Review of Developments Occurring Within the United States of America in the Field of Radio Astronomy

1. University of Alabama

Measurements of radiation from the sun and moon at millimeter wavelengths have been continued. The effective temperature of the sun, averaged over the entire disk, is found to be 6,500 °K at 8.6 mm. This temperature is in agreement with the trend shown by earlier measurements in this laboratory, which indicated temperatures of 4,500 °K at 6 mm and 5,600 °K at 7.5 mm. In these figures, the antenna efficiency and the effects of atmospheric attenuation and radiation have been taken into account.

Earlier experiments on lunar radiation between 7 and 8 mm have been repeated with better precision using a 60-in. paraboloidal antenna. A variation of lunar temperature with phase has been noted. There is evidence that the temperature varies with phase in a rather complex manner. The maximum temperature, averaged over the entire disk, is about 175 °K, and it occurs some 4 days after full moon. The minimum temperature, about 125 °K, occurs near new moon.

Work in progress includes the development of a model for radio emission from the lunar surface, and a program to determine the utility of a crystal audio radiometer for solar and lunar measurements in the wavelength range between 3 and 8 mm.

Bibliography: Mitchell, Whitehurst, Weaver (1957); Mitchell, Whitehurst (1958); Tyler, Whitehurst, Mitchell (1958); and Weaver, Mitchell, Whitehurst (1958).

2. Air Force Cambridge Research Center Sagamore Hill Radio Astronomy Observatory

During the period 1957–1960, radio astronomy techniques were used on a number of occasions to make measurements of atmospheric absorption, refraction, and scintillation with both solar and stellar radiation as the source of rf energy.

In July 1957, a comparison-type radiometer was used to make such measurements at C band (4,700 Mc/s) [Castelli, Aarons, Ferioli and Casey, 1959] with the sun as a source. Previous measurements by this group [Aarons, Barron, and Castelli 1958] had been made at 3.2 cm, 8.7 mm, and 218 Mc/s. The mean absorption, based on average solar temperatures at the various elevations for the period, was 0.00348 db/km. Average refractive errors were approximately the same as in the optical region although deviations from the mean during any day were large.

At C band, atmospheric scintillations for periods ranging from 0.5 to 90 sec. were recorded. At low angles, the scintillation amplitudes ranged from 2 to 20 percent of antenna signal temperature; at high-elevation angles, they rarely reached 10 percent and were generally less than 1 percent. Although the low-angle scintillations are probably of atmospheric origin, correlation between them and many meteorological parameters at ground level was unsuccessful.

Further light was shed on these phenomena by measurements made at three different frequencies (224, 1,300, and 3,000 Mc/s) during the solar eclipse of October 2, 1959 and during a control period bracketing this date [Aarons, Castelli, Straka, and Kidd, 1960: Aarons and Castelli, 1960]. Average refraction corrections were worked out during the control period to permit accurate antenna pointing and tracking of the sun. Interferometric solar maps for this period, taken by Bracewell at 3,300 Mc/s and by Christiansen at 1,420 Mc/s, indicated the presence of plage areas on both the east and west limbs of the sun: maps at 169 Mc/s by Denisse and Simon indicated no point sources of solar activity at this frequency range. A study of the signals received at the various frequencies revealed that scintillations of the signal were recorded for those frequencies (1,300 and 3,000 Mc/s) for which constant point sources of energy existed on the sun. During the early part of the eclipse, when the larger part of the solar disk was eclipsed and only the point sources were uncovered, scintillations of very large amplitude were evident. The periods ranged from 25 to 140 secs and large scintillations were recorded mainly for observations made below 4° of elevation.

Throughout the period studied, scintillations at the 1,300- and 3,000-Mc/s frequencies were remarkably well correlated in detail despite the fact that the frequencies had a ratio of 2.3 to 1, the apertures of the two antennas on which the data were received were quite different (84 and 8 ft.), and the two antennas were separated by 80 ft. Therefore, it has been concluded that, for this frequency range, the shadow patterns generated by the radiofrequency active areas on the sun are not frequency dependent: and that, within the distance between the centers of the two antennas, a single shadow pattern exists.

In cooperation with Stanford University, further analysis of the 3,000 Mc/s eclipse measurements was made, [Straka, Swarup, 1960] by comparing them with a 3,300 Mc/s two-dimensional solar brightness distribution map experimentally obtained at Stanford University by means of their interferometric cross 14 hr. before the eclipse. When the difference between the time at which the map was made and the time of the eclipse was taken into account, the curve obtained by artificially eclipsing the 3,300-Mc/s solar map was found to agree fairly well with the experimentally obtained eclipse measurements modified to compensate for absorption. In addition, the slope of the modified eclipse curve as a function of time was calculated at 1-min. intervals and averaged over a 2-min. period to smooth out scintillation effects. Reasonable agreement was obtained between increases in these slope measurements and the uncovering of spot regions on the interferometric map during the course of the eclipse.

During the lunar eclipse of March 13, 1960, a series of measurements of lunar temperatures at 1,300 and 3,000 Mc/s were made. Drift curves were taken of the moon with the 84-ft. Sagamore Hill Radio Telescope. Short-time constants were used and an accuracy of ± 2 percent resulted. For these frequencies, lunar temperatures were constant throughout the period of the eclipse. Additional measurements and analyses are being made at these same frequencies in order to determine temperatures over a lunation.

3. U.S. Army Signal Research and Development Laboratory

A program was established for observing the neutral hydrogen emission in the Andromeda nebula with the 60-ft. dish at the Evans area of USASRDL. However, shortly after the program began, the dish was requisitioned for Project Tiros. The dish should be released from this project in a few months. There is a possibility that radio astronomy research will be resumed either with this dish or with an 85-ft. dish in the Deal area, construction of which is scheduled to begin in 3 months.

After the change in project for the 60-ft dish, the 21-cm receiver was loaned to the Yale University Observatory with the understanding that it would be available part-time to Signal Corps personnel for research. In September 1959, by mutual agreement, the receiver was transferred to the Agassiz Station of the Harvard College Observatory.

External: Contracts with Cornell University and Dr. H. G. Booker entitled "Studies on Propagation in the Ionosphere" continued throughout this period. Papers under this contract have been presented at each URSI meeting. A new contract with the University of Virginia and Dr. E. C. Stevenson entitled "Research in Stellar Scintillations" is presently being negotiated.

4. California Institute of Technology Owens Valley Radio Observatory

One of the 90-ft telescopes commenced operation in April 1959 on a frequency of 960 Mc/s and was used principally for a "finding" program on radio stars and a survey of the Galaxy. The principal results from this unit up to January 1, 1960 were:

(1) The discovery of a band of decimeter radiation from Jupiter—following a lead provided by NRL;

(2) the finding of an extensive two-jet structure in NGC 5,128/Centaurus-A which is an almost perfect model for Cygnus-A;

(3) the result that the nonthermal radio stars have a very small spread in spectral index; and

(4) a survey of the galactic plane listing 110 galactic sources together with angular sizes and probable spectra. About half the sources can be identified with supernova remnants or emission nebulae.

The second 90-ft telescope began operation in September 1959 with a 21-cm line receiver. Absorption lines have been found in five additional galactic sources. Narrow-band self-absorption effects in a region near the anticenter suggests the presence of a considerable amount of hydrogen in dense cool clouds.

The two telescopes commenced operation as an interferometer at 960 Mc/s on January 15th. Using a spacing of 200 wavelengths, i.e. a fringe separation of 20 mins of arc, the minimum detectable signal (defined as having an amplitude equal to peak-to-peak noise fluctuations) is 4×10^{-27} watts $m^{-2}(c/s)^{-1}$.

