoretical studies are under way relating to the formation of absorption and emission features in the 21-cm line and related studies of the continuum.

At DTM, 21-cm research is in a state of transition. Several surveys of 21-cm profiles have been made at set galactic longitudes and from this work much useful information has been obtained to supplement the Dutch work. This program is being continued. In addition, a new 50-channel receiver is approaching completion and will in all likelihood be used with a new paraboloid antenna of 60 to 80 foot diameter. Careful attention is being given to the design of the mounting of the new dish, which incorporates several new features.

At Harvard's Agassiz Station primary emphasis continues to be upon related 21-cm and optical studies of sections of the Milky Way and objects of special interest. The construction and putting into operation of the new 60-foot G. R. Agassiz Radio Telescope has been completed. The radio telescope is being used presently with the electronic equipment previously attached to the 24-foot radio telescope, but shortly the new electronic equipment with a bandwidth of 5 kc/sec (radial velocity resolution of the order of 1 kc/sec) will go into operation.

The principal projects on which research has been completed recently or is now in progress are the following ones:

1. Studies of the neutral atomic hydrogen content of optically known gas and dust clouds of our galaxy.

2. Detailed studies of the spiral structure for some sections of the Milky Way, notably the sections between galactic longitude $l = 60^\circ$ and 110° and between $l = 335^\circ$ and $l = 15^\circ$; also a study of the Cygnus Complex.

3. Studies of 21-cm radiation associated with clusters and associations.

4. A comprehensive study of the Orion Aggregate, including the associations NGC 2244, NGC 2264 and λ Orionis.

5. The discovery and study of 21-cm emission from the Coma cluster of galaxies, shifted in frequency according to the prediction from the optically-observed radial velocity of recession.

Once the 60-footer and its new electronic equipment are in full-scale operation, special attention will be given to studies of absorption features and to research into the 21-cm radiation from beyond our own Milky Way System.

At Cal. Tech. the construction has recently been completed of a 30-foot paraboloid and associated electronic equipment and this instrument is now in operation on top of Mount Palomar. The initial work is being done with a bandwidth of 25 kc/sec, but a 10 kc/sec bandwidth is also available. The very ambitious future program involves the construction of a pair of 90-foot steerable paraboloids, each mounted equatorily, and used as an interferometer pair. A site has been selected near Bishop in California and construction has begun. One of the principal initial programs with this new equipment will be the study of the 21-cm spectra of a great many discrete radio sources. Assembly of the equipment at the site is expected to start early in 1957.

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