Observations to date include:

(1) Intensity measurements of 600 radio stars for the purposes of comparison with LF measurements in order to determine spectra.

(2) Angular size measurements of 220 radio stars including observations so far at five different baselines. About 100, mainly galactic objects have been resolved. This program is continuing.

(3) Precise position measurements on 70 radio stars. The results have now made certain the identification of at least 18 galaxies or multiple galaxies as radio emitters. One position has led to the discovery of the most distant cluster of galaxies known—with a red shift of at least c/2 and perhaps 2c/3.

(4) The radiation from the planet Jupiter at 960 Mc/s is 40 percent linearly polarized with the plane of polarization parallel to the equator.

Negative results have been obtained from observations of Mercury and Venus (upper limits are close to black body expectations) and on a number of planetary nebulae. For the latter it appears that earlier observations by Drake are in error.

5. Carnegie Institution of Washington Department of Terrestrial Magnetism

Since early 1957, a 340 Mc/s, 30 element Christiansen array giving 4.8′ resolution on the sun has been in nearly continuous operation. The quiet sun, the slowly varying component, and active bursts have been extensively studied. In 1959 this was supplemented by a north-south array of 16 elements. A 16-element, 87-Mc/s array has also been constructed and used to study radiation from the active sun.

Two corner reflectors each 600 ft long were constructed for use at 400 Mc/s. Used separately they give a resolution of 12′ and as an interferometer 4′ fringes are obtained. The arrays have been used to measure accurate radio source positions and brightness distributions of extended sources. We have demonstrated that these arrays give an absolute accuracy of 1′ and a relative accuracy of 0.1′ in measuring right ascension of strong sources.

With small arrays the flux intensities of the brighter sources have been measured from 18.5 to 207 Mc/s.

The 54-channel hydrogen radiometer began regular operation in 1958. The first project was a map of high latitude galactic hydrogen. This has been followed by a survey of the galactic circle between latitudes ±20 deg. These surveys covering the entire sky visible from Washington, D.C. are now virtually complete. The equipment is now being transferred to a larger (60-ft) paraboloid.

6. Cornell University

IGY activities. A 200 Mc/s solar noise patrol and an ionospheric-radio-disturbance flare patrol were maintained. Data were sent regularly to the IGY data centers, and to the editor of the Quarterly Bulletin of Solar Activity. These patrols were maintained continuously from the beginning of the period through December 31, 1958.

Solar burst polarization studies. Polarization of radiation from the active sun was measured using a narrow band 200 Mc/s polarimeter [Cohen, 1958a, 1958b]. Early measurements showed that a few percent of Type III bursts were weakly linearly polarized [Cohen, Fokker, 1959; Cohen, 1959]. Measurements made during the Spring and Summer of 1959 showed that a larger group of Type III bursts was weakly linearly or elliptically polarized, and that the degree of polarization decreases with the analyzing bandwidth. These results are interpreted in terms of Faraday rotations in the corona, an amount 10^4 radians or more [Akabane, Cohen, in press].

Radio wave propagation in the corona. Theoretical studies are being made of magneto-ionic mode coupling by means of magnetic field gradients in the corona [Cohen, in press]. "Transition" frequencies have been computed; for a given geometry these are at the transition between weak coupling (low frequencies) and strong coupling (high frequencies). The theory explains the observation that the wide-band microwave bursts commonly have opposite rotation directions at 1,000 and 10,000 Mc/s.

7. Collins Radio Company

Research conducted by the Radio Astronomy Group of the Collins Radio Company since the 12th General Assembly has been largely devoted to 8.7 mm and 1.9-cm solar and lunar observations, atmospheric emission, attenuation, and refraction investigations, and to the achievement of precise, all-weather navigation systems utilizing solar and lunar radio emission. Associated activities have included extensive radiometric instrumentation and structural design to achieve precision determination of solar and lunar positions, absolute antenna temperature calibration, and combined radiometric and phase-locked tracking ability for deep-space research.

The use of a combined radio sextant-radio telescope for simultaneous measurement of angle of arrival and received power has been found to be of great value in the study of atmospheric attenuation and refraction [Iliff, Marner, 1960]. It has been possible to determine atmospheric attenuation constant as a function of height above the earth at 8.7 mm [Marner, 1956] and 1.9 cm [Marner, 1958a] and to determine atmospheric refraction as a function of altitude angle and surface meteorological conditions [Marner and Iliff, 1958]. New high-precision measurements are in process.

Emission from the atmosphere at these wavelengths has also been observed as a function of altitude angle and weather conditions, and it appears possible to account for the observed power levels by the use of the same model atmospheres as used in the attenuation case [Marner, 1958b]. The absence of good absolute calibration facilities left some question as to whether any galactic radiation is detectable, and new efforts are being made to achieve excellent calibration relative to absolute zero. Substantial improvement in the atmospheric emission data is also anticipated.

Interesting fluctuation properties have been observed in all of these processes, and new high figure of merit receivers and combined analog-digital recorders are being placed in operation to study these atmospheric characteristics. Several daily radiosonde observations will be used in conjunction with the emission, attenuation, and refraction observations.

An extensive study has been made of the effect of atmospheric phenomena upon precise determination of the position of the sun, the moon, and the discrete sources [Bellville, Holt, and Iliff, 1958]. The attenuation and emission gradients with respect to altitude angle, as well as the refraction, cause apparent displacements of the celestial source position which, in some circumstances, can be of substantial significance. The general principles have been worked out, and numerical examples computed for the microwave region by use of the atmospheric data cited above. By employing special instrumentation techniques intended to reduce bore-sighting errors, direct observations of these effects while tracking the moon have produced experimental verification of the theory.

The same tracking equipment is currently being used to study the location of the radio symmetry center of the sun and moon. Extensive data reduction programs are now in process.

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The use of the combined radio-sextant radio telescope allows excellent attenuation corrections and the new equipments will be used to make careful studies of solar and lunar temperatures as a function of time and wavelength. Extensive solar activity observations are currently being reduced.

The radio astronomy techniques have been applied to the achievement of precise all-weather marine navigation systems [Marner, 1959, 1960a]. It has been found practical to achieve such navigation by the use of solar and lunar radiation.

The past period has experienced the advent of a new class of celestial object—the man-made satellites and space probes. An extensive amount of work has been done relative to the radio observation of these sources. Major tracking facilities were constructed for the Jet Propulsion Laboratory at Goldstone, California, Cape Canaveral, Florida, and Puerto Rico [Brockman, et al, 1960]. These employ phase-locked receivers [Jaffe and Rechtin, 1954; Hamilton, 1959] to accomplish angle tracking and telemetering functions for space probe research. Successful data reception was experienced with the Pioneer IV lunar probe until battery exhaustion at 407,000 miles range. The 0.2-w transmitter would otherwise have maintained contact to a range of 1.15×10^6 miles. A worldwide network of receiving stations is currently being installed for an extension of such space research.

The use of artificial satellites for communication has been studied and extensive observing facilities are being erected for radio scattering research in this connection. Research in the use of satellites for navigation has also been under way [Marner and McCoy, 1959; Marner, 1960], and planning is being conducted for balloon and satellite-borne radio astronomy research. A considerable expansion of these areas of research is anticipated during the next period.

8. University of Colorado High-Altitude Observatory

The most important development in our radio astronomy program since the last General Assembly is a radio spectrograph covering the range 15 to 60 Mc/s. This spectrograph sweeps this range once per second, at a bandwidth of the order of 20 kc/s. It is a phase-switch interferometer in order to make possible the detection of radio stars, and to measure changes in the position of radio sources. The receiver has a detector operating on the minimum detection principle, which permits the output recorder to omit the strong pips that would be produced on the record by interfering stations, atmospherics, and other types of undesirable noise, most troublesome in this LF range.

This receiver, in operation since July 1959, has built up a considerable amount of observational material on solar and Jupiter emission, and radio star scintillations. The observations of solar emission have been partially reported in the Astrophysical Journal,' Vol. 131, No. 1, January 1960, pp. 61–67. The remaining observations are as yet unpublished.

One of the principle objectives of our work has been in the study of ionospheric effects on discrete sources, in the low frequency range. To provide a stable means of routinely observing the larger sources, we have constructed a pair of scaled interferometers operating at 18 and 36 Mc/s, respectively. These interferometers regularly observe the meridian transits of Cassiopeia A, Cygnus A, and Taurus A. As a byproduct of these records, we have been able to estimate the sources in the LF range, where considerable discrepancies in the reported flux densities appear in the literature. Furthermore, it has been possible to observe Taurus A fairly close to the time of its occultation by the solar corona, near the middle of June. Our observations here cover only one occultation, that of June 1959, during which the sun was quite active. There is doubt about the precise time of ingress and egress from the corona, although with some reliability we can state that we have observed the source as early as 1 July, 1959, within 2 weeks of occultation.

These interferometers also provide a stable system for measures of the fluctuations in position of solar emission sources. From day to day, there are often striking changes in position which seem much too large to be accounted for by ionospheric effects such as scintillations or traveling disturbances. In this work we have been aided considerably by our swept-frequency interferometer.

The strong period of solar emission during the last week of August 1959 produced a splendid set of records, both with the spectrograph and with the fixed-frequency interferometers. The observations that are reported by NERA and the Fraunhofer Institute in the Information Bulletin of Solar Radio Observatories in Europe are confirmed by our records. Especially, we have detailed positional and intensity spectra, to our lowest limit at 15 Mc/s, of the enormous fluctuations in the apparent intensity of the solar noise during 23, 24, and 25 August. We also confirm the important sunset effects and their probable origin in ionospheric scintillations. Study of these records is still proceeding, and it is premature for us to identify which component of the fluctuations of the radiation during this event is produced locally and which may be produced in interplanetary space as suggested by Fokker. If such a separation is possible, however, our records, which show larger changes in these fluctuations, as a function of frequency, should provide strong observational tests for theories of their origin.

The final important material that has become available since the last Assembly is observations of the spectrum of Jupiter radio emission from 15 to 35 Mc/s. The striking feature of this emission on two of its strongest occasions is that the gross center of gravity of the emission appears first at the low end of the frequency range, and moves slowly towards higher frequencies, at 1 octave per hour. Interpretation of these records is still in progress.

However, there seems to be some possibility of connecting the emission to the presence of a magnetic field in Jupiter's atmosphere, and of identifying the mechanism with the synchrotron effect. Much remains to be done, especially in studies of the spectrum of the polarization of Jupiter bursts, of the time variations in the decimetric radiation, and between the decimetric radiation and the decametric radiation.

9. Harvard University Radio Astronomy Station

The research program at the Harvard Radio Astronomy Station, Fort Davis, Tex., has been devoted mainly to solar radio astronomy. The station has sweep frequency equipment covering the band 25 to 580 and 2,000 to 4,000 Mc/s, that is nearly 6 octaves of the electromagnetic spectrum [Maxwell, Swarup, Thompson, 1958; Maxwell, 1958; Maxwell, 1959]. Considerable efforts have been made to ensure continuity of the observations, and the Station has now accumulated and analyzed in detail some 3 years' records covering the maximum of the solar cycle. The characteristics of the various solar radio bursts and the statistics of their occurrence have been examined [Maxwell, Howard, Garmire, 1959; Goldstein, 1959], as well as their association with flares and prominences [Swarup, Stone, and Maxwell, 1960]. It has been shown that most slow drift bursts (Type II) and large continuum outbursts (Type IV) are generally associated with flares of large area and intensity, and that the fast drift bursts (Type III) are often associated with flares of lower importance.

The slow drift bursts, which are believed to be caused by a primary disturbance moving outwards through the solar atmosphere with a velocity of about 1,000 km/sec, are about 45 percent associated with the subsequent occurrence of terrestrial geomagnetic storms. The geomagnetic effects are enhanced if the bursts occur near the equinoxes, and if they are accompanied by a flare of importance 2 or 3, or by continuum radiation [Maxwell, Thompson, Garmire, 1959]. It has also been shown that the continuum bursts frequently precede the bombardment of the upper atmosphere by solar protons with energies up to about 300 MeV (low energy solar cosmic rays). The minimum time delay between the onset of the radio burst and the arrival at the earth of solar protons is the order of 45 min [Thompson, Maxwell, 1960a, b].

10. Hayden Planetarium

The Hayden Planetarium has a phase switching interferometer operating approximately at 20 m. Each array consists of eight inline dipoles oriented north-south, the arrays spaced 590 ft east-west. The dipoles are soon to be turned 90°. The equipment is still in the development stage. Radio frequency interference is a serious factor near Huntington, Long Island, and the sky can be seen only when the ionosphere is very transparent, e.g., during the recent communications blackout imposed by the sun. At that time, when WWV was barely detectable the sun itself provided a beautiful record each day during the week of March 28 to April 4, 1960, although it was in a sidelobe of the array. Another sidelobe sees Cygnus A, but weakly. Jupiter has not yet been detected.

A computing program will start soon at the Watson Labs at Columbia. This will involve R. E. Wilson's radial velocity catalogue. The coordinates will be changed to the Lund Pole, 1900.0, and the velocities to the local standard of rest, so that the stellar velocities may be compared directly with the 21-cm hydrogen velocities.

11. University of Illinois

Support has been secured from the Office of Naval Research for the construction of a large parabolic-cylindrical radio telescope at the University of Illinois. Engineering plans have been completed by the project staff and by Hanson, Collins, and Rice, consulting structural engineers. Construction commenced in October 1959, and is expected to be completed by June 1960. Extensive investigation has produced a suitable design for the line-feed system for the instrument. A noise survey of the site indicates that it is suitable from this standpoint.

The University has purchased a little over 200 acres of land about 5 miles southeast of Danville, Ill., and has appropriated funds for a building, access road, and power line.

The characteristics of the instrument are as follows: width (E–W), 400 ft; length (N–S), 600 ft; aperture-to-vertex depth, 60 ft; focal length, 160 ft; length of feed system, 425 ft; proposed frequency of operation, approximately 600 Mc/s; expected beam width, approximately 15 min of arc; beam steerable in declination by phasing of feed elements, within 30 deg of the zenith; beam shape circular at maximum zenith angle, slightly elliptical at the zenith. The purpose of this instrument is to conduct a survey of discrete sources.

Theoretical cosmological investigations have included an interpretation of the meaning of a uniform distribution in space of extra-galactic radio sources [McVittie, 1960a, b]. The assumption was made that these sources were galaxies and so shared in the redshift phenomenon and also that they were all of the same intrinsic power output. Distances can then be calculated for various limits of observed flux density. The conventional "minus-three-halves" law for the number of sources versus limiting flux-density was shown to imply that extra-galactic radio sources were more numerous per unit volume in the past than they are now. Another type of investigation [McVittie, Wyatt, 1959] concerned the background radiation, at radio and at optical wavelengths, received from all unresolved sources in the universe. The calculations were performed for Milne's model of an expanding universe and led to estimates of the number-density of radio sources responsible for the background radiation.

Studies have been made of the scintillation of trans-ionospheric radio signals [Keh, Swenson, 1959]. Twenty- and forty-megacycle signals from earth satellites have been used, in an effort to determine diurnal, seasonal, and geographic variations in the incidence of scintillations. It is believed that nighttime scintillation arises mainly at heights below about 220 km, and that they occur north of geographic latitude 40 deg at our longitude. Daytime scintillations arise lower in the ionosphere and occur sporadically at many latitudes.

12. U.S. Naval Research Laboratory Radio Astronomy Branch

12.1. Planets

Venus

Radiation from Venus at 3.15-cm wavelength was first detected on May 2, 1956. Further detailed observations were made using the 50-ft reflector at the U.S. Naval Research Laboratory on 34 days spread over the period May 5, 1956 to June 23, 1956, a period just prior to and including inferior conjunction [Mayer, McCullough, Sloanaker, 1958a, b]. About 600 measurements of the antenna temperature due to Venus at 3.15 cm were obtained. The measured values were characteristic of steady radiation with no apparent linearly polarized component. The measured flux density approximated the inverse-square-law variation as the distance between Venus and the earth decreased but suggested a slight decrease in the radiation level during the period. The apparent blackbody temperature of Venus deduced from the measurements was about 620 ±55 °K p.e. near the beginning of the period and about 560 ±45 °K p.e. near the end of the period.

In 1956 an attempt was made to put rough limits on the spectrum of the radio radiation from Venus by making observations with the 50-ft reflector at 9.4 cm wavelength [Mayer, McCullough, Sloanaker, 1958a, b]. A total of 11 measurements were made on June 25, 1956 and July 27, 1956. The average of the 9.4-cm measurements of the blackbody temperature of Venus was 580 ±160 °K estimated p.e. which compared closely with the result at 3.15-cm wavelength. Although the accuracy of the 9.4-cm results was poor, these measurements suggested that no great percentage of the radio radiation from Venus at centimeter wavelengths has a spectrum very different from that of thermal radiation.

Beginning about 2 weeks after the inferior conjunction of 1958 observations of Venus at 3.4 cm were made using the 50-ft reflector on 9 days during the period February 12 to March 5, 1958 [Mayer, McCullough, Sloanaker, 1958c]. The measured equivalent blackbody disk temperature deduced from these measurements was 575 ±60 °K p.e. This value agrees closely with the results determined in 1956 at 3.15 cm.

Later, about 80 days after the 1958 conjunction, Venus was again observed with the 50-ft reflector at 3.37-cm wavelength using a solid-state maser, designed and built at Columbia University [Alsop, Giordmaine, Mayer, Townes, 1958, 1959]. These observations, made on April 18 and 19, 1958, gave an apparent blackbody temperature based on the diameter of the visible disk of Venus of 575 ±58 °K p.e.

In order to obtain more reliable measurements near 10-cm wavelength, observations of Venus were made following the inferior conjunction of September 1, 1959 at 10.2-cm wavelength using the 84-ft reflector at the Maryland Point Observatory of the U.S. Naval Research Laboratory [Mayer, McCullough, Sloanaker, 1959]. Measurements were made on 11 days over the period September 17 to October 10, 1959. The measured blackbody temperature at 10.2 cm changed from about 535 °K 16 days after inferior conjunction to about 675 °K 39 days after conjunction. The mean apparent blackbody temperature over the entire period was 600±65 °K estimated p.e.

In summary, the observations near 3- and 10-cm wavelength indicate that Venus emits centimeter wavelength radiation with a spectrum of a blackbody at a temperature of about 580 °K. The most obvious interpretation of the results is that the centimeter wavelength radiation is emitted thermally at some level deep in the atmosphere, perhaps at the solid surface where the temperature is much higher than that which is inferred from infrared observations. However, in order to account for a temperature as high as 580 °K it is necessary to assume almost complete trapping of the absorbed solar radiation, or else some other source of heat. It is perhaps possible that the observed radiation is a combination of thermal and nonthermal components which by coincidence combine to give a blackbody spectrum, but a nonthermal mechanism with an appropriate spectrum has not been found. There has been no evidence of variability in the received radiation other than suggestions of possible phase effects. However, the present observations are not sufficiently accurate or complete to define a dependence of the radio emission on the phase or rotation of Venus. It is important to make further observations to establish whether such a dependence exists, both to obtain this basic information and to allow a better understanding of the origin of the radio emission.

Measurements at 8.6 mm at inferior conjunction in January 1958 [Gibson and McEwan, 1959] yielded a brightness temperature of 410 °K with a large uncertainty, and more recent observations in September 1959 support this or a somewhat smaller value for this wavelength.

Jupiter

The steady radio emission of Jupiter has been observed at wavelengths near 3, 10, and 21 cm.

During May 1956 a limited number of observations of Jupiter were made at 3.15-cm wavelength using the 50-ft reflector [Mayer, McCullough, Sloanaker, 1958b, d]. The measurements gave a blackbody temperature for Jupiter of 140±38 °K p.e.

A second series of observations of Jupiter with improved accuracy was made on seven days between March 23 and April 1, 1957 at 3.15 cm using the 50-ft reflector [Mayer, McCullough, Sloanaker, 1958b, d]. The measurements gave an equivalent blackbody temperature of 145±18 °K p.e. based on the mean diameter of the visible disk of Jupiter.

Another series of observations of Jupiter was made with the Columbia University maser and the 50-ft reflector. The measurements extended over the period from April 16, 1958 to February 7, 1959 and covered a range of wavelengths from 3.03 to 3.36 cm, [Giordmaine, Alsop, Townes, Mayer, 1959a, b]. The measurements gave equivalent blackbody disk temperatures of 171 ±20 °K p.e. at 3.03 cm (August 22 to September 4, 1958); 173 ±20 °K p.e. at 3.17 cm (May 24 to July 29, 1958; January 31 to February 7, 1959); and 189 ±20 °K p.e. at 3.36 cm (April 16 to May 8, 1958).

The apparent blackbody disk temperatures near 3-cm wavelength measured in 1958 and 1959 were higher than those measured in 1956 and 1957 by about 1½ times the probable error, and the apparent increase must be considered as a possible change in the emission of Jupiter. There was also some evidence that an anomolously high disk temperature of about 268 °K was observed on April 30 to May 1, 1958. No changes in the emission at wavelengths near 3 cm were noted which could be correlated with the rotation of Jupiter.

Thirty-three measurements of the apparent blackbody temperature of Jupiter were made between June 10 and August 20, 1958 at wavelengths of 10.2 and 10.3 cm using the 84-ft reflector [Sloanaker, 1959; McClain and Sloanaker, 1959]. The mean apparent blackbody temperature was 640 ±85 °K p.e. based on the mean diameter of the visible disk. The 10-cm measurements gave a roughly normal distribution of apparent blackbody temperature with a standard deviation of 190 °K. On the basis of the estimated measurement errors, the expected standard deviation was about 145 °K which was in reasonably good agreement with the observed scatter, but did not preclude the possibility of a variable component in the intensity of the radiation. The measured blackbody temperatures at 10 cm showed no longtime trends over the 71-day observation interval, but did show a suggestion of a cyclical variation of about 30 percent correlated with a rotation rate between 40 sec and 2 min longer than the rotation period of System II.

A series of measurements of the radiation from Jupiter at a wavelength of 20.96 cm was made on 28 days during a 1-month period from May 14 to June 18, 1959 using the 84-ft reflector [McClain, 1959]. The mean blackbody temperature for all of the 20.96-cm data was 2,496 °K with a standard deviation of 450 °K. The measured blackbody temperatures were highly suggestive of a cyclical variation with time, and an attempt was made to correlate the data with the System I and System II rotation periods. No significant correlation was observed for the System I period, but in the case of System II elevated temperatures corresponding to an enhancement of about 30 percent were observed at longitudes between 175 and 225°. While rather significant when subjected to a statistical test, this correlation with rotation is considered to be tentative because of the limited amount of data. An attempt was made to correlate the measured temperatures with solar flares [suggested by Drake, 1959 and Drake and Hvatum, 1959]. No strong correlation of this sort was noted in the measurements; however, there was a slight suggestion of elevated temperatures following an important 3+ flare on May 10 and the intense aurora of May 11 and 12, 1959.

To summarize, the emission of Jupiter at wavelengths near 3 cm can probably be accounted for as thermal radiation but the radio spectrum is not that of a blackbody at a constant temperature, and some other source of emission is necessary to account for the radiation at longer wavelengths.

Observations of Jupiter during 1959 yield a brightness temperature less than 200 °K at 8.6-mm wavelength.

Mars

The radio emission of Mars has been observed at two different times. Observations made using the 50-ft reflector at the favorable opposition of September 1956 at 3.15-cm wavelength [Mayer, McCullough and Sloanaker, 1958b, d] were sensitivity limited and it was necessary to average about 70 observations to obtain a measurement of reasonable accuracy. The result of this measurement corresponds to an apparent blackbody disk temperature for Mars of 218 ±51 °K p.e.

Mars was again observed about 6 weeks past the opposition of November 1958 using the Columbia University maser with the 50-ft reflector at 3.14-cm wavelength [Giordmaine, Alsop, Townes and Mayer, 1959a]. This measurement gave an apparent blackbody-disk temperature for Mars of 211 ±28 °K p.e. The apparent blackbody-disk temperature derived from the radio observations is about 40° smaller than that derived from the infrared observations, and is about 15° smaller than the estimated mean annual disk temperature. Considering the uncertainties in the observations and in the emissivities at both the radio and infrared wavelengths, the observed radio emission is consistent with the thermal radiation which would be expected on the basis of previous knowledge.

12.2. Cosmic Radio Sources

The radio sources Cygnus-A and Virgo-A were observed in 1958 at wavelengths near 3 cm using the

Columbia University maser with the 50-ft reflector [Alsop, Giordmaine, Mayer and Townes, 1959; Giordmaine, Alsop, Mayer and Townes, 1959b]. For the source Cygnus-A the measured antenna temperature was 4.6 °K at a wavelength of 3.2 cm which corresponds to a point source flux density of 1.24×10^{-24} w $m^{-2}(c/s)^{-1}$. The measured antenna temperature for the source Virgo-A was 1.25 °K at 3.37-cm wavelength which would correspond to a point source flux density of 3.4×10^{-25} w m^{-2} $(c/s)^{-1}$.

The positions, intensities, and sizes of eight bright discrete sources were measured during January 1959 at a wavelength of 10.2 cm using the 84-ft reflector [Sloanaker and Nichols, 1960]. For six of the sources for which accurate optical positions are available, the sources Cassiopeia-A, Cygnus-A, Taurus-A Virgo-A, Orion Nebula, and Centaurus-A, the measured radio-positions coincided with the positions of the optical centers of the sources to within the uncertainities in the radio measurements of ±1 min of arc p.e. in both R.A. and Dec. The positions of the optical centers of these sources, with the exception of the Orion Nebula source, refer to the optical positions given by Minkowski [1959], and Baade and Minkowski [1954]. For the Orion Nebula source, M 42, the optical position refers to the position of Theta-One Orionis, the exciting stars, obtained from Strand [1958]. The 10.2 cm measured position of the Sagittarius-A source for 1959.0 was $RA=17^h43^m 1.6^s\pm4.5^s$ p.e. and $Dec.=-28°57.3'\pm1'$ p.e. The measured position of the Omega Nebula source, M 17 for 1959.0 was $RA=18^h18^m6.1^s\pm4^s$ p.e. and $Dec.=-16°11.9\pm1'$ p.e. At 10.2 cm the sources Cas-A, Cyg-A, Tau-A, and Vir-A appeared as unresolved point sources with upper size limits of 3′ or 4′ equivalent gaussian diameters. The measured equivalent gaussian diameters of the other four sources were: Orion Nebula, $7'\pm0.5'$ p.e. in R.A. and $7'\pm1'$ p.e. in Dec.; Omega Nebula, $7.5'\pm0.5'$ R.A. and $8.5'\pm1'$ Dec.; Sag-A (bright central part only), $14'\pm0.3'$ R.A. and $16'\pm0.5'$ Dec.; Cent-A, $8'\pm0.5'$ R.A. and $5'\pm1.5'$ Dec. The measured 10.2 cm antenna temperatures for the sources were: Cas-A, 89 ± 2 °C p.e.; Cyg-A, 45 ± 1 °C; Tau-A, 48 ± 1 °C; Vir-A, 7.5 ± 0.4 °C; Orion Nebula, 25 ± 0.5 °C; Omega Nebula, 35 ± 0.7 °C; Sag-A (bright central part only), 28 ± 0.6 °C; and Cent-A, 10 ± 0.4 °C. Based on an estimated aperture efficiency of 0.385 ± 0.031 p.e. for the 84-ft reflector, the measured point source flux densities for the sources Cas-A, Cyg-A, Tau-A, and Vir-A were in units of watts $m^{-2}(c/s)^{-1}$ $(124\pm11$ p.e.$)\times10^{-25}$, $(63\pm6)\times10^{-25}$, $(67\pm6)\times10^{-25}$, and $(10\pm1)\times10^{-25}$, respectively. For the remaining four sources, Omega, Neb., Sag-A (bright central part only), and Cent-A, the measured flux densities corrected for the measured equivalent gaussian diameters listed above were: $(40\pm4$ p.e.$)\times10^{-25}$, $(58\pm5)\times10^{-25}$, $(65\pm7)\times10^{-25}$, and $(16\pm2)\times10^{-25}$ respectively in units of watts $m^{-2}(c/s)^{-1}$.

During 1956 and 1957 two different experiments were conducted using the 50-ft reflector at a wavelength of 3.15 cm, in an attempt to detect plane polarization in the radiation from the Crab Nebula (Taurus-A) [Mayer, McCullough, and Sloanaker, 1957]. The first measurements in May and June 1956 indicated a polarized component in the received wave of about 10 percent of the total radiation, with a position angle near the average over the nebula from the optical measurements. In April, May, and June 1957 more accurate measurements were made with a rotating plane-polarized feed horn installed in the 50-ft reflector. These observations indicated that about 7 percent of the total radiation of the Crab Nebula was plane-polarized at 3.15 cm with a position angle of about 150 deg. The observed position angle of the electric vector on the Crab Nebula differs from the average position vector over the nebula determined optically [Oort and Walraven, 1956] by about 11 deg. A Faraday rotation along the path of propagation of this order of magnitude is not unlikely at this wavelength, as was pointed out by Oort and Walraven [1956] Observations of the radio source Cas-A with the rotating polarization antenna did not show any measurable polarization in the received radiation.

In 1958 a search was made for linearly-polarized components of the 10.2-cm radiation from the radio sources Cas-A (IAU 23N5A), Tau-A (IAU 05N2A), Cyg-A (IAU 19N4A), Vir-A (IAU 12N1A), and M 17 (IAU 18S1A) using the 84-ft reflector [Mayer and Sloanaker, 1959]. Only the radiation from Taurus-A showed characteristics which could be interpreted as due to a plane-polarized component of the radiation. The measurements of Taurus-A gave results which could be interpreted as a linearly-polarized component of about 3 percent of the total radiation with a position angle for the electric vector of about 135 deg. The sources Cas-A, Cyg-A, and Tau-A were measured at two other wavelengths as well, 11.3 and 10.5 cm. The results were similar at the three wavelengths indicating that there is little Faraday rotation along the path between Taurus-A and the earth.

Several of the brighter discrete sources have been identified at 8.6-mm wavelength, and efforts are being made to determine their flux densities.

12.3. Sun

Measurements of solar radiation intensity throughout each day were made at wavelengths of 3.15 and 9.4 cm from March 1958 through April 1959 using 4- and 6-ft diam parabolic reflectors mounted on a common polar mount. These data were communicated to IGY [McCullough and Bologna, 1958 and 1959]. A plot of daily average flux of solar radiation with time shows 3.15-cm flux to be more intense than 9.4-cm flux by the expected amount and also shows the two flux values to vary in close agreement with solar activity. The bursts of radio radiation from the sun which accompany solar flares were classified according to type, time of occurrence (peak), duration, and maximum intensity.

Beginning with the International Geophysical

Year on July 1, 1957, Coates, Edelson, McCullough and Santini [1957, 1958, 1959] have conducted simultaneous observations of solar activity in the optical and radio regions. It was found that 99 percent of the 10-cm bursts were coincident with H-alpha activity. On the other hand, only 25 percent of the H-alpha events were coincident with 10-cm radio bursts. For simple 1 and simple 2 types of bursts a trend for larger peak radio flux values for larger H-alpha intensity values was evident [Coates, Edelson, McCullough, and Santini, 1958].

In March 1959 the time resolution of the H-alpha camera was increased to 6-sec intervals. Using this improved resolution flare light curves were compared directly with observed flux curves of the associated radio bursts. Measurements of time differences between the H-alpha maximum intensity and the 10-cm peak flux indicate that the events may be classified according to the 10-cm excitation level preceding the flux peak.

In the first type, the 10-cm radio flux rises rapidly to a peak from the quiet sun level in less than 2 min, and always precedes the H-alpha maxima. In 60 percent of the events of this class, the 10-cm burst peaks occur 2 to 10 sec before the H-alpha maxima; 35 percent have time differences of 10 to 20 sec; and 5-percent lead the H-alpha by 20 to 30 sec.

In the second type, 10-cm excitation exists for more than 4 min before the time of burst peak flux. Five percent of the events of this class have 10-cm peaks following the H-alpha maxima by 0 to 10 sec, while the great majority have 10-cm peaks preceding the flare maxima with the following time distribution: 30-percent lead by 0 to 10 sec, 35-percent lead by 10 to 20 sec, 25-percent lead by 20 to 30 sec, and 5-percent lead by 30 to 40 secs. There is evidence that several events of the second type may be associated with more than one source [Edelson, Coates, Santini, and McCullough, 1959].

On June 9, 1959 a burst of solar radiation was recorded at a wavelength of 4.3-mm by Coates and Edelson at the USNRL. Simultaneously, a large outburst was recorded at 10.7-cm by Covington at the National Research Council, Canada. The peak flux at 4.3 mm was 500×10^{-22} wm^{-2} cps^{-1} as compared with $2{,}000\times10^{-22}$ wm^{-2} cps^{-1} at 10.7 cm.

The position of the radio emitting source determined by a high-resolution scan at 10.7 cm agreed with the position of a jet on the NRL H-alpha spectroheliograms. The base of the ejection appeared to be beyond the limb on the back side of the sun. This region remained active as it rotated onto the front of the sun and it was possible to determine its position on June 9. Using this position and the known heights of the radio limb of the sun of 0.0057 R_θ at 4.3 mm and 0.03 R_θ at 10.7 cm, the minimum height of the emitting region was determined to be $20{,}000\pm10{,}000$ km and $37{,}000\pm10{,}000$ km, respectively. These are lower limits only; the actual emitting regions may have been located at much greater heights [Coates, Covington, and Edelson, 1959].

12.4. Moon

Observations of the moon at 2.2-cm wavelength [Grebenkemper, 1958] showed that the variation in brightness with lunar phase is much less than at shorter wavelengths, i.e. 8.6 and 12.5 mm, with the variation being about ±5 percent. The apparent mean brightness temperature was found to be 200° K. The diminished brightness variation with phase is in agreement with unpublished observations of Mayer, McCullough, and Sloanaker at 3.15-cm wavelength, and is readily accounted for by an increasing depth of penetration for the longer wavelengths, which places the origin of thermal radiation at greater depths where thermal changes are less.

The total lunar eclipse of 13 March 1960 was observed at 8.6-mm and 21-cm wavelengths, and analysis of the results is incomplete at the time of preparing the present report.

Lunar radiation of 4.3-mm wavelength was measured with the aid of an equatorially mounted paraboloidal antenna 10 ft in diameter [Coates, 1959]. By making repeated television-type scans across the moon's disk, it was possible to construct crude lunar maps for different phases. Because the angular resolution was 6.7 min of arc, compared with the moon's 31-min average diameter, the larger surface features are recognizable.

Such charts show primarily the distribution of temperature over the lunar disk. In particular, it was found that the large, dark, level areas (maria) warm up more rapidly toward full moon and afterward cool more rapidly than do the "continental" parts of the moon. However, Mare Imbrium is an exception to this general rule.

12.5. Atmospheric Attenuation

Atmospheric attenuation at 4.3-mm wavelength was measured in 1956 by Coates using a 10-ft precision paraboloid and a Dicke-type radiometer. The measured attenuations at the zenith were between 1.6 and 2.2 db depending on atmospheric conditions [Coates, 1957]. These values were verified by Edelson, Grant, and Santini in March 1960 using the same radiometer and a 2-ft precision paraboloid.

13. The National Aeronautics and Space Administration

The Astronomy and Astrophysics Programs of the Office of Satellite and Sounding Rocket Programs of NASA include projects designed to make basic astronomical observations from above the terrestrial atmosphere by radio techniques. Observations of the planets, sun, radio stars, and the galactic background will be made at radio frequencies which are absorbed by the terrestrial atmosphere and ionosphere.

The work is divided into two phases. Proposed LF (0.1 to 30 Mc/s) experiments include a space probe, to detect galactic noise, monitoring of solar bursts, polarization measurements, and multiple- and sweep-frequency measurements of the planets and galaxy. These are being done by Haddock of the University of Michigan and by the Canadian Defence Telecommunications Board as a byproduct of a topside sounder experiment. The HF (submillimeter frequencies) will include studies and radio spectra of the atmospheres of the sun and planets and mapping the sun, moon, planets, and galaxy in the region between the infrared and the atmospheric radio window. Because of the limitations of the present state of the art, current activity in the HF phase is limited to a survey by the University of Texas of existing techniques and of areas in which development should be encouraged promptly and to basic research in sub-millimeter techniques by Ohio State University. NASA is also supporting a measurement of the solar parallax by studying the Doppler Shift in the 21-cm line.

14. National Bureau of Standards Boulder Laboratories

The solar patrol, which was started in 1947, has been continued until the end of the International Geophysical Year. Consistent calibration and scaling of hourly medians and outstanding occurrences are complete on both 167 and 460 Mc/s. Reports were submitted regularly to the I.A.U. Quarterly Bulletin of Solar Activity. Since January 1959, the patrol has been reduced to the single frequency 167 Mc/s, and scaling has been less detailed.

The National Bureau of Standards has recently completed a program of interferometric observations of Cygnus-A for the purpose of studying ionospheric effects, particularly angular and amplitude scintillations. An important feature of this program has been the frequent observation, during daytime, of irregular angular fluctuations having a period of about 20 min and a magnitude of as much as ½ deg at 108 Mc/s [Lawrence, 1958; Lawrence and Jesperson, 1959].

15. National Radio Astronomy Observatory Green Bank, West Virginia

The National Science Foundation contracted with Associated Universities, Inc., on November 17, 1956, to proceed with the construction and operation of the National Radio Astronomy Observatory, Green Bank, W. Va. In May 1957, Associated Universities, Inc., set up a field office on the site. Ground-breaking ceremonies were held on October 17, 1957, and the Howard E. Tatel 85-ft telescope was dedicated on October 16, 1958.

In the 12 months ending May 1960, the National Radio Astronomy Observatory has completed a transition from the first phase of site acquisition, development, and construction into an operating observatory. A key factor for the future success of the Observatory was the appointment of Dr. Otto Struve as the first Director.

The buildings that have been completed are the central section of one Karl Guthe Jansky Laboratory, which houses the Astronomy and Research Equipment Development Departments as well as space for the office of the Director, administration, and engineering and construction, and a residence hall and cafeteria. A small amount of additional housing is available in a few renovated farmhouses acquired with the site. A work area building, for central shops and other service purposes, was completed the previous year. A central water supply and sewer system has been installed for the complex of the principal buildings and with the cooperation of the Monongahela Power Company a new 3-mw electric power supply has been brought to the site. On the site, the distribution system is below ground; within view of the radio telescopes. The 12-kv feeder line is in shielded cable, mounted on poles to simplify maintenance.

The Howard E. Tatel 85-ft radio telescope was used for observational programs throughout the spring, summer and early fall of 1959, at which time the Blaw Knox Co. returned to make final adjustments and corrections before turning the telescope over to Observatory. The E. W. Bliss Co. shipped two sections of the polar shaft of the 140-ft telescope in August 1959; Darin and Armstrong, the subcontractor for field work at Green Bank, has welded these sections together and the shaft is now mounted on temporary horizontal bearings in anticipation of future machining operations. Work at Green Bank is now shut down pending shipment of additional telescope components, as scheduled through the last 8 months of 1960 into 1961.

In addition to the scientific contributions that have already come from the Observatory, it has attracted many nonprofessional visitors and plans are being made to accommodate an increasing flow during the summer of 1960 and the years ahead.

15.1. The Flux Density of Radiation From Cas A at 1,400 Mc/s

As a part of the program of source calibration at the National Radio Astronomy Observatory experiments have been started to measure the flux density from the Cas A source. One major experimental difficulty in such measurements is to determine exactly the effective collecting area of the antenna that is used. To minimize this difficulty a horn antenna of about 10 m^2 collecting area has been built. The horn is large enough to give an antenna temperature from the Cas A source of about 8° K. The gain of such a horn can be calculated from its linear dimensions to a high accuracy. The horn is fixed in position at an elevation angle of 30° and is used as a transit instrument. It is 120-ft in length and is made of sheet aluminum with all joints internally welded to ensure high electrical conductivity.

16. Ohio State University

16.1. Radio Telescopes

A design for a radio telescope which provides a large aperture at low cost is described [Kraus, 1958a].

Equations are derived from the numbers of radio sources which a radio telescope can detect and the number which it can resolve. Based on these relations curves for the number of sources which can be both detected and resolved, as a function of frequency and aperture, are presented.

Construction of a large aperture antenna at low cost is described [Kraus, 1959a]. The antenna consists of a 360- by 70-ft standing paraboloid and tiltable flat reflector. At the highest frequency of operation (15-cm wavelength) the half-power beam widths of the antenna will be 0.1° in a R. A. by 0.5° in declination. The antenna is expected to be in operation by 1961.

16.2. Cosmic Radio Noise

The results of a survey of cosmic radio background radiation at 250 Mc/s are described [Ko, 1958a].

Radio maps made at other frequencies by various groups are summarized. To present an over-all picture of the radio sky at different frequencies, eight radio maps are shown for frequencies from 64 to 910 Mc/s. All maps are modified to have the same scale, coordinates and units to facilitate intercomparison. General features of the galactic background radiation are discussed.

A radio map of the Cygnus region made at 915 Mc/s using a 40-ft dish is presented [Eaton and Kraus, 1959].

Observations are described of radio emissions from the sun and Jupiter, during 1956 and early 1957 at a wavelength of 11 m [Kraus, 1959b].

The results of amplitude scintillation of Cygnus A at 945 Mc/s are described [Ko, 1958b]. The scintillation is strongest near the horizon with a mean-fluctuation index of 20 percent and mean fluctuation rate of 2 to 6 peaks/min. The scintillation characteristics are markedly affected by the presence of aurorae.

16.3. Earth Satellite Observations

A peculiar fluctuation on Sputnik I signal at 20 Mc/s is described and a hypothesis is advanced that the fluctuations are caused by the satellite induced ionization [Kraus and Albus, 1958].

The feasibility of detecting silent earth satellites by refraction of cw signals from a high-frequency radio station is described [Kraus, 1958b]. The possible application for long-distance communication is suggested.

Observations during the last days of Sputnik I's orbiting using cw reflection technique are described [Kraus and Dreese, 1958]. Some conclusions are drawn as to the details of the actual breakup phenomenon of the satellite.

Observations of the U.S. Satellites Explorers I and III by cw reflection using WWV signals are described [Kraus, Higgy, and Albus, 1958].

A statistical study of the satellite ionization phenomenon is described and some radar observations are also reported [Kraus, Higgy, Scheer, and Crone, 1960].

16.4. Interplanetary Medium

Some observations are described which are suggestive of doppler shifted reflections of radio signals from solar corpuscular clouds in the vicinity of the earth [Kraus and Crone, 1959].

17. Rensselaer Polytechnic Institute

Radio astronomy work at Rensselaer during the past continues to be primarily in the constructional phases of our two principal projects. The 517-Mc/s swept-lobe interferometer has successfully measured positions of some solar bursts; we expect in the next few months to be able to record angular motions, and to place the equipment in its permanent location, for which site preparation is currently in progress. A second 18-Mc/s cosmic-noise recorder is being built to provide greater stability and improved rejection of station signals; the antenna is being built in a location which will allow eventual expansion to a narrower directional pattern. Records have been secured and published at 18-Mc/s, and simultaneous records are being taken of certain meteorological parameters, with some indications of unexpectedly high tropospheric absorptions of 18-Mc/s radiation.

18. Stanford University

At the Radioscience Laboratory, Stanford, R. N. Bracewell has completed the construction of a microwave spectroheliograph and obtained sequences of maps, as yet unpublished, of the brightness distribution over the sun. V. R. E. Eshleman has obtained radar echoes from the sun. He has also investigated the character of the cislunar medium using radar echoes from the moon. R. Mlodnosky has continued theoretical and observational studies of the distribution of meteor radiants.

19. Yale University

The work of the past year has continued to be concentrated almost exclusively on the Jupiter program.

Functioning equipment now includes as basic monitoring units six phase-switching interferometers working respectively at 23.0, 22.2, 20.0, 19.2, 16.15, and 13.25 Mc/s. An additional 20.0 Mc/s interfermometer is located 11 miles away from the others. This monitoring equipment, running semi-automatically and continuously, to some degree covers the sun and other planets as well as Jupiter. But during all possible Jupiter reception periods an observer is on duty to achieve optimum tuning and sensitivity of the channels. Compared to last year, Jupiter is about twice as active during this observing season. Complete reduction for rotation periods, of our monitoring records plus all other available Jupiter storm data, is under way as a part of J. Douglas' thesis.

New projects completed include facilities for high-speed recording, and for spectrum analysis using 10 separate 20-kc/s channels spaced 100 kc/s apart, the comb-filter unit centered near 22 Mc/s. Successful recordings have been obtained on four strong Jupiter storms in the last few weeks. These fail to show any recognizable spike activity of several millisecond duration of the kind previously suggested by others. However, the recordings do show excellent correlation of fine structure down to several tenths of a second duration over bandwidths normally greater than a megacycle. There is no appreciable tendency for any of the elementary pulses to drift in frequency. But a new class of Jupiter event has appeared in which the bursts composing a group are so modulated as to make the group appear to drift from HF to LF at about 1 Mc/s/min (that is, the spectral energy distribution of the successive individual bursts changes gradually, with the peak appearing at progressively lower frequencies).

Bibliography: Smith and Douglas, 1959; and Smith 1959.

20. University of Michigan

20.1. University of Michigan 85-Foot Radio Telescope

In the summer of 1958 field construction began on the University of Michigan 85-ft antenna, designed and fabricated by the Blaw Knox Company of Pittsburgh. The antenna is polar-mounted, made of galvanized steel except for the lead counterweights and the aluminum surface panels and feed supports. The telescope may be rotated about the polar and declination axes at a fixed rate of about 20 deg/min or at a variable rate between zero and 8 deg/min. In addition, the polar axis can be driven at the sidereal or solar rate.

Mechanical testing was performed during and after construction. The axes were alined to an accuracy of 30 sec of arc and surface panels were adjusted to within 1.5 mm from a paraboloid. Antenna gain and beam width measurements indicate an aerial efficiency of about 50 percent and a beamwidth of 6 min of arc at a wavelength of 3.45 cm.

20.2. Traveling-Wave Tube Receiver at 8,000 Mc/s

The 85-ft radio telescope was initially instrumented at 8,000 Mc/s with a radiometer made by the Ewen-Knight Co. It is capable of detecting signals of the order of 0.1 °K or less with a 20-sec time constant. This sensitivity is obtained through its large bandwidth of 1,000 Mc/s. The receiver is composed of three traveling-wave tubes in cascade followed by conventional Dicke circuitry using a ferrite switch. The receiver is being used to study galactic and extragalactic radio sources, the planets and planetary nebulae.

20.3. Maser Radiometer at 8,700 Mc/s

A ruby maser radiometer has been constructed by the University of Michigan Willow Run Laboratories and is mounted at the focus of the 85-ft antenna. The maser, operating at liquid helium temperature of 4.25 °K, has a gain of 20 to 23 db and a bandwidth of 20 Mc/s, however, as used in the present radiometer the bandwidth is 8 Mc/s as determined by the IF amplifiers. Continuous operation for a period of 15 hr has been obtained before adding more liquid helium. The signal frequency is 8,700 Mc/s, the "double-pump" frequency is 22,450 Mc/s, and the operating magnetic field is 3,870 gauss.

The maser radiometer is being used in attempts to observe radiation from weak radio sources. Operation began in February 1960 and preliminary results are very promising.

20.4. Radiometer at 1.8 CM-Wavelength

A Dicke radiometer operating at 16,000 Mc/s has also been installed on the 85-ft antenna. Its bandwidth is 10 Mc/s. It employs a "magic-tee" balanced crystal mixer, and is switched by an electronically controlled ferrite. The sources Cas A, Tau A, and Venus have been measured.

20.5. Theoretical Radio Spectrum of Venus

The radio results obtained at the Naval Research Laboratory of the planet Venus have been analyzed in terms of a model atmosphere in an attempt to explain the discrepancy between the radio and infrared temperatures. Although the data is still meager in the millimeter band of wavelengths, it appears that radio results afford a means of probing below the cloud cover. On the basis of an atmosphere of 75-percent CO_2, 22- to 25-percent N_2, and 0- to 3-percent H_2O, the pressure at the surface of Venus must be between 10 and 30 (terrestrial) atm to coincide with the infrared and radio temperatures. This work will be published in brief in the June issue of the Journal of Geophysical Research and in full in the Astrophysical Journal.

Since September 1957, the sun has been observed by three mechanically tuned superheterodyne receivers. A total frequency range of 100 to 600 Mc/s is observed 3 times a second. The output is displayed as an intensity-modulated line on a high-resolution cathode-ray tube and is photographed on a slowly moving 35-mm film, producing a frequency-time-intensity plot of solar emission. Each receiver is fed from a separate broadband antenna mounted at the focus of a 28-ft equatorially mounted paraboloid reflector.

We believe that we have obtained the first evidence of three harmonically related frequencies being radiated simultaneously by the sun. That is, three bands of radiation in a 1 to 2 to 3 frequency ratio. This event occurred in the first week of observation and consisted of three U-type bursts—bursts that start drifting rapidly from high to low frequencies, then reversing and drifting back to high frequencies again in a symmetrical manner.

Dr. Takakura, a Japanese radio astronomer who was with us for a year (1957–1958), analyzed a number of these U-type bursts and found a remarkable uniformity in their duration which was independent of the reversing frequency. This fact is in discord with a popular hypothesis for the origin of U-bursts. An alternative hypothesis has been suggested that is consistent with our observations.

The dynamic spectra of a new type of radio burst has been observed for the first time. This type of burst was discovered by Drs. Boischot and Denisse in Paris on single frequency records. They denoted it as type IV. The observed dynamic radio spectra gave strong evidence in favor of the French hypothesis that the type IV bursts were generated in the sun's atmosphere by very energetic electrons being accelerated in the sun's magnetic field.

Solar emission has been recorded since August 28, 1957 to the present time. The equipment has been in operation at least 90 percent of the time when the sun has been above the horizon.

In the summer of 1959, a new electronically sweep receiver was installed in order to record dynamic spectra of solar bursts in the frequency range of 2,000 to 4,000 Mc/s. It uses a broad-band horn located at the focus of the above 28-ft paraboloid reflector and operates simultaneously with the above equipment. The rf signal is mixed with the local oscillator signal in a broadband balanced mixer and converted directly to a videofrequency. The videofrequency is then amplified and displayed as described above for the 100 to 600 Mc/s equipment.

The local oscillator is a backward-wave oscillator electronically sweeping on a frequency range of 2,000 to 4,000 Mc/s in 0.1 sec.

Although the equipment is not operating with satisfactory reliability, at least six broadband solar bursts had been observed by April 1960. The first was July 29, 1959. These records show that the centimeter-wave emission of solar bursts is a broadband continuum radiation, similar in nature to that of type IV emission on meter waves.

A comparison is being made of the centimeter-wave bursts with different spectral types of bursts on meter waves.

Statistical studies have been made of the relation between solar radio emission and ionospheric absorption of cosmic noise in polar cap regions (PCA), which is caused by fast protons from the sun after big flares. Broadband meter-wave outbursts (BCO)—believed to be of the same nature as type IV continuum radiation on meter-waves—have been found to be closely associated with PCA events. Further, the PCA events have a tendency to start within 5 hr after intense BCO's; for the less intense BCO's the delay appears to be greater.

The *duration* of the PCA events is closely related to the duration of "active regions" of noise storms on the sun (which in turn are associated with BCO or type IV flares) after the occurrence of BCO (or type IV) events, but is not related to the presence of "active regions" before the onset of the BCO. The PCA start within several hours after a BCO event and last approximately as long as the "active region" is present. Our results support the suggestion that these solar cosmic rays are accelerated by the same process as the fast electrons which are responsible for BCO or type IV radio emission near the sun and are trapped in the same region of the solar atmosphere associated with "active regions" of noise storms and are not stored in interplanetary space. The energetic electrons lose their energy rapidly by this radiation, whereas radiation damping of the protons is negligible.

Two space radio astronomy experiments in the 0.1- to 30-Mc/s band are under preparation, (1) spot-frequency measurements from high-altitude probes, and (2) sweep-frequency measurements of solar radio bursts from satellites. These will be carried out at the lowest frequencies which are stopped by, or seriously affected in their passage through, the ionosphere. The former will give information on the spectral distribution of cosmic noise and also on electron density in the outer ionosphere and possibly in interplanetary regions; the latter will examine solar outbursts and it is hoped will extend the spectrum below the currently known lower limit. In principle, both experiments can be carried out by use of sweep-frequency receivers, but the frequency range desired and the problems of accurate calibration and telemetering make spot frequency more feasible for the former measurements.

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